DENMARK'S NATIONAL INVENTORY REPORT 2023

Emission Inventories 1990-2021 – Submitted under the United Nations Framework Convention on Climate Change

Scientific Report from DCE – Danish Centre for Environment and Energy No. 541 2023

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DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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Data sheet

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Abstract: This report is Denmark's National Inventory Report 2023, which serves as documentation for the Danish greenhouse gas inventories submitted to the European Union and the United Nations. The report contains information on Denmark's emission inventories for all years' from 1990 to 2021 for CO_2, CH_4, N_2O, HFCs, PFCs and SF_6.

Keywords: Emission Inventory; UNFCCC; IPCC; CO_2; CH_4; N_2O; HFCs; PFCs; SF_6

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List of abbreviations

BAT	Best Available Techniques
CH_4	Methane
CHP	Combined Heat and Power
CHR	Central Husbandry Register
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CO	Carbon monoxide
CO_2	Carbon dioxide
COPERT	COmputer Programme to calculate Emissions from Road Transport
CORINAIR	CORe INventory on AIR emissions
CRF	Common Reporting Format
DAAS	Danish Agricultural Advisory Service
DAFA	Danish AgriFish Agency
DCA	Danish Centre for food and Agriculture
DCE	Danish Centre for Environment and energy
DEA	Danish Energy Agency
DEPA	Danish Environmental Protection Agency
DST	Statistics Denmark
EEA	European Environment Agency
EF	Emission Factor
EIONET	European Environment Information and Observation Network
EMEP	European Monitoring and Evaluation Programme
ENVS	Department of ENVironmental Science, Aarhus University
EU ETS	European Union Emission Trading Scheme
FSE	Full Scale Equivalent
GE	Gross Energy
GHG	Greenhouse gas
GWP	Global Warming Potential
HFCs	Hydrofluorocarbons
IDA	Integrated Database model for Agricultural emissions
IEF	Implied Emission Factor
IGN	Department of Geosciences and Natural Resource Management, Copenhagen University
IPCC	Intergovernmental Panel on Climate Change
KCA	Key Category Analysis
LPG	Liquefied Petroleum Gas
LRTAP	Long-Range Transboundary Air Pollution
LTO	Landing and Take Off
LULUCF	Land Use, Land-Use Change and Forestry
MCF	Methane Conversion Factor
MSW	Municipal Solid Waste
N_2O	Nitrous oxide
NF_3	Nitrogen trifluoride
NFI	National Forest Inventory
NFR	Nomenclature For Reporting
NH_3	Ammonia
NIR	National Inventory Report
NMVOC	Non-Methane Volatile Organic Compounds
NO_x	Nitrogen Oxides
PFCs	Perfluorocarbons
QA	Quality Assurance

QC	Quality Control
SCR	Selective Catalytic Reduction
SF_6	Sulphur hexafluoride
SNAP	Selected Nomenclature for Air Pollution
SO_2	Sulphur dioxide
SWDS	Solid Waste Disposal Sites
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
VS	Volatile Solids
WWTP	WasteWater Treatment Plant

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- SEGES for information and discussions on actual farming practice regarding storage of animal manure.

Executive summary

ES.1 Background information on greenhouse gas inventories and climate change

ES.1.1 Reporting

This report is Denmark's National Inventory Report (NIR) 2023 for submission to the United Nations Framework Convention on Climate Change due April 15, 2023. The report contains detailed information about Denmark's inventories for all years from 1990 to 2021. The structure of the report is in accordance with the UNFCCC reporting guidelines (UNFCCC, 2013). The main difference between Denmark's NIR 2023 report to the European Commission, due March 15, 2023 and the report to UNFCCC, is reporting of territories. The NIR 2023 to the EU Commission is for Denmark, while the NIR 2023 to the UNFCCC is for Denmark, Greenland and the Faroe Islands. In practical terms the difference between the two reports is the inclusion of Chapters 11-13 in the UNFCCC reporting. The report includes detailed and complete information on the inventories for all years from year 1990 to the year 2021, in order to ensure transparency.

The annual emission inventories for the years from 1990 to 2021 are reported in the Common Reporting Format (CRF). Within this submission separate CRF's are available for Denmark (EU), Greenland, the Faroe Islands and for Denmark, Greenland and the Faroe Islands (UNFCCC). The CRF spreadsheets contain data on emissions, activity data and implied emission factors for each year. Emission trends are given for each greenhouse gas and for total greenhouse gas emissions in CO_2 equivalents.

The issues addressed in this report are: Trends in greenhouse gas emissions, description of each emission category of the CRF, uncertainty estimates, explanations on recalculations, planned improvements and procedure for quality assurance and control. The information presented in Chapters 2-10 refers to Denmark (EU) only. Specific information regarding the submission of Greenland and the Faroe Islands is included in Chapter 11 and 12, respectively. Chapter 13 contains information on the aggregated submission of Denmark, Greenland and the Faroe Islands under the UNFCCC.

This report itself does not contain the full set of CRF tables. The full set of CRF tables is available at the EIONET, Central Data Repository, kept by the European Environmental Agency:
http://cdr.eionet.europa.eu/dk/Air_Emission_Inventories

In the report, English notation is used: "." (full stop) for decimal sign and mostly space for division of thousands. The English notation for division of thousand as "," (comma) is not used due to the risk of being misinterpreted by Danish readers.

ES.1.2 Institutions responsible

On behalf of the Ministry of the Environment and Food and the Ministry of Energy, Utilities and Climate, the Danish Centre for Environment and Energy (DCE), Aarhus University, is responsible for the calculation and reporting of the Danish national emission inventory to EU, the UNFCCC (United Nations Framework Convention on Climate Change) and the UNECE LRTAP

(Long Range Transboundary Air Pollution) conventions. Hence, DCE prepares and publishes the annual submission for Denmark to the EU and UNFCCC of the National Inventory Report and the greenhouse gas (GHG) inventories in the Common Reporting Format, in accordance with the UNFCCC guidelines. Further, DCE is responsible for reporting the national inventory for the Kingdom of Denmark to the UNFCCC. Furthermore, DCE participates when reporting issues are discussed in the regime of UNFCCC and EU (Monitoring Mechanism).

The work concerning the annual greenhouse gas emission inventory is carried out in cooperation with Danish ministries, research institutes, organisations and companies. The Government of Greenland is responsible for finalising and transferring the inventory for Greenland to DCE. The Faroe Islands Environmental Agency is responsible for finalising and transferring the inventory for the Faroe Islands to DCE.

ES.1.3 Greenhouse gases

The greenhouse gases reported are those under the UN Climate Convention:

- Carbon dioxide CO_2
- Methane CH_4
- Nitrous oxide N_2O
- Hydrofluorocarbons HFCs
- Perfluorocarbons PFCs
- Sulphur hexafluoride SF_6
- Nitrogen trifluoride NF_3

The global warming potential (GWP) for various greenhouse gases has been defined as the warming effect over a given time frame of a given weight of a specific substance relative to the same weight of CO_2. The purpose of this measure is to be able to compare and integrate the effects of the individual greenhouse gases on the global climate. Typical lifetimes in the atmosphere of greenhouse gases are very different, e.g. approximately 12 and 109 years for CH_4 and N_2O, respectively. So the time perspective clearly plays a decisive role. The timeframe chosen is typically 100 years. The effect of the various greenhouse gases can then be converted into the equivalent quantity of CO_2, i.e. the quantity of CO_2 giving the same effect in absorbing solar radiation. According to the IPCC Fifth Assessment Report, which has been used from this submission and will be used by all Parties in the reporting under the Paris Agreement, the global warming potentials for a 100-year time horizon are:

- Carbon dioxide (CO_2): 1
- Methane (CH_4): 28
- Nitrous oxide (N_2O): 265

Based on weight and a 100-year period, CH_4 is thus 28 times more powerful a greenhouse gas than CO_2 and N_2O is 265 times more powerful than CO_2. Some of the other greenhouse gases (hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) have considerably higher global warming potentials. For example, sulphur hexafluoride has a global warming potential of 23 500. The values for global warming potential used in this report are those prescribed by UNFCCC. The indirect greenhouse gases reported are nitrogen oxides (NO_x), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and sulphur dioxide (SO_2).

ES.2 Summary of national emission and removal trends

Summary ES.2-4 refers to the inventory for Denmark only. The inventories for Greenland and the Faroe islands are described in Chapter 11 and 12, respectively. The emissions from Greenland and the Faroe Islands are minor compared to the emissions from Denmark and shows limited fluctuations.

ES.2.1 Greenhouse gas emissions inventory

The greenhouse gas emissions are estimated according to the IPCC guidelines and are aggregated into five main sectors. The greenhouse gases include CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3. Figure 2.1 shows the estimated total greenhouse gas emissions in CO_2 equivalents (without indirect CO_2) from 1990 to 2021. The emissions are not corrected for electricity trade or temperature variations.

CO_2 is the most important greenhouse gas contributing in 2021 to the national total in CO_2 equivalents excluding LULUCF (Land Use and Land Use Change and Forestry) and excluding indirect CO_2 emissions with 67.9%, followed by CH_4 with 19.7 %, N_2O with 11.7 %, and f-gases (HFCs, PFCs, SF_6 and NF_3) with 0.7 %. If including LULUCF and indirect CO_2, the CO_2 emissions account for 69.0%, followed by CH_4 with 19.2 %, N_2O with 11.1 %, and f-gases (HFCs, PFCs, SF_6 and NF_3) with 0.6 %.

The energy sector and agricultural sector represent the largest sources, followed by LULUCF, industrial processes and product use and waste, see Figure 2.1. The total national greenhouse gas emission in CO_2 equivalents excluding LULUCF has decreased by 38.7 % from 1990 to 2021 when considering indirect CO_2, if excluding indirect CO_2 the emissions have decreased by 38.1 %. The emissions including LULUCF and indirect CO_2 have decreased by 41.0 % from 1990 to 2021. Comments on the overall trends etc. seen in Figure 2.1 are given in the sections below on the individual greenhouse gases.

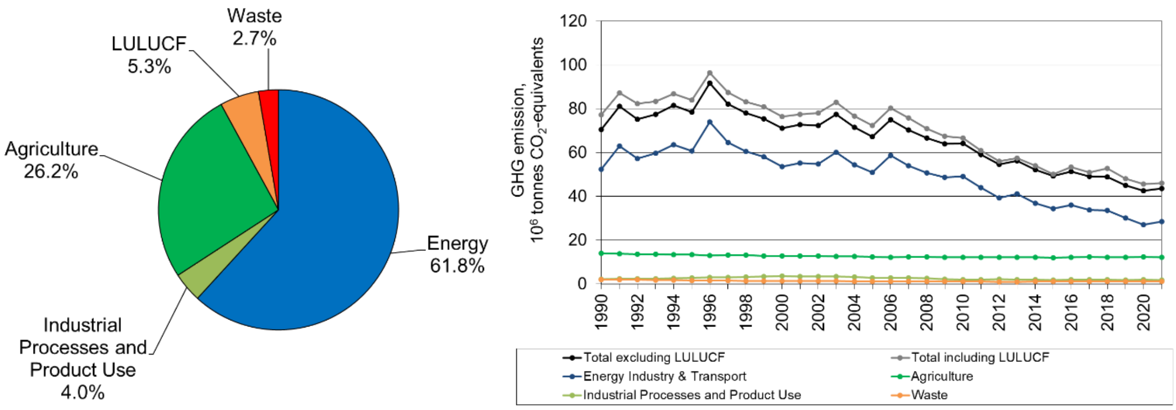


Figure ES.1 Greenhouse gas emissions in CO_2 equivalents distributed on main sectors for 2021 (excluding LULUCF and indirect CO_2) and time series for 1990 to 2021.

ES.3 Overview of source and sink category emission estimates and trends

ES.3.1 Greenhouse gas emissions inventory

Energy

The emission from the energy sector in 2021 covers 61.5 % of the total emission in CO_2 equivalents (incl. LULUCF and indirect CO_2). The emission of CO_2 equivalents from energy industries (CRF 1A1) has decreased by 68.3 %

from 1990 to 2021. The relatively large fluctuations in the emission through the time-series 1990-2021 is due to inter-country electricity trade. Thus, the high emissions in 1991, 1996, 2003 and 2006 reflect a large electricity export and the low emission in 1990, 2005, 2008, 2011 and 2012 is due to import of electricity. In general, CO_2 emissions are decreasing due to a lower consumption of fossil fuels and a higher electricity production based on renewable energy, mainly wind power.

The increasing emission of CH_4 is due to the increasing use of gas engines in decentralised cogeneration plants. However, in later years the CH_4 emission has decreased due to less use of natural gas in gas engines. The CH_4 emission from residential combustion (mainly wood) increased as a result of increased use of wood. However, the wood consumption has decreased substantially over the last years, so that emission is decreasing. The emission of CO_2 equivalents from the transport sector (CRF 1A3) increased by 13.5 % from 1990 to 2021, mainly due to increasing road traffic. A large decrease in transport emissions occurred between 2019 and 2020, which can to a large extend be attributed to the restrictions to mobility in battling the COVID-19 pandemic.

Industrial processes and product use

The emissions from industrial processes and product use, i.e. emissions from processes other than fuel combustion, amount in 2021 to 4.0 % of the total emission in CO_2 equivalents (incl. LULUCF and indirect CO_2). The main sources are cement production and f-gases used in refrigeration and air conditioning.

The largest source is CO_2 emissions from cement production, which in 2021 contributes with 1214.6 kt CO_2, i.e. 2.6 % of the national greenhouse gas emissions (incl. LULUCF and indirect CO_2). The CO_2 emission from cement production has increased by 56.8 % since 1990. The second largest source is the emission from consumption of HFCs mainly from refrigeration and air condition equipment. This source contributes with 275.2 kt CO_2 equivalents, i.e. 0.6 % of the national total. Historically (1990-2004), the emission of N_2O from the production of nitric acid has been the second largest source (after cement), with up to 1002.5 kt CO_2 equivalents (1990). However, the production of nitric acid ceased in 2004, which reduced the N_2O emission from industrial processes drastically.

Agriculture

The agricultural sector contributes in 2021 with 26.1 % of the total emission in CO_2 equivalents (incl. LULUCF and indirect CO_2) and the major part is related to the livestock production. Since 1990, the agricultural emission has decreased 13.1 % mainly due to a decrease in the N_2O emission.

In 2021, the agricultural activities accounts for 83.0 % of the total CH_4 emission (excl. LULUCF). Since 1990, the emission of CH_4 from enteric fermentation has decreased by 7.7 %, which is mainly due to the decrease in the number of dairy cattle. However, the emission from manure management has in the same period increased 21.5 %, which is mainly driven by a change from traditional housing systems towards slurry-based housing systems. In total, the CH_4 emission from the agriculture sector 1990 – 2021 has increased by 2.8 %.

In 2021, the agricultural activities accounts for 89.7 % of the total N_2O emission (excl. LULUCF). Since 1990, the N_2O emission has decreased 26.8 %. A string of measures have been introduced by action plans to prevent the loss of nitrogen from agriculture to the aquatic environment. These actions have brought a decrease in animal nitrogen excretion, improvement in use of nitrogen in manure and a fall in the use of inorganic N fertiliser, which all have led to reductions of the N_2O emission.

Land Use and Land Use Change and Forestry (LULUCF)

The total sector has been estimated to be a net source of 4.3 % of the total Danish emission incl. LULUCF (average previous 10 years (2012-2021) (variation 1.7-7.2 % depending of year). The average emission over the past 10 years (2012-2021) has been estimated to 2148 kt CO_2-eq. with an emission of 2420 kt CO_2 equivalents in 2021. Emissions/removals from the sector fluctuate based on specific conditions in the given year. In general, the forest sector is a net sink or around in its equilibrium state, while Cropland and Grassland are net sources. The latter due to a large area with drained organic soils. CO_2 emissions from drained organic soils within cropland and grassland accounts for 9.6 % of the total Danish emission incl. LULUCF and indirect CO_2 in 2021.

In 2021, Cropland has been estimated to be a net source of 6.0% of the total Danish emission incl. LULUCF and indirect CO_2. Grassland is a net source contributing to 5.0 % of the total Danish emission, also due to a large area with drained organic soils. Emissions from Cropland and Grassland have shown a continuous decrease since 1990. However, large variations occur between years.

Waste

The waste sector contributes in 2021 to 2.7 % of the total emission in CO_2 equivalents (incl. LULUCF and indirect CO_2). The emission from the sector has decreased by 37.5 % since 1990. Historically, the most important activity in the sector is solid waste disposal on land. In 2021, the emissions contributed by 35.1 % of the sectoral total GHG emission. The CH_4 emission from solid waste disposal has been decreasing since 1990 by 71.6 % due to banning of deposing organic waste and an overall decrease in waste deposited because waste has increasingly been used for power and heat production and/or recycled.

Biological treatment of solid waste (5.B) has in the later years become the largest contributor to the sectoral total GHG emission. It contributes to the sectoral total in CO_2 equivalents in 2021 with 45.5 %. The emissions from biological treatment of solid waste have increased by 1273 % for CH_4 and 230 % for N_2O since 1990, due to an increase in the number of biogas plants and the amount of bio-waste composted in Denmark.

Wastewater handling contributes to the sectoral total in CO_2 equivalents in 2021 with 17.3 %. The CH_4 emissions from wastewater handling have increased by 30.5 % from 1990 to 2021 while the N_2O emission has decreased by 57.9 %.

Since all incinerated waste (municipal, industrial, hazardous) is used for power and heat production, the emissions are included in the 1A1a category.

ES.4 Other information

ES.4.1 Quality assurance and quality control

A plan for Quality Assurance (QA) and Quality Control (QC) in greenhouse gas emission inventories is included in the report. The plan is in accordance with the guidelines provided by the UNFCCC (Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories and Guidelines for National Systems). ISO 9000 standards are also used as an important input for the plan.

The plan comprises a framework for documenting and reporting emissions in a way that emphasize transparency, consistency, comparability, completeness and accuracy. To fulfil these high criteria, the data structure describes the pathway, from the collection of raw data to data compilation and modelling and finally reporting.

As part of the Quality Assurance (QA) activities, emission inventory sector reports are being prepared and sent for review to national experts not involved in the inventory development. To date, the reviews have been completed for the stationary combustion plants sector, the fugitive emissions from fuels sector, the transport sector, the solvents and other product use sector and the agricultural sector. In order to evaluate the Danish emission inventories, a project where emission levels and emission factors are compared with those in other countries has been conducted.

ES.4.2 Completeness

The Danish greenhouse gas emission inventories include all sources identified by the revised IPPC guidelines.

Please see Annex 5 for more information.

ES.4.3 Recalculations and improvements

Recalculations and improvements are continuously made to the inventory. The sector-specific recalculations and improvements are documented in the sectoral chapters of this report (Chapter 3-7) and a general overview is provided in Chapter 9.

Sammenfatning

S.1 Baggrund for opgørelse af drivhusgasemissioner og klimaændringer

S.1.1 Rapporteringen

Denne rapport er Danmarks årlige rapport – den såkaldte Nationale Inventory Report (NIR) for 2023. Rapporten beskriver drivhusgasopgørelsen som blev fremsendt til FN's konvention om klimaændringer (UNFCCC) og Kyotoprotokollen den 15. april 2023. Rapporten indeholder detaljerede informationer om Danmarks drivhusgasudslip for alle år fra 1990 til 2021. Rapportens struktur er i overensstemmelse med UNFCCC's retningslinjer for rapportering. Forskellen mellem Danmarks NIR 2022 som blev fremsendt til EU-Kommissionen den 15. marts 2023 og denne rapport til UNFCCC, vedrører det territorium rapporteringen omfatter. NIR 2023 til EU-Kommissionen omfatter Danmark, mens NIR 2023 til UNFCCC omfatter Danmark, Grønland og Færøerne. I praksis er forskellen inkluderingen af kapitel 11-13 i NIR'en til UNFCCC. For at sikre at opgørelserne er sammenhængende og gennemskuelige, indeholder rapporten detaljerede oplysninger om opgørelsesmetoder og baggrundsdata for alle årene fra 1990 og til 2021.

Denne emissionsopgørelse for årene 1990 til 2021, er som tidligere årlige opgørelser, rapporteret i formatet Common Reporting Format (CRF) som Klimakonventionen foreskriver anvendt. Emissionsopgørelsen i CRF foreligger med denne rapportering således, at der er separate CRF for Danmark (EU), Grønland, Færøerne samt for Danmark, Grønland og Færøerne (Klimakonventionen). CRF-tabellerne indeholder oplysninger om emissioner, aktivitetsdata og emissionsfaktorer for hvert år, emissionsudvikling for de enkelte drivhusgasser samt den totale drivhusgasemission i CO_2-ækvivalenter.

Følgende emner er beskrevet i rapporten: Udviklingen i drivhusgasemissionerne, metoder mv. som anvendes til opgørelserne i de emissionskategorier som findes i CRF-formatet, usikkerheder, genberegninger, planlagte forbedringer og procedure for kvalitetssikring og –kontrol. Teksten i kapitel 2-10 omhandler kun Danmark som omfattet af EU. Oplysninger om emissionsopgørelsen for Grønland og Færøerne er inkluderet i henholdsvis kapitel 11 og 12. Kapitel 13 indeholder informationer for den samlede aflevering for Kongeriget under UNFCCC.

Denne rapport indeholder ikke det fulde sæt af CRF-tabeller. Det fulde sæt af CRF-tabeller er tilgængelige på EIONET, som er det Europæiske Miljøagenturs rapporterings-internetsite:
http://cdr.eionet.europa.eu/dk/Air_Emission_Inventories

Med hensyn til gengivelsen af tal i CRF-formatet, gøres opmærksom på at det er med dansk notation: "," (komma) for decimaladskillelse og "." (punktum) til adskillelse af tusinder. I rapporten er den engelske notation brugt: "." (punktum) for decimaltegn og for det meste mellemrum for adskillelse af tusinder. Den engelske notation for adskillelse af tusinder med "," (komma) er for det meste ikke brugt på grund af risikoen for fejltolkninger for danske læsere.

S.1.2 Ansvarlige institutioner

DCE - Nationalt Center for Miljø og Energi ved Aarhus Universitet er på vegne af Miljø- og Fødevareministeriet samt Energi-, Forsynings- og Klimaministeriet ansvarlig for udregning og afrapportering af den nationale emissionsopgørelse til EU og til UNFCCC (FN's konvention om klimaændringer) såvel som til UNECE-konventionen om langtransporteret grænseoverskridende luftforurening. Som følge heraf, er DCE ansvarlig for udførelse og publicering af opgørelserne af drivhusgasemissioner og den årlige rapportering til EU og UNFCCC for Danmark. DCE er den centrale institution for Danmarks nationale system til drivhusgasopgørelser under Kyotoprotokollen. Ydermere er DCE ansvarlig for rapportering af drivhusgasemissionsopgørelser til Klimakonventionen for Kongeriget Danmark (Færøerne, Grønland og Danmark), samt Danmarks og Grønlands samlede rapportering til Kyotoprotokollen. DCE deltager desuden i arbejdet i regi af Klimakonventionen og Kyotoprotokollen, hvor retningslinjer for rapportering diskuteres og vedtages og i EU's moniteringsmekanisme for opgørelse af drivhusgasser, hvor retningslinjer for rapportering til EU reguleres.

Arbejdet med de årlige opgørelser udføres i samarbejde med andre danske ministerier, forskningsinstitutioner, organisationer og private virksomheder. Grønlands Klima- og Infrastrukturstyrelse er ansvarlig for levering af opgørelser for Grønland til DCE. Færøernes miljømyndighed (Umhvørvisstovan) er ansvarlig for de færøske opgørelser.

S.1.3 Drivhusgasser

Til Klimakonventionen rapporteres følgende drivhusgasser:

- Kuldioxid CO_2
- Metan CH_4
- Lattergas N_2O
- Hydrofluorcarboner HFC'er
- Perfluorcarboner PFC'er
- Svovlhexafluorid SF_6
- Nitrogentrifluorid NF_3

Det globale opvarmningspotentiale, på engelsk Global Warming Potential (GWP), udtrykker klimapåvirkningen over en nærmere angivet tid af en vægtenhed af en given drivhusgas relativt til samme vægtenhed af CO_2. Drivhusgasser har forskellige karakteristiske levetider i atmosfæren, således for CH_4 ca. 12 år og for N_2O ca. 109 år. Derfor spiller tidshorisonten en afgørende rolle for størrelsen af GWP. Typisk vælges 100 år. Herefter kan effekten af de forskellige drivhusgasser omregnes til en ækvivalent mængde CO_2, dvs. til den mængde CO_2 der vil give samme klimapåvirkning. Til rapporteringen til Klimakonventionen er der fra dette års aflevering anvendt GWP-værdier for en 100-årig tidshorisont ifølge IPCC's femte hovedrapport og disse vil blive anvendt af alle lande i rapporteringen under Parisaftalen:

- Kuldioxid, CO_2: 1
- Metan, CH_4: 28
- Lattergas, N_2O: 265

Regnet efter vægt og over en 100-årig periode er metan således ca. 28 og lattergas ca. 265 gange så effektive drivhusgasser som kuldioxid. For andre drivhusgasser, der indgår i rapporteringen, de såkaldte F-gasser (HFC, PFC,

SF_6, NF_3) findes væsentlig højere GWP-værdier. Under Klimakonventionen er der ligeledes vedtaget GWP-værdier for disse baseret på IPCC's anbefalinger. Således har f.eks. SF_6 en GWP-værdi på 23 500.

Endvidere rapporteres de indirekte drivhusgasser kvælstofilte (NO_x), kulilte (CO), ikke-metan flygtige organiske forbindelser (NMVOC) og svovldioxid (SO_2).

S.2 Udviklingen i drivhusgasemissioner og optag

Sammenfatning S.2.-4. omhandler alene opgørelsen for Danmark. Opgørelsen for Grønland samt for Færøerne beskrives i kapitel 11 og 12.

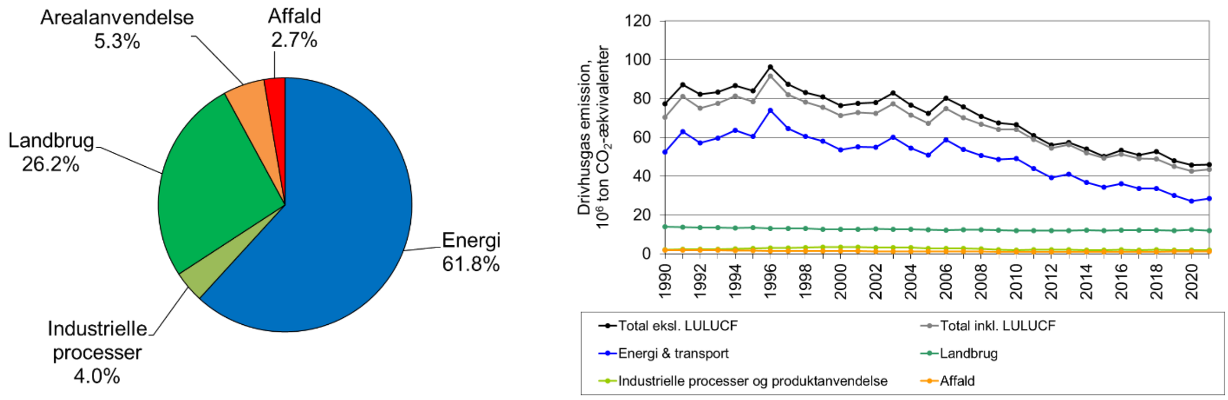
S.2.1 Drivhusgasemissionsopgørelse

De danske opgørelser af drivhusgasemissioner følger metoderne som beskrevet i IPCC's retningslinjer. Opgørelserne er opdelt i fem overordnede sektorer, 1. energi, 2. industrielle processer og produktanvendelse, 3. landbrug, 4. arealanvendelse (Land Use Land Use Change and Forestry: LULUCF) og 5. affald. Drivhusgasserne omfatter CO_2, CH_4, N_2O og F-gasserne: HFC'er, PFC'er, SF_6 og NF_3. I figur S.1 ses de estimerede drivhusgasemissioner for Danmark i CO_2-ækvivalenter for perioden 1990 til 2021. Figuren viser Danmarks totale udledning med og uden LULUCF-sektoren (Land Use and Land Use Change and Forestry). Til venstre i figur S.1 ses det relative bidrag til Danmarks totale udledning i 2021 fra de forskellige sektorer.

I overensstemmelse med retningslinjerne for opgørelserne er emissionerne ikke korrigerede for handel med elektricitet med andre lande og temperatursvingninger fra år til år.

CO_2 er den vigtigste drivhusgas og bidrager i 2021 med 67,9 % af den nationale totale udledning uden LULUCF-sektoren og uden indirekte CO_2, efterfulgt af CH_4 med 19,7 % og N_2O med 11,7 %, mens HFC'er, PFC'er og SF_6 kun udgør 0,7 % af de totale emissioner uden LULUCF-sektoren. Hvis man medregner LULUCF-sektoren samt indirekte CO_2, så udgør CO_2 69,0 % fulgt af CH_4 med 19,2 %, N_2O med 11,1 % og f-gasser (HFCs, PFCs, SF_6 and NF_3) med 0,6 %.

Energisektoren og landbrugssektoren er de største kilder efterfulgt af LULUCF, industrielle processer og affald, se figur S.1. De nationale totale drivhusgasemissioner i CO_2-ækvivalenter inklusiv indirekte CO_2 er faldet med 38,7 % fra 1990 til 2021, hvis nettobidraget fra skovenes og jordernes udledninger og optag af CO_2 (LULUCF) ikke indregnes. Eksklusiv LULUCF og indirekte CO_2 er emissionen faldet med 38,1 %. Emissionen inklusiv LULUCF og indirekte CO_2 er faldet med 41,0 % mellem 1990 og 2021.



Figur S.1 Danske drivhusgasemissioner. Bidrag til total emission fra hovedsektorer for 2021 og tidsserier i CO_2-ækvivalenter for 1990-2021, hvor data er angivet med og uden LULUCF.

S.3 Oversigt over drivhusgasemissioner og optag fra sektorer

S.3.1 Drivhusgasemissionsopgørelse

Energi

Emissionen fra energisektoren udgjorde i 2021 61,5 % af den samlede drivhusgasemission udtrykt i CO_2-ækvivalenter (inkl. LULUCF og indirekte CO_2). Drivhusgasemissionen fra energisektoren (CRF 1A1) er faldet med 68,3 % fra 1990 til 2021. De relativt store udsving i emissionerne fra år til år skyldes handel med elektricitet med andre lande, herunder særligt de nordiske. De høje emissioner i 1991, 1996, 2003 og 2006 er et resultat af stor eksport af elektricitet, mens de lave emissioner i 1990, 2005, 2008, 2011 og 2012 skyldes import af elektricitet. Den væsentligste årsag til den faldende tendens er faldende fossilt brændselsforbrug, hovedsageligt for kul og naturgas.

Udledningen af CH_4 fra energiproduktion har været stigende på grund af øget anvendelse af gasmotorer, som har en stor CH_4-emission i forhold til andre forbrændingsteknologier. Anvendelsen af gasmotorer er dog blevet mindre siden liberaliseringen af elmarkedet, hvilket har ført til lavere CH_4-emissioner fra energisektoren. CH_4-emissionen fra husholdninger er stegte på grund af et stigende forbrug af brænde i ovne og kedler. Fra 2016 er træforbruget dog faldet væsentligt, hvilket har reduceret emissionen. Transportsektorens drivhusgasemissioner er steget med 13,5 % siden 1990 hovedsagelig på grund af voksende vejtrafik. Et betydeligt fald i emissionerne fra transport fandt sted mellem 2019 og 2020, hvilket i vid udstrækning kan tilskrives restriktioner i forbindelse med COVID-19 pandemien.

Industrielle processer og produktanvendelse

Emissionen fra industrielle processer og produktanvendelse – hvilket vil sige andre processer end forbrændingsprocesser – udgør i 2021 4,0 % af de totale danske drivhusgasemissioner. De vigtigste kilder er cementproduktion, og fluorerede gasser anvendt i kølesystemer.

CO_2-emissionen fra cementproduktion - som er den største kilde - bidrager med 1214,6 kt CO_2 svarende til 2,6 % af den totale emission i 2021. Emissionen fra cementproduktion er steget med 56,8 % siden 1990. Den anden største kilde er emission af HFC'er i forbindelse med køling og aircondition. Denne kilde bidrog i 2021 med 275,2 kt CO_2-ækvivalenter svarende til 0,6 % af den nationale total. Tidligere (1990-2004) var den andenstørste kilde N_2O fra produktion af salpetersyre med op til 1002,5 kt CO_2-ækvivalenter (1990).

Produktionen af salpetersyre stoppede i midten af 2004, hvilket betød, at N_2O-emissionen fra industrielle processer og produktanvendelse faldt drastisk.

Landbrug

Landbrugssektoren bidrager i 2021 med 26.1 % af den totale drivhusgasemission i CO_2-ækvivalenter og er den vigtigste sektor, hvad angår emissioner af N_2O og CH_4. Siden 1990 er drivhusgasemissionen fra landbruget faldet med 13,1 %. Faldet skyldes hovedsageligt et fald i emissionen af N_2O.

I 2021 bidrog landbruget med 83,9 % af den totale emission af CH_4. Siden 1990 er emissionen af CH_4 fra husdyrenes fordøjelsessystem faldet med 7.7 % grundet et faldende antal kvæg. Emissionen fra gødningshåndtering er dog i samme periode steget med 21,5 %. Dette skyldes, at der er sket en overgang fra traditionelle staldsystemer med fast gødning til flere gyllebaserede staldsystemer med højere emissioner. Samlet set er CH_4 emissionen fra landbrug steget med 2,8 % siden 1990.

I 2021 bidrog landbruget med 89,7 % af den totale emission af N_2O. Siden 1990 er N_2O emissionen faldet med 26.8 %, hvilket skyldes en lang række virkemidler med formål at begrænse tabet af kvælstof til vandmiljøet. Dette har medført et fald i udskillelsen af kvælstof fra husdyr, bedre udnyttelse af kvælstoffet i husdyrgødningen samt et fald i anvendelsen af handelsgødning. Disse ting har alle ført til en reduceret emission af N_2O.

Arealanvendelse - skove og jorder (LULUCF)

Sektoren som helhed er estimeret til at værre en nettoudledning på 4,3 % af den samlede danske emission inklusiv LULUCF (gennemsnit for de seneste 10 år (2012-2021), variation mellem 1,7 og 7,2 % afhængig af år). Den gennemsnitlige emission over de seneste 10 år (2012-2021) er beregnet til 2148 kt CO_2-ækvivalenter med en emission på 2420 kt CO_2-ækvivalenter i 2021. Emissioner/optag fra sektoren fluktuerer baseret på de forhold (især klimatiske) i det enkelte år. Generelt har skov været et nettooptag, mens landbrugsjorde og græsarealer har været nettokilder. Grunden til at landbrug og græsarealer har været kilder er et betydeligt areal med drænede organiske jorde.

I 2021 er landbrugsjorde opgjort til at være en kilde svarende til 6,0 % af den samlede danske drivhusgasemission. Græsarealer er opgjort til at være en kilde svarende til 5,0 % af den samlede danske drivhusgasemission. Emissioner fra landbrugsjorde og græsarealer er faldet stødt siden 1990, men med store variationer mellem år.

Affald

Affaldssektoren bidrager i 2021 med 2,7 % af den samlede drivhusgasemission inklusiv LULUCF og indirekte CO_2. Emissionen fra sektoren er faldet med 37,5 % siden 1990. Historisk set har den vigtigste aktivitet inden for sektoren været affaldsdeponier, som i 2021 står for 35,1 % af sektorens drivhusgasemissioner.CH_4-emissionen fra deponier er faldet med 71,6 % siden 1990, hvilket skyldes et forbud mod deponering af forbrændingsegnet affald og et generelt fald i mængderne af deponeret affald pga. stigende affaldsforbrænding og genanvendelse.

Biologisk behandling af affald er i de senere år blevet den størst kilde til affaldssektorens drivhusgasemissioner. Kategorien bidrager med 45,5 % af sektorens emissioner i 2021. Emissionerne fra biologisk affaldsbehandling er steget kraftigt siden 1990 – CH_4 er steget med 1273 % og N_2O med 230 %. Dette skyldes den stigende popularitet af kompostering og biogasbehandling som affaldsbehandlingsmetoder.

Spildevandsbehandling bidrager til sektorens samlede emission med 17,3 % i 2021. CH_4-emissionen fra spildevandsbehandling er steget med 30,5 % siden 1990 mens N_2O-emissionen er faldet med 57,9 %.

Siden al affaldsforbrænding (husholdnings- og industriaffald samt farligt affald) udnyttes til produktion af varme og/eller elektricitet, så er emissionerne inkluderet under energisektoren, nærmere bestemt kategori 1A1a.

S.4 Andre informationer

S.4.1 Kvalitetssikring og - kontrol

Rapporten indeholder en plan for kvalitetssikring og -kontrol af emissionsopgørelserne. Kvalitetsplanen bygger på IPCC's retningslinjer og ISO 9000-standarderne. Planen skaber rammer for dokumentation og rapportering af emissionerne, så opgørelserne er gennemskuelige, konsistente, sammenlignelige, komplette og nøjagtige. For at opfylde disse kriterier, understøtter datastrukturen arbejdsgangen fra indsamling af data til sammenstilling, modellering og til sidst rapportering af data.

Som en del af kvalitetssikringen, udarbejdes der for emissionskilderne rapporter, der detaljeret beskriver og dokumenterer anvendte data og beregningsmetoder. Disse rapporter evalueres af personer uden for Aarhus Universitet, der har høj faglig ekspertise inden for det pågældende område, men som ikke direkte er involveret i arbejdet med opgørelserne. Indtil nu er rapporter for stationære forbrændingsanlæg, transport og landbrug blevet evalueret. Desuden er der gennemført et projekt, hvor de danske opgørelsesmetoder, emissionsfaktorer og usikkerheder sammenlignes med andre landes, for yderligere at verificere rigtigheden af opgørelserne.

S.4.2 Fuldstændighed i forhold til IPCC's retningslinjer for kilder og gasser

De danske opgørelser af drivhusgasemissioner indeholder alle de kilder, der er beskrevet i IPCC's retningslinjer.

I anneks 5 er der flere informationer om fuldstændigheden af den danske drivhusgasopgørelse.

S. 4.3 Genberegninger og forbedringer

Genberegninger og forbedringer bliver løbende udført i forbindelse med emissionsopgørelserne. De sektorspecifikke genberegninger og forbedringer er beskrevet i sektorafsnittene i denne rapport (kapitel 3-7). Et generelt overblik er inkluderet i kapitel 9.

1 Introduction

1.1 Background information on greenhouse gas inventories and climate change

1.1.1 Annual report

This report is Denmark's National Inventory Report (NIR) 2023 for submission to the United Nations Framework Convention on Climate Change due April 15, 2023. The report contains detailed information about Denmark's inventories for all years from 1990 to 2021. The structure of the report is in accordance with the UNFCCC reporting guidelines (UNFCCC, 2013). The main difference between Denmark's NIR 2023 report to the European Commission, due March 15, 2023, and this report to UNFCCC is reporting of territories. The NIR 2023 to the EU Commission was for Denmark, while this NIR 2023 to the UNFCCC is for Denmark, Greenland and the Faroe Islands. The report includes detailed and complete information on the inventories for all years from year 1990 to the year 2021, in order to ensure transparency.

The information in the sectoral chapters in this report relates to Denmark only, while information for Greenland is included in Chapter 11 and for the Faroe Islands in Chapter 12. Chapter 13 contains on the aggregated submission for the Kingdom of Denmark.

The issues addressed in this report are trends in greenhouse gas emissions, a description of each IPCC category, uncertainty estimates, recalculations, planned improvements and procedures for quality assurance and control.

The annual emission inventories for the years from 1990 to 2021 are reported in the Common Reporting Format (CRF) as requested in the reporting guidelines. The CRF-spreadsheets contain data on emissions, activity data and implied emission factors for each year. Emission trends are given for each greenhouse gas and for the total greenhouse gas emissions in CO_2 equivalents.

According to the instrument of ratification, the Danish government has ratified the UNFCCC on behalf of Denmark, Greenland and the Faroe Islands.

This report itself does not contain the full set of CRF Tables. The full set of CRF tables is available at the EIONET, Central Data Repository, kept by the European Environmental Agency:
http://cdr.eionet.europa.eu/dk/Air_Emission_Inventories/Submission_UNFCCC

1.1.2 Greenhouse gases

The greenhouse gases to be reported under the Climate Convention are:

- Carbon dioxide CO_2
- Methane CH_4
- Nitrous Oxide N_2O
- Hydrofluorocarbons HFCs
- Perfluorocarbons PFCs
- Sulphur hexafluoride SF_6
- Nitrogen trifluoride NF_3

The main greenhouse gas responsible for the anthropogenic influence on the heat balance is CO_2. The atmospheric concentration of CO_2 has increased from a pre-industrial value of about 278 ppm to about 410 ppm in 2019 (an increase of about 47 %) (IPCC, 2021), and exceeds the natural range of 180-300 ppm over the last 650 000 years as determined by ice cores. The main cause for the increase in CO_2 is the use of fossil fuels, but changing land use, including forest clearance, has also been a significant factor. The greenhouse gases CH_4 and N_2O are very much linked to agricultural production; CH_4 has increased from a pre-industrial atmospheric concentration of about 729 ppb to 1866 ppb in 2019 (an increase of about 156 %) and N_2O has increased from a pre-industrial atmospheric concentration of about 270 ppb to 332 ppb in 2019 (an increase of about 23 %) (IPCC, 2021). Changes in the concentrations of greenhouse gases are not related in simple terms to the effect on the heat balance, however. The various gases absorb radiation at different wavelengths and with different efficiency. This must be considered in assessing the effects of changes in the concentrations of various gases. Furthermore, the lifetime of the gases in the atmosphere needs to be taken into account – the longer they remain in the atmosphere, the greater the overall effect. The global warming potential (GWP) for various gases has been defined as the warming effect over a given time of a given weight of a specific substance relative to the same weight of CO_2. The purpose of this measure is to be able to compare and integrate the effects of individual substances on the global climate. Typical lifetimes in the atmosphere of substances are very different, e.g. 12 and 109 years approximately for CH_4 and N_2O, respectively (Smith et al., 2021). Therefore, the time perspective clearly plays a decisive role. The time frame chosen is typically 100 years. The effect of the various greenhouse gases can, then, be converted into the equivalent quantity of CO_2, i.e. the quantity of CO_2 giving the same effect in absorbing solar radiation. According to the IPCC and their Fifth Assessment Report (Myhre et al., 2013), which UNFCCC (UNFCCC, 2018) has decided to use as reference for reporting under the Paris Agreement, the global warming potentials for a 100-year time horizon are:

- Carbon dioxide (CO_2): 1
- Methane (CH_4): 28
- Nitrous oxide (N_2O): 265

Based on weight and a 100-year period, methane is thus 28 times more powerful a greenhouse gas than CO_2, and N_2O is 265 times more powerful. Some of the other greenhouse gases (hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) have considerably higher global warming potential values. For example, sulphur hexafluoride has a global warming potential of 23 500.

The indirect greenhouse gases reported are nitrogen oxides (NO_x), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and sulphur dioxide (SO_2).

1.1.3 The Climate Convention and the Paris Agreement

At the United Nations Conference on Environment and Development in Rio de Janeiro in June 1992, more than 150 countries signed the UNFCCC (the Climate Convention). On the 21st of December 1993, the Climate Convention was ratified by a sufficient number of countries, including Denmark, for it to enter into force on the 21st of March 1994. One of the provisions of the treaty was to stabilise the greenhouse gas emissions from the industrialised nations by the end of 2000. At the first conference under the UN Climate Convention in March 1995, it was decided that the stabilisation goal was inadequate. At the third conference in December 1997 in Kyoto in Japan, a legally binding agreement was reached committing the industrialised countries to reduce the six greenhouse gases by 5.2 % by 2008-2012 compared with the base year. For F-gases, the countries can choose freely between 1990 and 1995 as the base year. On May 16, 2002, the Danish parliament voted for the Danish ratification of the Kyoto Protocol. Denmark (including Greenland and excluding the Faroe Islands) is, thus, under a legal commitment to meet the requirements of the Kyoto Protocol, when it came into force on the 16th of February 2005. Hence, Denmark (including Greenland) was committed to reduce greenhouse gases with 8 %. The European Union was under the first commitment period of the Kyoto Protocol committed to reduce emissions of greenhouse gases by 8 %. However, within the EU member states have made a political agreement – the Burden Sharing Agreement – on the contributions to be made by each member state to the overall EU reduction level of 8 %.

Under the Burden Sharing Agreement, Denmark (excluding Greenland and the Faroe Islands) had to reduce emissions by an average of 21 % in the period 2008-2012 compared with the base year emission level.

For the second commitment period (2013-2020), the EU had a target of 20 % reduction compared to the base year. The reduction commitment within the EU distinguishes between the emissions covered by the EU Emission Trading System (ETS) and the non-ETS emissions. For the ETS there was a reduction of 24 % in allowances. For the non-ETS emissions, each Member State has a separate target set out in the Effort Sharing Decision, (ESD) (Decision No 406/2009/EC). In the ESD, Denmark had a reduction commitment of 20 % in 2020 compared to the emission level in 2005.

For the period starting in 2021, the EU has implemented its climate action in the non-ETS sectors through the effort sharing regulation (Regulation (EU) 2018/842). Under the ESR EU Member States have binding annual greenhouse gas emission targets for 2021-2030 for those sectors of the economy that fall outside the scope of the EU ETS. These sectors include transport, buildings, agriculture, non-ETS industry and waste. Overall for the EU, the target is a reduction of 30 % by 2030 compared to 2005. The reduction commitment for Denmark is a reduction of 39 %.

1.1.4 The role of the European Union

The European Union (EU) is a party to the UNFCCC and the Paris Agreement. Therefore, the EU has to submit similar datasets and reports for the collective 27 EU Member States.

The EU imposes some additional guidelines and obligations to the Member States through Regulation (EU) No 2018/1999 on the Governance of the Energy Union and Climate Action. The Implementing Regulation detailing the reporting requirements was decided in 2020 (2020/1208/EU). As mentioned above the ESR is the legal framework for Member States reduction commitments in the non-ETS sectors.

1.2 A description of the institutional arrangement for inventory preparation

On behalf of the Ministry of Environment and Food and the Ministry of Climate, Energy and Utilities, the Danish Centre for Environment and Energy (DCE) is responsible for the calculation and reporting of the Danish national emission inventory to the EU, the UNFCCC (United Nations Framework Convention on Climate Change) and UNECE CLRTAP (Convention on Long-Range Transboundary Air Pollution). Hence, DCE prepares and publishes the annual submission for Denmark to the EU and UNFCCC of the National Inventory Report and the GHG inventories in the Common Reporting Format, in accordance with the UNFCCC guidelines. Furthermore, DCE is responsible for reporting the national inventory for the Kingdom of Denmark to the UNFCCC.

The work concerning the annual greenhouse gas emission inventory is carried out in cooperation with Danish ministries, research institutes, organisations and companies. The Government of Greenland is responsible for finalising and transferring the inventory for Greenland to DCE. The environmental authority in the Faroe Islands (Umhvørvisstovan) is responsible for finalising and transferring the inventory for the Faroe Islands to DCE.

There are now data agreements in place with both Greenland and the Faroe Islands ensuring the data delivery. These agreements contain deadlines for when DCE is to receive the data and documentation.

DCE has been and is engaged in the work in connection with meetings of the Conference of the Parties (COP) to the UNFCCC, the Conference of the Parties serving as the Meeting of the Parties (CMP) to the Kyoto protocol and the Conference of the Parties serving as the Meeting of the Parties (CMA) to the Paris Agreement and the subsidiary bodies, where the reporting rules are negotiated and settled. Furthermore, DCE participates in the EU Working Group 1 (WG1) under the Climate Change Committee, where the guidelines, methodologies etc. on inventories to be prepared by the EU Member States are regulated.

The main experts responsible for the sectoral inventories and the corresponding chapters and annexes in this report are:

Project leader		**Ole-Kenneth Nielsen (okn@envs.au.dk)**
Sector	Sub-sector	Responsible expert(s)
Energy	Stationary combustion:	Malene Nielsen
	Transport and other mobile sources	Morten Winther
	Fugitive emissions:	Marlene Plejdrup
Industrial processes and product use		Katja Hjelgaard
Agriculture		Mette Hjorth Mikkelsen Rikke Albrektsen
LULUCF	Forestry and HWP	Vivian Kvist Johannsen
LULUCF	Cropland, grassland, wetlands, settlements	Steen Gyldenkærne
Waste		Katja Hjelgaard
Greenland		Lene Baunbæk
Faroe Islands		Maria Gunnleivsdóttir Hansen

The work concerning the annual greenhouse emission inventory is carried out in cooperation with other Danish ministries, research institutes, organisations and companies:

Danish Energy Agency, Ministry of Climate, Energy and Utilities: Annual energy statistics in a format suitable for the emission inventory work and fuel-use data for the large combustion plants. Company reports submitted under EU ETS.

Danish Environmental Protection Agency, Ministry of the Environment: Database on waste and emissions of F-gases.

Danish Nature Agency, Ministry of the Environment: Database on Danish wastewater quality parameters.

Statistics Denmark, Ministry of Digital Government and Gender Equality: Statistical yearbook, sales statistics for manufacturing industries and agricultural statistics.

Danish Centre for Food and Agriculture (DCA), Aarhus University: Data on use of mineral fertiliser, feeding stuff consumption and nitrogen turnover in animals.

Department of Transport, Technical University of Denmark: Number of vehicles grouped in categories corresponding to the EU classification, mileage (urban, rural, highway), trip speed (urban, rural, highway).

Department of Geosciences and Natural Resource Management, University of Copenhagen: Background data for Forestry and CO_2 uptake by forest and estimations of harvested wood products.

Civil Aviation Agency of Denmark, Ministry of Transport: City-pair flight data (aircraft type and origin and destination airports) for all flights leaving major Danish airports.

Danish Railways, Ministry of Transport: Fuel-related emission factors for diesel locomotives.

Danish companies: Audited green accounts and direct information gathered from producers and agency enterprises.

Formerly, the provision of data was strictly on a voluntary basis, but more formal agreements are now prepared. This is the case for e.g. the Danish Energy Agency, where the data agreement specifies the data needed and the deadlines for when DCE is to receive the data. Agreements are also in place with DCA, Statistics Denmark and the Ministry of Transport.

No written agreements are done with companies, but most of the information used in the inventory is based on other legal requirements under environmental law.

Additionally, DCE receives data from Greenland and the Faroe Islands in order to report for the Kingdom of Denmark. In both cases based on written data agreements.

Statistics Greenland, Government of Greenland: Complete CRF tables for Greenland and documentation for the inventory process.

The Faroe Islands Environmental Authority: Complete CRF tables for the Faroe Islands and documentation for the inventory process.

The complete emission inventories for the different submissions (EU and UNFCCC) by Denmark are compiled by DCE and along with the documentation report (NIR) sent for official approval. This means that the emission inventory is finalised no later than March 15, whereupon the official approval is done prior to the reporting deadlines under the UNFCCC and the Kyoto Protocol.

1.3 Brief description of the process of inventory preparation. Data collection and processing, data storage and archiving

The background data (activity data and emission factors) for estimation of the Danish emission inventories is collected and stored in central databases located at the Department of Environmental Science (ENVS), Aarhus University. The databases are in Access format and handled with software developed by the European Environmental Agency and developed originally by the former National Environmental Research Institute (NERI), but is now maintained and further developed by ENVS. As input to the databases, various sub-models are used to estimate and aggregate the background data in order to fit the format and level in the central databases. The methodologies and data sources used for the different sectors are described in Chapter 1.4 and Chapters 3 to 7. As part of the QA/QC plan (Chapter 1.6), the data structure for data processing supports the pathway from collection of raw data to data compilation, modelling and final reporting.

For each submission, databases and additional tools and sub-models are frozen together with the resulting CRF-reporting format. This material is placed on central institutional servers, which are subject to routine back-up services. Material, which has been backed up, is archived safely. A further documentation and archiving system is the official archive for DCE. In this archiving system, correspondence, both incoming and outgoing, is registered, which in this case involves the registration of submissions and communication on inventories with the UNFCCC Secretariat, the European Commission, review teams, etc.

Figure 1.1 shows a schematic overview of the process of inventory preparation. The figure illustrates the process of inventory preparation from the first step of collecting external data to the last step, where the reporting schemes are generated for the UNFCCC and EU (in the CRF format (Common Reporting Format)) and to the United Nations Economic Commission for Europe/Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (UNECE/EMEP) (in the NFR format (Nomenclature For Reporting)). For data handling, the software tool is CollectER (Pulles et al., 1999) and for reporting the software tool is the CRF reporter tool developed by the UNFCCC Secretariat together with additional tools originally developed by NERI, but now maintained and further developed by ENVS. Data files and programme files used in the inventory preparation process are listed in Table 1.1.

Table 1.1 List of current data structure; data files and programme files in use.

QA/QC Level	Name	Application type	Path	Type	Input sources
4 store	CFR Submissions (UNFCCC and EU)	External report	U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_4a_Storage\	MS Excel, xml	CRF Reporter
4 store	NFR Report	External report	U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_4a_Storage\	xls	NRF Report N8 Process
3 process	CRF Reporter	Management tool	Working path: local machine Archive path: U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_3b_Processes	(exe + mdb)	National Compiler and Importer2CRF(xml) and IDAtoCRF(xml)
3 process	NRF Report N8 Process	Helptool	U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_3b_Processes\NFR	Excel	NERIRep and Report Template (xls)
3 process	Importer2CRF	Help tool	U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_3b_Processes	MS Access	CRF Reporter, Col-lectEr2CRF, and excel files
3 process	CollectER2CRF	Help tool	U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_3b_Processes	MS Access	NERIRep
3 proces	IDA2CRF	Help tool	U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_3b_Processes	MS Access	IDA_backend
2 process 3 store	NERIRep	Help tool	Working path: I:\ROSPROJ\LUFT_EMI\DMURep	MS Access	CollectER databases; dk1972.mdb..dkxxxx.mdb and IDA_backend
2 process	CollectER	Management tool	Working path: local machine Archive path: U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_2b_Processes	(exe +mdb)	Sector Expert
2 store	dk1980.mdb.dkxxxx.mdb	Datastore	U:\ST_ENVS-Luft-Emi\Inventory\AllYears\8_AllSectors\Level_2a_Storage	MS Access	CollectER
1 process	IDA	Management	U:\ST_ENVS-Luft-Emi\Agriculture\InventoryAgricultureData	MS Access	Sector Expert
1 store	IDA_Backend	Datastore	U:\ST_ENVS-Luft-Emi\Agriculture\InventoryAgricultureData	MS Access	IDA

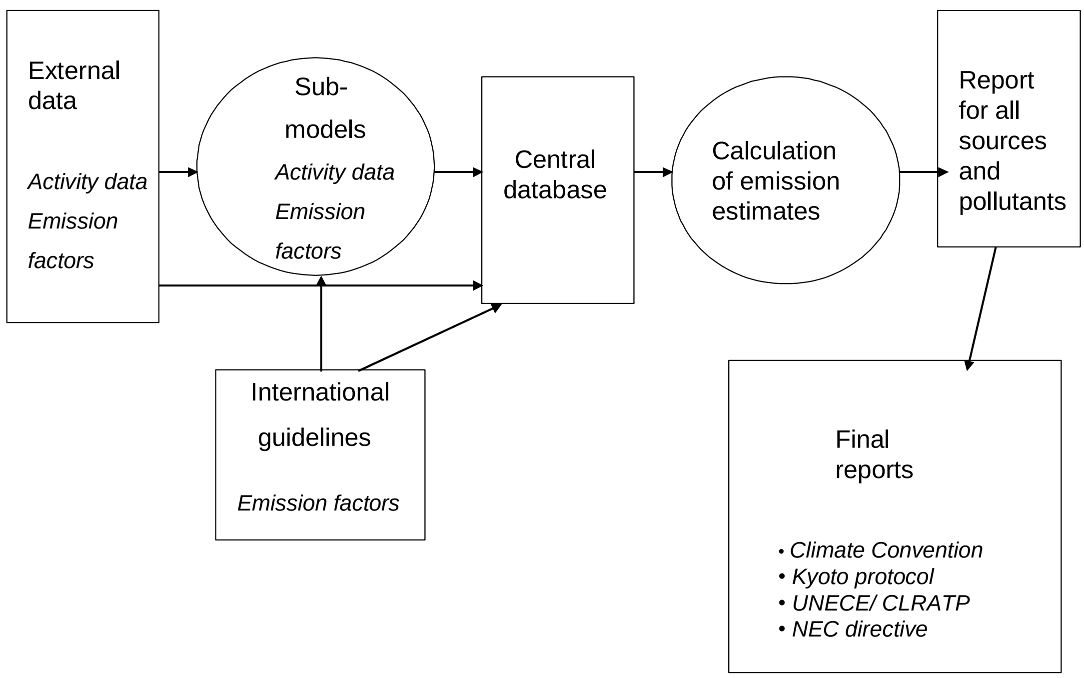


Figure 1.1 Schematic diagram of the process of inventory preparation.

Denmark has different geographical definitions for different submissions. Under the European Union, only mainland Denmark is included. The reporting under the UNFCCC includes Denmark, Greenland and the Faroe Islands.

Due to the different geographical scopes of the Danish inventory submissions, it is necessary to operate different versions of the CRF Reporter.

For the preparation of the Danish submission under the UNFCCC CRFs for Denmark, Greenland and the Faroe Islands are aggregated.

The process of aggregation requires additional software tools and installations of CRF Reporter. The process of aggregating the inventory is described in Chapter 13.

1.4 Brief general description of methodologies and data sources used

Denmark's air emission inventories are based on the 2006 IPCC Guidelines and the CORINAIR methodology. CORINAIR (COoRdination of INformation on AIR emissions) is a European air emission inventory programme for national sector-wise emission estimations, harmonised with the IPCC guidelines. To ensure estimates are as timely, consistent, transparent, accurate and comparable as possible, the inventory programme has developed calculation methodologies for most subsectors and software for storage and further data processing (EMEP-/CORINAIR, 2007).

A thorough description of the CORINAIR inventory programme used for Danish emission estimations is given in Illerup et al. (2000). The CORINAIR calculation principle is to calculate the emissions as activities multiplied by emission factors. Activities are numbers referring to a specific process generating emissions, while an emission factor is the mass of emissions per unit activity. Information on activities to carry out the CORINAIR inventory is largely based on official statistics. The most consistent emission factors have been used either as national values or as default factors proposed by international guidelines.

A list of all subsectors at the most detailed level is given in Illerup et al. (2000) together with a translation between CORINAIR and IPCC codes for sector classifications.

1.4.1 Stationary Combustion Plants

Stationary combustion plants are part of the CRF emission sources *1A1 Energy Industries*, *1A2 Manufacturing Industries* and *1A4 Other sectors*.

The Danish emission inventory for stationary combustion plants is based on the CORINAIR system described in Illerup et al. (2000). The emission inventory for stationary combustion is based on activity rates from the Danish energy statistics. General emission factors for various fuels, plants and sectors have been determined. Some large plants, such as power plants, are registered individually as large point sources and plant-specific emission data are used.

The fuel consumption rates are based on the official Danish energy statistics prepared by the Danish Energy Agency (DEA). DCE aggregates fuel consumption rates to SNAP categories. The fuel consumption of the NFR category 1A4 Manufacturing industries and construction is disaggregated to subsectors according to the DEA data prepared and reported to Eurostat.

For each of the fuel and SNAP categories (sector and e.g. type of plant), a set of general emission factors has been determined. Some emission factors refer to the EMEP/EEA guidebook and some are country specific and refer to Danish legislation, Danish research reports or calculations based on emission data from a considerable number of plants.

Some of the large plants, such as e.g. power plants and municipal waste incineration plants are registered individually as large point sources and emission data from the actual plants are used. This enables use of plant specific emission factors that refer to emission measurements stated in annual environmental reports, etc. At present, the emission factors for CH_4 and N_2O are, however, not plant-specific, whereas emission factors for SO_2 and NO_X often are. For CO_2 it was possible to use data reported under the EU-ETS in the emission inventory from 2006. Therefore, it was possible to derive some plant specific CO_2 emission factors for coal and oil fired power plants.

The CO_2 from incineration of the plastic part of municipal waste is included in the Danish inventory.

Please refer to Chapter 3.2 and Annex 3A for further information on the emission inventory for stationary combustion plants.

1.4.2 Transport

The emissions from transport, referring to SNAP category 07 (road transport) and the sub-categories in 08 (other mobile sources), are made up in the IPCC categories: 1A2f (Industry-other), 1A3a (Civil aviation), 1A3b (road transport), 1A3c (Railways), 1A3d (Navigation), 1A4a (Commercial and Institutional), 1A4b (Residential), 1A4c (Agriculture/forestry/fisheries) and 1A5 (Other).

An internal DCE model with a structure similar to the European COPERT IV emission model (EEA, 2019) is used to calculate the Danish annual emissions for road traffic. The emissions are calculated for operationally hot engines, during cold start and fuel evaporation. The model also includes the emission effect of catalyst wear. Input data for vehicle stock and mileage is obtained from DTU Transport and Statistics Denmark, and is grouped according to average fuel consumption and emission behaviour. For each group, the emissions are estimated by combining vehicle type and annual mileage figures with hot emission factors, cold:hot ratios and evaporation factors (Tier 2 approach).

For air traffic, from 2001 onwards estimates are made on a city-pair level, using flight data provided by the Danish Civil Aviation Agency (CAA-DK) for flights between Danish airports and flights between Denmark and Greenland/Faroe Islands), and LTO and distance-related emission factors from the CORINAIR guidelines (Tier 2 approach). For previous years, the background data consists of LTO/aircraft type statistics from Copenhagen Airport and total LTO numbers from CAA-DK. With appropriate assumptions, consistent time series of emissions are produced back to 1990, and include the findings from a Danish city-pair emission inventory in 1998.

Off-road working machines and equipment are grouped in the following sectors: inland waterways (pleasure craft), agriculture, forestry, industry, and household and gardening. The sources for stock and operational data are various branch organisations and key experts. In general, the emissions are calculated by combining information on the number of different machine types and their respective load factors, engine sizes, annual working hours and emission factors (Tier 2 approach).

The inventory for navigation consists of regional ferries, local ferries and other national sea transport (sea transport between Danish ports and between Denmark and Greenland/Faroe Islands). For regional ferries, the fuel consumption and emissions are calculated as a product of number of round trips per ferry route (Statistics Denmark), sailing time per round trip, share of round trips per ferry, engine size, engine load factor and fuel consumption/emission factor. The estimates take into account the changes in emission factors and ferry specific data during the inventory period.

For the remaining navigation categories, the emissions are calculated simply as a product of total fuel consumption and average emission factors. For each inventory year, this emission factor average comprises the emission factors for all present engine production years, according to engine life times.

Please refer to Chapter 3.3 and Annex 3B for further information on emissions from transport.

1.4.3 Fugitive emissions from fuels

Fugitive emissions from oil (1.B.2.a)

Fugitive emissions from oil are estimated according to the methodology described in the Emission Inventory Guidebook (EEA, 2019). The sources include offshore extraction of oil and gas, onshore oil tanks, onshore and offshore loading of ships, and gasoline distribution. Activity data is given in the Danish Energy Statistics by the Danish Energy Agency. The emission factors are based on the figures given in the guidebook except in the case of onshore oil tanks and gasoline distribution where national values are included.

The VOC emissions from petroleum refinery processes cover non-combustion emissions from feed stock handling/storage, petroleum products processing, and product storage/handling. SO_2 is also emitted from non-combustion processes and it includes emissions from product processing and sulphur-recovery plants. The emission calculations are based on information from the Danish refineries.

Fugitive emissions from natural gas (1.B.2.b)

Inventories of NMVOC emission from transmission and distribution of natural gas and town gas are based on annual environmental reports from the Danish gas transmission company and annual reports for the gas distribution companies. The annual gas composition is based on Energinet.dk.

Fugitive emissions from flaring (1.B.2.c)

Emissions from flaring offshore, in gas treatment and storage plants, and in refineries are included in the inventory. Emissions calculations are based on annual reports from the Danish Energy Agency and environmental reports from gas storage and treatment plants and the refineries. Calorific values are based on the reports for the EU ETS for offshore flaring, on annual gas quality data from Energinet.dk, and on additional data from the refineries. Emission factors are based on the Emission Inventory Guidebook (EEA, 2019).

Please refer to Chapter 3.5 for further information on fugitive emissions from fuels.

1.4.4 Industrial processes and product use

Energy consumption associated with industrial processes and the emissions thereof are included in the Energy sector of the inventory. This is due to the overall use of energy balance statistics for the inventory.

There is only one producer of cement in Denmark, Aalborg Portland Ltd. The activity data for the production of cement clinker is obtained from the company and the CO_2 emission is from the company report to EU-ETS. The methodology is approved by the Danish Energy Agency and the yearly emission estimate is in accordance with the methodology.

The reference for the activity data for production of lime, hydrated lime, expanded clay products and bricks, is the production statistics from the manufacturing industries, published by Statistics Denmark.

Limestone is used for the refining of sugar as well as for wet flue gas cleaning at power plants and waste incineration plants. The reference for the activity data is Statistics Denmark for sugar, Energinet.dk for gypsum from power plants combined with specific information on consumption of $CaCO_3$ at specific power plants and National Waste Statistics for gypsum from waste incineration. The emission factors are based on stoichiometric relations between consumption of $CaCO_3$ and gypsum generation as well as consumption of lime for sugar refining and precipitation with CO_2. This information is supplemented with company reports to EU-ETS.

The reference for the activity data for asphalt roofing is Statistics Denmark for consumption of roofing materials, combined with technical specifications for roofing materials produced in Denmark. The emission factors are default factors.

For road paving with asphalt, the reference for the activity data is Statistics Denmark for consumption of asphalt and cutback asphalt. The emission factors are default factors for consumption of asphalt and an estimated emission factor for cutback asphalt based on the statistics on the emission of NMVOC compiled by the industrial organisations in question.

The reference for activity data for the production of glass and glass wool are obtained from the producers published in their environmental reports. Emission factors are based on stoichiometric relations between raw materials and CO_2 emissions. This information is supplemented with company reports to EU-ETS.

The production of lime and yellow bricks gives rise to CO_2 emissions. The emission factors are based on stoichiometric relations, assumption on $CaCO_3$ content in clay as well as a default emission factor for expanded clay products. This information is supplemented with company reports to EU-ETS.

There was one producer of nitric acid in Denmark. The data in the inventory relies on information from the producer. The producer reported emissions of

NO_x and NH_3 as measured emissions and emissions of N_2O for 2003 as estimated emissions. The emission of N_2O in 2005 and forward is not occurring as the nitric acid production was closed down in the middle of 2004.

There is one producer of catalysts in Denmark. The data in the inventory relies on information published by the producer in environmental reports.

There was one steelwork in Denmark. The activity data as well as data on consumption of raw materials (coke) has been published by the producer in environmental reports. Emission factors are based on stoichiometric relations between raw materials and CO_2 emission. The electro steelwork was closed in 2005.

The inventory on F-gases (HFCs, PFCs and SF_6) is based on work carried out by the Danish Consultant Company "Provice". Their yearly report (DEPA, 2023) documents the inventory data up to the year 2021. The methodology is implemented for the whole time series 1990-2021, but full information on activities only exists since 1995.

Emissions from other product use such as fireworks, tobacco and charcoal for grilling are included in the inventory. Activity data on consumption of fireworks, tobacco and charcoal are obtained from Statistics Denmark. The emission factors used refer to international literature.

Please refer to Chapter 4 for further information on the emission inventory for industrial processes and product use.

1.4.5 Agriculture

The calculation of emissions from the agricultural sector is based on methods described in the IPCC Guidelines (IPCC, 2006). Activity data for livestock is on a one-year average basis from the agricultural statistics published by Statistics Denmark. Data concerning the land use and crop yield is also from the agricultural statistics. Data concerning the feed consumption and nitrogen excretion is based on information from the Danish Centre for Food and Agriculture (Aarhus University). The CH_4 Implied Emission Factors for Enteric Fermentation and Manure Management are based on a Tier 2/CS approach for all animal categories except for poultry, which are based on a Tier 1 approach. All livestock categories in the Danish emission inventory are based on an average of certain subgroups separated by differences in animal breed, age and weight class. The emissions from enteric fermentation for fur farming are estimated to be not applicable.

Emission of N_2O is closely related to the nitrogen balance. Thus, quite a lot of the activity data is related to the Danish calculations for ammonia emission (Albrektsen et al., 2017). National standards are used to estimate the amount of ammonia emission. When estimating the N_2O emission the IPCC standard value is used for all emission sources. The emission of CO_2 from Agricultural Soils is included in the LULUCF sector.

A model-based system is applied for the calculation of the emissions in Denmark. This model (IDA – Integrated Database model for Agricultural emissions) is used to estimate emission from both greenhouse gases and ammonia. A more detailed description is published in Albrektsen et al. (2017). The emissions from the agricultural sector are mainly related to livestock production. IDA works on a detailed level and includes around 38 livestock categories, and each category is subdivided according to housing type and manure type. The emissions are calculated from each subcategory and the emissions are aggregated in accordance with the livestock category given in the CRF.

To ensure data quality, both data used as activity data and background data used to estimate the emission factor are collected, and discussed in cooperation with specialists and researchers in different institutions. Thus, the emission inventory will be evaluated continuously according to the latest knowledge. Furthermore, time series of both emission factors and emissions in relation to the CRF categories are prepared. Any considerable variations in the time series are explained.

The uncertainties for assessment of emissions from enteric fermentation, manure management, agricultural soils and field burning of agricultural residue have been estimated based on a Tier 1 approach. The most significant uncertainties are related to the emissions of N_2O from agricultural soils.

A more detailed description of the methodology for the agricultural sector is given in Chapter 5 and Annex 3D.

1.4.6 Land Use, Land Use Change and Forestry

A complete Land Use Change matrix based on satellite imaging of the entire Danish land area, together with cadastral information has been prepared for the six major area classes. This has improved the coverage and the quality of the inventory substantially.

CO_2 emissions from cropland and grassland are based on census data from Statistics Denmark as regards size of area and crop yield combined with GIS-analysis on land use from the EU agricultural subsidiary system. This gives a very high accuracy for land use. All applicable pools are reported for Cropland and Grassland. The emission from mineral soils for cropland is estimated with a three-pooled dynamical soil carbon model (C-TOOL). C-TOOL was initialised in 1980. The model is run for each region corresponding to former counties in Denmark. Emissions from organic soils in cropland are based on new nationally developed emission factors. For grassland IPCC Tier 1b values are used. National models have been developed for wooden perennial crops in cropland based on land use statistics from Statistic Denmark. These are of minor importance. Sinks in hedgerows are calculated based on a nationally developed model. The area with hedgerows is estimated from information on hedgerows established with financial support from the Danish Government and aerial photos. Emissions from liming are calculated from annual sales data collected by the Danish Agricultural Advisory Centre, combined with the acid neutralisation capacity for each lot produced.

For wetlands, emissions are reported from peat extraction areas. Natural wetlands are not reported. A comprehensive programme for restoration of wetlands is implemented in Denmark. Other land uses converted to wetlands is therefore reported.

For having estimates for the KP accounting other land uses converted to settlements is reported but not settlements remaining as settlements.

No estimates are made for other land remaining other land and no conversion of land to other land is occurring. For having estimates for the KP accounting estimates for living biomass are provided for land converted from other land to other land uses.

1.4.7 Waste

For 5.A Solid waste disposal, only managed waste disposal sites are of importance and registered; i.e. unmanaged and illegal disposal of waste is considered to play a negligible role in the context of this category. The CH_4 emission at the Danish SWDSs is based on a First Order Decay (FOD) model corresponding to an IPCC tier 2/3 approach (IPCC, 2006). Data on waste types and amounts deposited at solid waste disposal sites is according to the official registration collected by the Danish Environmental Protection Agency (DEPA, 2022). The model calculations are performed using landfill site characteristics and statistics on the amounts of waste fractions deposited each year. Improved documentation of the methodology, input parameter data including uncertainty analysis is described in Chapter 7.2.

Regarding 5.C Incineration and open burning of waste, all municipal, industrial, hazardous and medical waste incinerated is used for energy and heat production. This production is included in the energy statistics, hence emissions are included in the CRF under fuel combustion activities (CRF sector 1A), and more specifically waste incineration takes place in CRF sectors 1A1a, 1A2f and 1A4a. Reporting in this category covers incineration of corpses and carcasses. The activity data are obtained from the National Association of Danish Crematoria and the three facilities incinerating carcasses.

For 5.D Wastewater treatment and discharge, country-specific methodologies are used for calculating the emissions of CH_4 and N_2O at wastewater treatment plants (WWTPs). Fugitive methane releases from the municipal and private WWTPs have been divided into contributions from 1) the sewer system, primary settling tank and biological N and P removal processes, 2) from anaerobic treatment processes in closed systems with biogas extraction and combustion for energy production and 3) septic tanks. N_2O formation and releases during the treatment processes at the WWTPs and from discharged effluent wastewater are included. Documentation of the methodology, emission factors and activity data are included in Chapter 7.3.

In CRF category 5.E Other emissions from accidental fires have been reported.

Please refer to Chapter 7 and Annex 3F for further information on emission inventories for waste.

1.4.8 Use of EU Emission Trading Scheme data

In 2004, the first guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to the EU Emission Trading Scheme (ETS) Directive (2003/87/EC) were implemented (EU Commission, 2004). The guidelines were updated in 2007, 2012 and 2018 and are available from the EU Commission website (EU Commission, 2018).

The Danish emission inventory only includes data from plants using higher tier methods as defined in the EU decision establishing guidelines for monitoring and reporting (EU Commission, 2018). In the Guidelines, the specific methods for determining carbon contents, oxidation factor and calorific value are specified.

In the Danish inventory plant or activity based CO_2 emission factors have been derived for power plants combusting coal and oil, refinery gas and flare gas in refineries, fuel gas and flare gas at off-shore installations, cement production, production of brick and tiles and lime production. For all these sources, the EU ETS reports are only used in the Danish inventory for plants using high tier methods. The EU ETS data have been applied for the years 2006 onwards.

The EU ETS reporting guidelines emphasizes the need for a high quality reporting through ensuring completeness, consistency, accuracy, transparency and faithfulness. The quality criteria as defined under the EU ETS reporting guidelines are in complete agreement with the principles in the IPCC good practice guidance. For all activities covered by the EU ETS installations are divided into three categories (A, B and C) depending on the annual CO_2 emission. A category A installation has an annual emission of less than 50 kt CO_2, a category B installation has an annual emission of between 50 and 500 kt CO_2 and a category C installation has an annual emission of more than 500 kt CO_2. For each activity Table 1 of the EU ETS guidelines (EU Commission, 2018) specifies the minimum tier level for the different calculation parameters. An example for combustion installations is shown in Table 1.2. The full list for all activities is available in the EU ETS guidelines (EU Commission, 2018).

Table 1.2 Example of minimum requirements in EU ETS guidelines (EU Commission, 2018).

	Activity data						Emission factor			Oxidation factor		
	Fuel flow			Net calorific value								
Activity	A	B	C	A	B	C	A	B	C	A	B	C
Commercial standard fuels	2	2	2	2a/2b	2a/2b	2a/2b	2a/2b	2a/2b	2a/2b	1	1	1
Other gaseous and liquid fuels	2	3	4	2a/2b	2a/2b	3	2a/2b	2a/2b	3	1	1	1
Solid fuels	1	2	3	2a/2b	3	3	2a/2b	3	3	1	1	1

The determination of the variables needed for the emission calculation has to be done in accordance with international standards. It is not possible to list all the relevant standards here, but the principles are described in Article 42 of the EU ETS guidelines. There are also demands concerning sampling methods and frequency of analysis.

As an example the tier 3 regarding fuel flow for fuel combustion, corresponds to a determination of the fuel consumption with a maximum uncertainty of 2.5 % taking into account possible effects of stock change. Tier 4 has a maximum uncertainty of 1.5 %. These uncertainties are very low and are in line with what could be expected from a well-functioning energy statistics system. More information regarding the use of EU ETS data in the specific subsectors of the inventory is included in Chapter 3.2.5 (CHP plants), Chapter 3.5.2 (Refineries and off-shore installations) and Chapter 4.2.2 (Cement production and other mineral products).

The operators shall establish, document, implement and maintain effective data acquisition and handling activities. This means assigning responsibilities for the quality process, as well as quality assurance, reviews and validation of data. Furthermore, an independent verification ensuring that emissions have been monitored in accordance with the EU ETS guidelines and that reliable and correct emission data are reported. There are also demands that records and documentation of the control activities must be stored for at least 10 years. The demands for the QA/QC system in the EU ETS guidelines are fully comparable to the requirements in the IPCC good practice guidance. Even so, DCE also performs QC checks of the data received as part of company reporting under EU ETS. This includes comparing the reported parameters with previous years, identifying outliers etc. In case DCE detects what is considered to be outliers, DCE contacts the Danish Energy Agency, which is the regulating authority for the EU ETS system in Denmark.

1.5 Brief description of key categories

The key category analysis described in this section covers only Denmark. A key category analysis covering Greenland is included in Chapter 11.

All KCA have been carried out in accordance with IPCC Guidelines (IPCC, 2006).

The KCA for Denmark includes a total of 12 different analyses:

- Base year, reporting year and trend
- Including and excluding LULUCF
- Approach 1 and approach 2

The KCA is based on 224 emission source categories including 35 LULUCF source categories.

The 12 different KCA for Denmark point out 22-48 key source categories each and a total of 75 different key source categories. The number of key categories in each of the main sectors is: energy 35, IPPU 4, agriculture 15, LULUCF 15 and waste 6.

Approach 1 point out mainly the large emission sources as key categories and thus CO_2 emission from stationary and mobile combustion are important key categories. Approach 2 point out some of the sources with larger uncertainty rates.

Table 1.3 shows the 75 source categories that are key categories in at least one of the six key category analysis including LULUCF. The table includes ranking in the analysis. A similar table for the KCAs excluding LULUCF is included in Annex 1.

The categorisation and detailed results of each of the KCAs are included in Annex 1.

Table 1.3 Key categories for KCAs including LULUCF. The numbers show the ranking in each of the KCAs.

IPCC Source Categories (LULUCF included)		GHG	Key categories with number according to ranking in analysis Identification criteria					
			Level Approach 1 1990	Level Approach 1 2021	Trend Approach 1 1990-2021	Level Approach 2 1990	Level Approach 2 2021	Trend Approach 2 1990-2021
Energy	1A Stationary combustion, Coal, ETS data, CO_2	CO_2		3	3			
Energy	1A Stationary combustion, Coal, no ETS data, CO_2	CO_2	1	46	1	17		10
Energy	1A Stationary combustion, Fossil waste, ETS data, CO_2	CO_2		10	9			42
Energy	1A Stationary combustion, Fossil waste, no ETS data, CO_2	CO_2	24	26	31			
Energy	1A Stationary combustion, Petroleum coke, ETS data, CO_2	CO_2		21	14			
Energy	1A Stationary combustion, Petroleum coke, no ETS data, CO_2	CO_2	30		29			
Energy	1A Stationary combustion, Residual oil, ETS data, CO_2	CO_2		35	30			
Energy	1A Stationary combustion, Residual oil, no ETS data, CO_2	CO_2	7		8			48
Energy	1A Stationary combustion, Gas oil, CO_2	CO_2	3	16	4	28		32
Energy	1A Stationary combustion, Kerosene, CO_2	CO_2	31		28			
Energy	1A Stationary combustion, LPG, CO_2	CO_2	38	37				
Energy	1A1b Stationary combustion, Petroleum refining, Refinery gas, CO_2	CO_2	17	14	21			
Energy	1A Stationary combustion, Natural gas, onshore, CO_2	CO_2	6	4	5			
Energy	1A1c_ii Stationary combustion, Oil and gas extraction, Off shore gas turbines, Natural gas, CO_2	CO_2	28	15	15			
Energy	1A4b_i Stationary combustion, Residential wood combustion, CH_4	CH_4				29		
Energy	1A1 Stationary Combustion, Solid fuels, N_2O	N_2O				22		22
Energy	1A1 Stationary Combustion, Waste, N_2O	N_2O						47
Energy	1A1 Stationary Combustion, Biomass, N_2O	N_2O					17	13
Energy	1A2 Stationary Combustion, Liquid fuels, N_2O	N_2O				19		20
Energy	1A2 Stationary Combustion, Gaseous fuels, N_2O	N_2O					22	18
Energy	1A4 Stationary Combustion, Liquid fuels, N_2O	N_2O						34
Energy	1A4b_i Stationary Combustion, Residential wood combustion, N_2O	N_2O					18	14
Energy	1.A.2.g Industry (mobile)	CO_2	27	20	23	21	16	16
Energy	1.A.3.a Civil aviation	CO_2	36					
Energy	1.A.3.b Road Transport	CO_2	2	1	2	16	11	7
Energy	1.A.3.c Railways	CO_2	34	36				
Energy	1.A.3.d Navigation (large vessels)	CO_2	20	23	33			
Energy	1.A.4.a Commercial/Institutional (mobile)	CO_2		38				
Energy	1.A.4.c ii Agriculture (mobile)	CO_2	26	18	24	27	19	26
Energy	1.A.4.c iii Fisheries	CO_2	23	31				
Energy	1.A.5.b Other (small boats)	CO_2		41				
Energy	1.A.2.g Industry (mobile)	N_2O					33	39
Energy	1.A.3.b Road Transport	N_2O		45				
Energy	1.A.4.c ii Agriculture (mobile)	N_2O					32	37
Energy	1.B.2.c.2.iii Flaring, combined	CO_2	33					
IPPU	2A1 Cement production	CO_2	18	9	12			
IPPU	2B2 Nitric acid production	N_2O	14		16	20		15
IPPU	2F1 Refrigeration and air conditioning	HFCs		33	27		23	17
IPPU	2F2 Foam blowing agents	HFCs			34			31
Agriculture	3A Enteric Fermentation	CH_4	4	2	7	10	8	9
Agriculture	3B Manure Management	CH_4	8	5	6	15	10	6
Agriculture	3B Manure Management	N_2O	21	28	38	12	12	21

IPCC Source Categories (LULUCF included)		GHG	Key categories with number according to ranking in analysis Identification criteria					
			Level Approach 1 1990	Level Approach 1 2021	Trend Approach 1 1990-2021	Level Approach 2 1990	Level Approach 2 2021	Trend Approach 2 1990-2021
Agriculture	3B5 Atmospheric deposition	N_2O				23	27	
Agriculture	3Da1 Inorganic N fertilizer	N_2O	10	12		1	1	19
Agriculture	3Da2a Animal manure applied to soils	N_2O	15	17	25	2	3	2
Agriculture	3Da2b Sewage sludge applied to soils	N_2O						46
Agriculture	3Da2c Other organic fertilizer applied to soils	N_2O					34	30
Agriculture	3Da3 Urine and dung deposited by grazing animals	N_2O				24	26	
Agriculture	3Da4 Crop Residues	N_2O	22	13	17	5	2	1
Agriculture	3Da5 Mineralization	N_2O				14	24	11
Agriculture	3Da6 Cultivation of organic soils	N_2O	19	25	36	4	4	8
Agriculture	3Db1 Atmospheric deposition	N_2O	32	39		7	9	12
Agriculture	3Db2 Leaching	N_2O	16	27		3	5	
Agriculture	3G Liming	CO_2	25	32		13	15	28
LULUCF	4.A.1 Forest land remaining forest land, Living biomass	CO_2	35	8	11		36	35
LULUCF	4.A.1 Forest land remaining forest land, Dead organic matter	CO_2		19	20			
LULUCF	4.A.1 Forest land remaining forest land, Organic soils	CO_2		42				
LULUCF	4.A.2 Land converted to forest land	CO_2	12	11	26	26	20	45
LULUCF	4.B.1 Cropland remaining cropland, Living bio-mass	CO_2		24	18		31	27
LULUCF	4.B.1 Cropland remaining cropland, Mineral soils	CO_2	13	22	10	11	14	3
LULUCF	4.B.1 Cropland remaining cropland, Organic soils	CO_2	5	6	32	6	6	23
LULUCF	4.B.2 Forest land converted to cropland	CO_2			37			36
LULUCF	4.B.2 Other land uses converted to cropland	CO_2						44
LULUCF	4.C.1 Grassland remaining grassland, Organic soils	CO_2	9	7	13	9	7	5
LULUCF	4.C.2 Other land uses converted to grassland	CO_2		43	39			38
LULUCF	4.E.2 Other land uses converted to settlements	CO_2	29	34		18	21	40
LULUCF	4.G Harvested wood products	CO_2						43
LULUCF	4(II) Cropland on organic soils	CH_4				25	29	
LULUCF	4(II) Grassland on organic soils	CH_4		40			25	41
Waste	5.A Solid waste disposal	CH_4	11	29	19	8	13	4
Waste	5.B.1 Composting	CH_4					28	25
Waste	5.B.2. Anaerobic digestion at biogas facilities	CH_4		30	22		30	24
Waste	5.B.1 Composting	N_2O						33
Waste	5.D.1 Domestic wastewater	N_2O		44			35	
Waste	5.D.2 Industrial wastewater	N_2O	37		35			29

1.6 Information on QA/QC plan including verification and treatment of confidential issues where relevant

1.6.1 Introduction

This section outlines the Quality Control (QC) and Quality Assurance (QA) plan for greenhouse gas emission inventories performed by DCE (Sørensen et al., 2005; Nielsen et al., 2013; Nielsen et al., 2020). The plan is in accordance with the guidelines provided by the IPCC (IPCC, 2006. The ISO 9000 standards are also used as important input for the plan.

The QA/QC plan also covers Greenland and the Faroe Islands. DCE receives the data corresponding to data processing level 3 and data storage level 4 and the data undergoes the same QA/QC procedure as the Danish data, some further QC checks are described in Chapter 13.

1.6.2 Concepts of quality work

The quality planning is based on the following definitions as outlined by the ISO 9000 standards as well as the IPCC Guidance (IPCC, 2006):

- Quality management (*QM*) Coordinates activity to direct and control with regard to quality.
- Quality Planning (*QP*) Defines quality objectives including specification of necessary operational processes and resources to fulfil the quality objectives.
- Quality Control (*QC*) Fulfils quality requirements.
- Quality Assurance (*QA*) Provides confidence that quality requirements will be fulfilled.
- Quality Improvement (*QI*) Increases the ability to fulfil quality requirements.

The activities are considered inter-related in this report as shown in Figure 1.2.

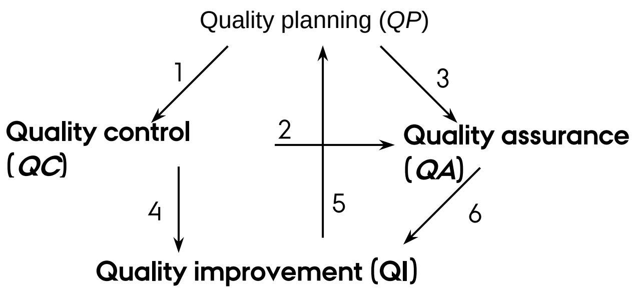


Figure 1.2 Interrelation between the activities with regard to quality. The arrows are explained in the text below this figure.
1: The *QP* sets up the objectives and, from these, measurable properties valid for the *QC*.
2: The *QC* investigates the measurable properties that are communicated to *QA* for assessment in order to ensure sufficient quality.
3. The *QP* identifies and defines measurable indicators for the fulfilment of the quality objectives. This yields the basis for the *QA* and has to be supported by the input coming from the *QC*.
4: The result from *QC* highlights the degree of fulfilment for every quality objective. It is thus a good basis for suggestions for improvements to the inventory to meet the quality objectives.
5: Suggested improvements in the quality may induce changes in the quality objectives and their measurability.
6: The evaluation carried out by external authorities is important input when improvements in quality are being considered.

1.6.3 Definition of quality

A solid definition of quality is essential. Without such a solid definition, the fulfilment of the objectives will never be clear and the process of quality control and assurance can easily turn out to be a fuzzy and unpleasant experience for the people involved. On the contrary, in case of a solid definition and thus a clear goal, it will be possible the make a valid statement of "good quality" and thus form constructive conditions and motivate the inventory work positively. A clear definition of quality has not been given in the UNFCCC guidelines. In the Good Practice Guidance, Chapter 8.2, however, it is mentioned that:

"Quality control requirements, improved accuracy and reduced uncertainty need to be balanced against requirements for timeliness and cost effectiveness." The statement of balancing requirements and costs is not a solid basis for QC as long as this balancing is not well defined.

The resulting standard of the inventory is defined as being composed of accuracy and regulatory usefulness. The goal is to maximise the standard of the inventory and the following statement defines the quality objective:

The quality objective is only inadequately fulfilled if it is possible to make an inventory of a higher standard without exceeding the frame of resources.

1.6.4 Definition of Critical Control Points (*CCP*)

A Critical Control Point (*CCP*) is defined in this submission as an element or an action, which needs to be taken into account in order to fulfil the quality objectives. Every *CCP* has to be necessary for the objectives and the *CCP* list needs to be extended if other factors, not defined by the *CCP* list, are needed in order to reach at least one of the quality objectives.

The objectives for the *QM*, as formulated by IPCC (2006), are to improve elements of transparency, consistency, comparability, completeness and confidence.

The objectives for the *QM* are used as *CCP*s, including the elements mentioned above. The following explanation is given by UNFCCC guidelines (UNFCCC, 2013) for each *CCP*:

Transparency means that the data sources, assumptions and methodologies used for an inventory should be clearly explained, in order to facilitate the replication and assessment of the inventory by users of the reported information. The transparency of inventories is fundamental to the success of the process for the communication and consideration of the information. The use of the common reporting format (CRF) tables and the preparation of a structured national inventory report (NIR) contribute to the transparency of the information and facilitate national and international reviews.

Consistency means that an annual GHG inventory should be internally consistent for all reported years in all its elements across sectors, categories and gases. An inventory is consistent if the same methodologies are used for the base and all subsequent years and if consistent data sets are used to estimate emissions or removals from sources or sinks. Under certain circumstances referred to in paragraphs 16 to 18 below, an inventory using different methodologies for different years can be considered to be consistent if it has been recalculated in a transparent manner, in accordance with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (hereinafter referred to as the 2006 IPCC Guidelines).

Comparability means that estimates of emissions and removals reported by Annex I Parties in their inventories should be comparable among Annex I Parties. For that purpose, Annex I Parties should use the methodologies and formats agreed by the COP for making estimations and reporting their inventories. The allocation of different source/sink categories should follow the CRF tables provided in annex II to decision 24/CP.19 at the level of the summary and sectoral tables.

Completeness means that an annual GHG inventory covers at least all sources and sinks, as well as all gases, for which methodologies are provided in the 2006 IPCC Guidelines or for which supplementary methodologies have been agreed by the COP. Completeness also means the full geographical coverage of the sources and sinks of an Annex I Party.

Accuracy means that emission and removal estimates should be accurate in the sense that they are systematically neither over nor under true emissions or removals, as far as can be judged, and that uncertainties are reduced as far as practicable. Appropriate methodologies should be used, in accordance with the 2006 IPCC Guidelines, to promote accuracy in inventories.

The robustness against unexpected disturbance of the inventory work has to be high in order to secure high quality, which is not covered by the *CCP*s above. The correctness of the inventory is formulated as an independent objective. This is so because the correctness of the inventory is a condition for all other objectives to be effective. A large part of the Tier 1 procedure given by the IPCC (IPCC, 2006) is actually checks for miscalculations and, thus, supports the objective of correctness. Correctness, as defined here, is not similar to accuracy, because the correctness takes into account miscalculations, while accuracy relates to minimizing the always present data-value uncertainty.

Robustness implies arrangement of inventory work as regards e.g. inventory experts and data sources in order to minimize the consequences of any unexpected disturbance due to external and internal conditions. A change in an external condition could be interruption of access to an external data source and an internal change could be a sudden reduction in qualified staff, where a skilled person suddenly leaves the inventory work.

Correctness has to be secured in order to avoid uncontrollable occurrence of uncertainty directly due to errors in the calculations.

The different *CCP*s are not independent and represent different degrees of generality. E.g., deviation from *comparability* may be accepted if a high degree of *transparency* is applied. Furthermore, there may even be a conflict between the different *CCP*s. E.g. new knowledge may suggest improvements in calculation methods for better *completeness*, but the same improvements may to some degree, violate the *consistency* and *comparability* criteria with regard to earlier years' inventories and the reporting from other nations. It is, therefore, a multi-criteria problem of optimisation to apply the set of *CCP*s in the aim for good quality.

1.6.5 Process-oriented QC

The strategy is based on a process-oriented principle (ISO 9000 series) and the first step is, thus, to set up a system for the process of the inventory work. The product specification for the inventory is a dataset of emission figures and the process, thereby, equates with the data flow in the preparation of the inventory.

The data flow needs to support the QC/QA in order to facilitate a cost-effective procedure. The flow of data has to take place in a transparent way by making the transformation of data detectable. It should be easy to find the original background data for any calculation and to trace the sequence of calculations from the raw data to the final emission result. Computer programming for automated calculations and checking will enhance the accuracy and minimize the number of miscalculations and flaws in input value settings. Especially manual typing of numbers needs to be minimized. This assumes, however, that the quality of the programming has been verified to ensure the correctness of the automated calculations. Automated value control is also one of the important means to secure accuracy. Realistic uncertainty estimates are necessary for securing accuracy, but they can be difficult to produce due to the uncertainty related to the uncertainty estimates themselves. It is, therefore, important to include the uncertainty calculation procedures into the data structure as far as possible. The QC/QA needs to be supported as far as possible by the data structure; otherwise, the procedures can easily become troublesome and subject to frustration.

Both data processing and data storage form the data structure. The data processing is carried out using mathematical operations or models. The models may be complicated where they concern human activity or be simple summations of lower aggregated data. The data storage includes databases and file systems of data that are calculated either using the data processing at the lower level, using input to new processing steps or even using both output and input in the data structure. The measure for quality is basically different for processing and storage, so these need to be kept separate in a well-designed quality manual. A graphical display of the data flow is seen in Figure 1.3 and explained in the following.

The data storage takes place for the following types of data:

***External Data*:** a single numerical value of a parameter coming from an external source. These data govern the calculation of *Emission calculation input.*

***Emission calculation input*:** Data for input to the final emission calculation in terms of data for release source strength and activity. The data is directly applicable for use in the standardized forms for calculation. These data are calculated using external data or represent a direct use of *External Data* when they are directly applicable for *Emission Calculations*.

***Emission Data*:** Estimated emissions based on the *emission calculation input.*

***Emission Reporting*:** Reporting of emission data in requested formats and aggregation level.

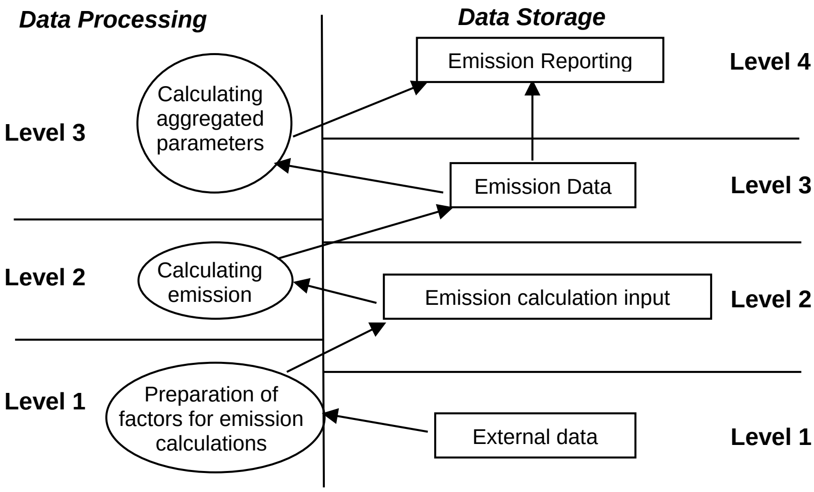


Figure 1.3 The general data structure for the emission inventory.

Key levels are defined in the data structure as:

Data storage Level 1, External data
Collection of external data for calculation of emission factors and activity data. The activity data are collected from different sectors and statistical surveys, typically reported on a yearly basis. The data consist of raw data, having an identical format to the data received and gathered from external sources. Level 1 data acts as a base-set, on which all subsequent calculations are based. If alterations in calculation procedures are made, they are based on the same dataset. When new data are introduced, they can be implemented in accordance with the QA/QC structure of the inventory.

Data storage Level 2, Data directly usable for the inventory
This level represents data that have been prepared and compiled in a form that is directly applicable for calculation of emissions. The compiled data are structured in a database for internal use as a link between more or less raw data and data that are ready for reporting. The data are compiled in a way that elucidates the different approaches in emission assessment: (1) directly on measured emission rates, especially for larger point sources, (2) based on activities and emission factors, where the value setting of these factors are stored at this level.

Data storage Level 3, Emission data
The emission calculations are reported by the most detailed figures and divided in sectors. The unit at this level is typically mass per year for the country. For sources included in the SNAP system, the SNAP level 3 is relevant. Internal reporting is performed at this level to feed the external communication of results.

Data storage Level 4, Final reports for all subcategories
The complete emission inventory is reported to UNFCCC at this level by summing up the results from every subcategory.

Data processing Level 1 Compilation of external data
Preparation of input data for the emission inventory based on the external data sources. Some external data may be used directly as input to the data processing at level 2, while other data needs to be interpreted using more or less complicated models, which takes place at this level. The interpretation of activity data is to be seen in connection with availability of emission factors and vice versa. These models are compiled and processed as an integrated part of the inventory preparation.

Data processing Level 2 Calculation of inventory figures
The emission for every subcategory is calculated, including the uncertainty for all sectors and activities. The summation of all contributions from subsources makes up the inventory.

Data processing Level 3 Calculation aggregated parameters
Some aggregated parameters need to be reported as part of the final reporting. This does not involve complicated calculations but important figures, e.g. implied emission factors at a higher aggregated level to be compared in time series and with other countries.

1.6.6 Definition of Point of Measurements (*PM*)

The *CCP*s have to be based on clear measurable factors - otherwise the *QP* will end up being just a loose declaration of intent. Thus, in the following, a series of *Points for Measuring* (*PM*) is identified as building blocks for a solid *QC*. Table 8.1 in Good Practice Guidance is a listing of such *PM*s. However, the listing in Table 1.2 is an extended and modified listing, in comparison to Table 8.1 in the Good Practice Guidance supporting all the *CCP*s. The *PM*s will be routinely checked in the QC reporting and, when external reviews take place, the reviewers will be asked to assess the fulfilment of the *PM*s using a checklist system. The list of *PM*s is continually evaluated and modified to offer the best possible support for the *CCP*s. The actual list used is seen in Table 1.4.

Table 1.4 The list of *PM*s as used.

Level	CCP	Id	Description	
Data Storage level 1	1. Accuracy	DS.1.1.1	General level of uncertainty for every dataset including the reasoning for the specific values	Sectoral
		DS.1.1.2	Quantification of the uncertainty level of every single data value, including the reasoning for the specific values.	Sectoral
	2. Comparability	DS1.2.1	Comparability of the data values with similar data from other countries, which are comparable with Denmark, and evaluation of the discrepancy.	Sectoral
	3.Completeness	DS.1.3.1	Documentation showing that all possible national data sources are included, by setting down the reasoning behind the selection of datasets.	Sectoral
	4.Consistency	DS.1.4.1	The origin of external data has to be preserved whenever possible without explicit arguments (referring to other PMs)	Sectoral
	6.Robustness	DS.1.6.1	Explicit agreements between the external institution holding the data and DCE about the conditions of delivery	Sectoral
		DS.1.6.2	At least two employees must have a detailed insight into the gathering of every external dataset.	General
	7.Transparency	DS.1.7.1	Summary of each dataset including the reasoning behind the selection of the specific dataset	Sectoral
		DS.1.7.2	The archiving of datasets needs to be easily accessible for any person in the emission inventory	General
		DS.1.7.3	References for citation for any external dataset have to be available for any single number in any dataset.	Sectoral
		DS.1.7.4	Listing of external contacts for every dataset	Sectoral
Data Processing level 1	1. Accuracy	DP.1.1.1	Uncertainty assessment for every data source as input to Data Storage level 2 in relation to type of variability. (Distribution as: normal, log normal or other type of variability)	Sectoral
		DP.1.1.2	Uncertainty assessment for every data source as input to Data Storage level 2 in relation to scale of variability (size of variation intervals)	Sectoral
		DP.1.1.3	Evaluation of the methodological approach using international guidelines	Sectoral
		DP.1.1.4	Verification of calculation results using guideline values	Sectoral
	2.Comparability	DP.1.2.1	The inventory calculation has to follow the international guidelines suggested by UNFCCC and IPCC.	Sectoral
	3.Completeness	DP.1.3.1	Assessment of the most important quantitative knowledge, which is lacking.	Sectoral
		DP.1.3.2	Assessment of the most important cases where access is lacking with regard to critical data sources that could improve quantitative knowledge.	Sectoral
	4.Consistency	DP.1.4.1	In order to keep consistency at a high level, an explicit description of the activities needs to accompany any change in the calculation procedure	Sectoral
		DP.1.4.2	Identification of parameters (e.g. activity data, constants) that are common to multiple source categories and confirmation that there is consistency in the values used for these parameters in the emission calculations	General
	5.Correctness	DP.1.5.1	Shows at least once, by independent calculation, the correctness of every data manipulation	Sectoral

Level	CCP	Id	Description	
		DP.1.5.2	Verification of calculation results using time series	Sectoral
		DP.1.5.3	Verification of calculation results using other measures	Sectoral
		DP.1.5.4	Show one-to-one correctness between external data sources and the databases at Data Storage level 2	Sectoral
	6.Robustness	DP.1.6.1	Any calculation must be anchored to two responsible persons who can replace each other in the technical issue of performing the calculations.	General
	7.Transparency	DP.1.7.1	The calculation principle and equations used must be described	Sectoral
		DP.1.7.2	The theoretical reasoning for all methods must be described	Sectoral
		DP.1.7.3	Explicit listing of assumptions behind all methods	Sectoral
		DP.1.7.4	Clear reference to dataset at Data Storage level 1	Sectoral
		DP.1.7.5	A manual log to collect information about recalculations	Sectoral
Data Storage level 2	2.Comparability	DS.2.2.1	Comparison with other countries that are closely related to Denmark and explanation of the largest discrepancies	General
	5.Correctness	DS.2.5.1	Documentation of a correct connection between all data types at level 2 to data at level 1	Sectoral
		DS.2.5.2	Check if a correct data import to level 2 has been made	Sectoral
	6.Robustness	DS.2.6.1	All persons in the inventory work must be able to handle and understand all data at level 2.	General
	7.Transparency	DS.2.7.1	The time trend for every single parameter must be graphically available and easy to map	General
Data Processing level 2	1. Accuracy	DP.2.1.1	Documentation of the methodological approach for the uncertainty analysis	General
		DP.2.1.2	Quantification of uncertainty	General
	2.Comparability	DP.2.2.1	The inventory calculation has to follow the international guidelines suggested by UNFCCC and IPCC	General
	6.Robustness	DP.2.6.1	Any calculation at level 4 must be anchored to two responsible persons who can replace each other in the technical issue of performing the calculations.	General
	7.Transparency	DP.2.7.1	Reporting of the calculation principle and equations used	General
		DP.2.7.2	The reasoning for the choice of methodology for uncertainty analysis needs to be written explicitly.	General
Data Storage level 3	1. Accuracy	DS.3.1.1	Quantification of uncertainty	General
	5.Correctness	DS.3.5.1	Comparison with inventories of the previous years on the level of the categories of the CRF as well as on SNAP source categories. Any major changes are checked, verified, etc.	General
		DS.3.5.2	Total emissions, when aggregated to CRF source categories, are compared with totals based on SNAP source categories (control of data transfer).	General
		DS.3.5.3	Checking of time series of the CRF and SNAP source categories as they are found in the Corinair databases. Considerable trends and changes are checked and explained.	General
	7. Transparency	DS.3.7.1	The databases and other software used shall be clearly documented. The documentation should include a description that the appropriate data processing steps are correctly represented in the database; that data relationships are correctly represented in the database and that data fields are properly labelled and have the correct design specifications.	General
		DS.3.7.2	The documentation referred to under DS.3.7.1 should be archived at the same network folder as the program is located in.	General
Data Processing level 3	6. Robustness	DP.3.6.1	The process of generating the official submissions must be anchored by at least two responsible persons who can replace each other in the technical issue of generating CRF tables including of the aggregation of the submission for the Kingdom of Denmark.	General

Level	CCP	Id	Description	
	7. Transparency	DP.3.7.1	The databases and other software used shall be clearly documented. The documentation should include a description that the appropriate data processing steps are correctly represented in the database; that data relationships are correctly represented in the database and that data fields are properly labelled and have the correct design specifications.	General
	7. Transparency	DP.3.7.2	The documentation referred to under DP.3.7.1 should be archived at the same network folder as the program is located in.	General
Data Storage level 4	2.Comparability	DS.4.2.1	Description of similarities and differences in relation to other countries' inventories for the methodological approach.	General
	3.Completeness	DS.4.3.1	National and international verification including explanation of the discrepancies.	General
		DS.4.3.2	Check that the no sources where a methodology exists in the IPCC guidelines are reported as NE.	General
		DS.4.3.3	Check that no sources where methodology exists in the IPCC guidelines are reported as NE by Greenland and the Faroe Islands.	General
	4.Consistency	DS.4.4.1	The inventory reporting must follow the international guidelines suggested by UNFCCC and IPCC.	General
		DS.4.4.2	Check time series consistency of the reporting by Greenland and the Faroe Islands prior to aggregating the final submissions.	General
		DS.4.4.3	The IEFs from the CRF are checked regarding both level and trend. The level is compared to relevant emission factors to ensure correctness. Large dips/jumps in the time series are explained.	Sectoral
	5.Correctness	DS.4.5.1	Check that the aggregated submissions for Denmark under the UNFCCC match the sum of the individual submissions.	General
		DS.4.5.2	Check that additional information and information related to land-use changes has been correctly aggregated compared to the individual submissions of Denmark, Greenland and the Faroe Islands.	Sectoral
	6. Robustness	DS.4.6.1	The reporting to the UNFCCC must be anchored to two responsible persons who can replace each other in the technical issue of reporting to and communicating with the UNFCCC secretariat.	General
	7.Transparency	DS.4.7.1	Perform QA on the documentation report provided by the Governments of Greenland and the Faroe Islands.	General

1.6.7 Plan for the quality work

The IPCC uses the concept of a tiered approach, i.e. a stepwise approach, where complexity, advancement and comprehensiveness increase. Generally, more detailed and advanced methods are recommended in order to give guidance to countries, which have more detailed datasets and more capacity, as well as to countries with less available data and manpower. The tiered approach helps to focus attention on the areas of the inventories that are relatively weak, rather than investing effort in irrelevant areas. Furthermore, the IPCC guidelines recommend using higher tier methods for key categories in particular. Therefore, the identification of key categories is crucial for planning quality work. However, several issues regarding the listing of priority categories exist: (1) The contribution to the total emission figure (key source listing); (2) The contribution to the total uncertainty; (3) Most critical categories in relation to implementation of new methodologies and thus highest risk for miscalculations. All the points listed are necessary for different aspects of producing high quality work. These listings will be used to secure implementation of the full quality scheme for the most relevant categories. Verification in relation to other countries has been undertaken for priority categories.

1.6.8 Implementation of the QA/QC plan

The PMs listed in Table 1.2 are described for each sector in the QA/QC sections of Chapters 3-8, where a status with regard to implementation is also given. Some of the PMs are the same for all sectors and a common description for these PMs is given in Section 1.6.10, below. The focus has been on level 1 for both data storage and data processing as this is the most labour-intensive part. The quality system will be evaluated and adjusted continuously.

1.6.9 Archiving of data and documentations

The QA/QC work is supported by an inventory file system, where all data, models and QA/QC procedures and checks are stored as files in folders (Figure 1.4).

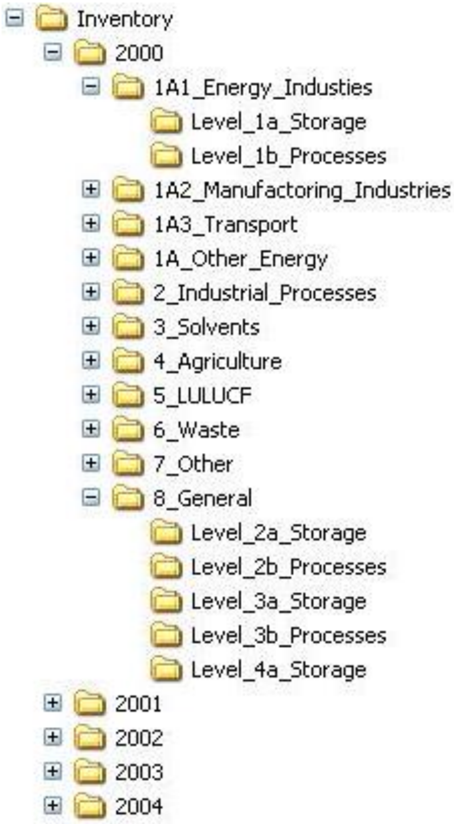


Figure 1.4 Schematic diagram of the folder structure in the inventory file system.

The inventory file system consists of the following levels: year, sector and the level for the process of the inventory work, as illustrated in Figure 1.4. The first level in the file system is year, which here means the inventory year and not the calendar year. The sector level contains the PMs relevant for the individual sectors i.e. the first levels (DS1 and DP1) (except the PMs described in Section 1.6.10), while the rest of the PMs (DS2-4 and DP2-3), are common for all sectors.

All data, models and other QA/QC related files are stored in the inventory file system and are accessible for all staff involved in the inventory work.

1.6.10 Common QA/QC PMs

The following PMs are common for all the sectors:

Data storage Level 1

Data Storage level 1	6. Robustness	DS.1.6.2	At least two employees must have a detailed insight into the gathering of every external dataset.

For all sectors: energy, industrial processes and product use, agriculture, LULUCF and waste, two persons have detailed insight in data gathering and processing. A strong effort is continuously made to ensure the robustness of the inventory process.

Data Storage level 1	7. Transparency	DS.1.7.2	The archiving of datasets needs to be easily accessible for any person involved in the emission inventory.

All data, models and other QA/QC related files are stored in the inventory file system and are accessible for all inventory staff members. Refer to Section 1.6.9.

Data processing Level 1

Data Processing level 1	4. Consistency	DP.1.4.2	Identification of parameters (e.g. activity data, constants) that are common to multiple source categories and confirmation that there is consistency in the values used for these parameters in the emission calculations.

This PM is supported by the inventory file system where it is possible to compare and harmonise parameters that are common to multiple source categories.

Data Processing level 1	6.Robustness	DP.1.6.1	Any calculation must be anchored to two responsible persons who can replace each other in the technical issue of performing the calculations.

All data, models and other QA/QC related files are stored in the inventory file system and are accessible for all inventory staff members. Refer to Section 1.6.9.

Data storage Level 2

Data Storage level 2	2.Comparability	DS.2.2.1	Comparison with other countries that are closely related to Denmark and explanation of the largest discrepancies.

Systematic inter-country comparison has only been made on data storage level 4. Refer to DS 4.3.2.

Data Storage level 2	6.Robustness	DS.2.6.1	All persons in the inventory work must be able to handle and understand all data at level 2.

This PM is fulfilled for all sectors. The PM is supported by the inventory file system. Refer to Section 1.6.9.

Data Storage level 2	7.Transparency	DS.2.7.1	The time trend for every single parameter must be graphically available and easy to map.

Programs exist to make time series for all parameters. A tool for graphically showing time series has not yet been developed.

Data Processing Level 2

Data Processing level 2	1. Accuracy	DP.2.1.1	Documentation of the methodological approach for the uncertainty analysis

Refer to Chapter 1.7.

Data Processing level 2	1. Accuracy	DP.2.1.2	Quantification of uncertainty

Refer to Chapter 1.7 and the uncertainty sections in the sectoral chapters (Chapter 3-7).

Data Processing level 2	2.Comparability	DP.2.2.1	The inventory calculation has to follow the international guidelines suggested by UNFCCC and IPCC.

The emission calculations follow the international guidelines.

Data Processing level 2	6.Robustness	DS.2.6.1	All persons in the inventory work must be able to handle and understand all data at level 2.

At present, the emission calculations are carried out using applications developed at DCE. The software development and programme runs are anchored to two inventory staff members.

Data Processing level 2	7.Transparency	DP.2.7.1	Reporting of the calculation principle and equations used.

Due to the uniform treatment of input data in the calculation routines used by the DCE software programmes, a central documentation of calculation principles, equations, theoretical reasoning and assumptions must be given, treating all national emission sources. This documentation remains to be made, but is planned to be carried out in the future.

Data Processing level 2	7.Transparency	DP.2.7.2	The reasoning for the choice of methodology for uncertainty analysis needs to written explicitly.

Refer to Chapter 1.7 and the QA/QC sections in the sectoral chapters.

Data storage Level 3

Data Storage level 3	1. Accuracy	DS.3.1.1	Quantification of uncertainty

Refer to Chapter 1.7 and the QA/QC sections in the sector chapters.

Data Storage level 3	5.Correctness	DS.3.5.1	Comparison with inventories of the previous years on the level of the categories of the CRF as well as on SNAP source categories. Any major changes are checked, verified, etc.

Time series is prepared and checked, any major change is closely examined with the purpose of verifying and explaining changes from earlier inventories.

Data Storage level 3	5.Correctness	DS.3.5.2	Total emissions when aggregated to CRF source categories are compared with totals based on SNAP source categories (control of data transfer).

Total emission, when aggregated to IPCC and LRTAP reporting tables, is compared with totals based on SNAP source categories (control of data transfer).

Data Storage level 3	5.Correctness	DS.3.5.3	Checking of time series of the CRF and SNAP source categories as they are found in the Corinair databases. Considerable trends and changes are checked and explained.

Time series are prepared and checked, any major change is closely examined with the purpose of verifying and explaining fluctuations.

Data Storage level 3	7. Transparency	DS.3.7.1	The databases and other software used shall be clearly documented. The documentation should include a description that the appropriate data processing steps are correctly represented in the database; that data relationships are correctly represented in the database and that data fields are properly labelled and have the correct design specifications.

The databases used at data storage level 3 are documented. The documentation includes description of the queries and programming code used in the data processing. The documentation further includes information on all data fields in the database and the design specifications. Part of the detailed documentation is built into the database while the overall documentation is prepared as a separate documentation note.

Data Storage level 3	7. Transparency	DS.3.7.2	The documentation referred to under DS.3.7.1 should be archived at the same network folder as the program is located in.

The documentation prepared as part of DS.3.7.1 is archived in the same folder as the program is stored. For information on the file structure, please see Chapter 1.6.9.

Data Processing Level 3

Data Processing level 3	6. Robustness	DP.3.6.1	The process of generating the official submissions must be anchored by at least two responsible persons who can replace each other in the technical issue of generating CRF tables including of the aggregation of the submission for the Kingdom of Denmark.

The process of generating the official submissions including the aggregation of submissions to the UNFCCC is currently anchored by two people within the team. In the future, the goal is to have three team members capable of completing this task.

Data Processing level 3	7. Transparency	DP.3.7.1	The databases and other software used shall be clearly documented. The documentation should include a description that the appropriate data processing steps are correctly represented in the database; that data relationships are correctly represented in the database and that data fields are properly labelled and have the correct design specifications.

The databases used at data storage level 3 are documented. The documentation includes description of the queries and programming code used in the data processing. The documentation further includes information on all data fields in the database and the design specifications. Part of the detailed documentation is built into the database while the overall documentation is prepared as a separate documentation note.

Data Processing level 3	7. Transparency	DP.3.7.2	The documentation referred to under DS.3.7.1 should be archived at the same network folder as the program is located in.

The documentation prepared as part of DS.3.7.1 is archived in the same folder as the program is stored. For information on the file structure, please see Chapter 1.6.9.

Data Storage Level 4

Data Storage level 4	2.Comparability	DS.4.2.1	Description of similarities and differences in relation to other countries' inventories for the methodological approach

For each key source category, a comparison has been made between Denmark and the EU-15 countries (Fauser et al., 2007 & 2013). This is performed by comparing emission density indicators, defined as emission intensity value divided by a chosen indicator. The indicators are identical to the ones identified in the Norwegian verification inventory (Holtskog et al., 2000). The correlation between emissions and an independent indicator does not necessarily imply cause and effect, but in cases where the indicator is directly associated with the emission intensity value, such as for the energy sector, the emission density indicator is a measure of the implied emission factor and a direct comparison can be made. A qualitative verification of implied emission factors can be made when a measured or theoretical value of the CO_2 content in the respective fuel type (or other relevant parameter) is available. For the energy sector, all countries are, in principle, comparable and inter-country deviations arise from variations in fuel purities and fuel combustion efficiencies. A comparison of national emission density indicators, analogous to the implied emission factors, will give valuable information on the quality and efficiency of the national energy sectors.

Furthermore, the inter-country comparison of emission density indicators and comparison of theoretical values gives a methodological verification of the derivation of emission intensity values, and of the correlation between emission intensity values and activity values.

When emissions are compared with non-dependent parameters, similarities with regard to geography, climate, industry structure and level of economic development may be necessary for obtaining comparable emission density indicators.

Data Storage level 4	3.Completeness	DS.4.3.1	National and international validation including explanation of the discrepancies.

Refer to DS 4.2.1

Data Storage level 4	3.Completeness	DS.4.3.2	Check that the no sources where a methodology exists in the IPCC guidelines are reported as NE.

It is verified both by DCE experts and by EU consistency checks that no sources where methodologies and default parameters exist have been reported as NE. If methodologies do exist efforts are made to estimate and report emissions.

Data Storage level 4	4.Consistency	DS.4.4.1	The inventory reporting must follow the international guidelines suggested by UNFCCC and IPCC.

The inventory reporting is in accordance with the UNFCCC reporting guidelines (UNFCCC, 2013). The present report includes detailed and complete information on the inventories for all years from the base year to the year of the current annual inventory submission, in order to ensure the transparency of the inventory. The annual emission inventory for Denmark is reported in the Common Reporting Format (CRF) as requested in the reporting guidelines. The CRF-spreadsheets contain data on emissions, activity data and implied emission factors for each year. Emission trends are given for each greenhouse gas and for total greenhouse gas emissions in CO_2 equivalents. The link to complete sets of CRF-files and more information on the Danish emission inventories are on the ENVS homepage
(http://envs.au.dk/videnudveksling/luft/emissioner/emissioninventory).

Data Storage level 4	4.Consistency	DS.4.4.2	Check time series consistency of the reporting of Greenland and the Faroe Islands prior to aggregating the final submissions.

The time series for all pollutants in the submissions from Greenland and the Faroe Islands are checked at the CRF 3 level for large variations in the time series. Any large variations are explained or corrected in cooperation with the authorities in Greenland and the Faroe Islands.

Data Storage level 4	5.Correctness	DS.4.5.1	Check that the aggregated submission for Denmark under the UNFCCC matches the sum of the individual submissions.

To ensure that the submission for Denmark under the UNFCCC matches the sum of the submissions of Denmark, Greenland and the Faroe Islands a spreadsheet check has been implemented to ensure complete correctness of the submitted inventory. Special attention is paid to the additional information provided in the CRF, e.g. for the agricultural sector. Certain parameters cannot simply be added, e.g. animal weights. In these cases, a weighted average is reported in the CRF tables.

Data Storage level 4	6. Robustness	DS.4.6.1	The reporting to the UNFCCC must be anchored to two responsible persons who can replace each other in the technical issue of reporting to and communicating with the UNFCCC secretariat.

The reporting to the UNFCCC secretariat is currently anchored by two team members. All official correspondence between the secretariat and DCE involves both the responsible team members.

Data Storage level 4	7.Transparency	DS.4.7.1	Perform QA on the documentation reports provided by the Government of Greenland and the Faroe Islands.

The documentation reports are received by DCE from the Government of Greenland and the Faroe Islands in the early spring every year. The documentation reports are included in the NIR as Chapters 11 and 12. DCE experts read and provide comments on the report to the Government of Greenland, so that any questions are resolved prior to the UNFCCC reporting deadline of April 15.

1.7 General uncertainty evaluation, including data on the overall uncertainty for the inventory totals

1.7.1 Tier 1 uncertainties

The uncertainty estimates are based on the Approach 1 methodology in the 2006 IPCC Guidelines (IPCC, 2006). Uncertainty estimates for all sectors are included in the current year. The sources included in the uncertainty estimate cover 100 % of the total net Danish greenhouse gas emissions and removals.

The uncertainties for the activity rates and emission factors are shown in Table 1.5.

Table 1.5 Summary of base year and 2021 emissions in kt CO_2 equivalents and activity data and emission factor uncertainties. Calculated Approach 1 uncertainties for each emission source are given as percentage of the total 2021 emission. The base year for F-gases is 1995 and for all other gases, the base year is 1990.

IPCC Source category	Gas	Base year emission kt CO_2 eqv.	2021 emission kt CO_2 eqv.	Activity data uncertainty %	Emission factor uncertainty %	Approach 1 Combined uncertainty % of total emissions
1A Stationary combustion, Coal, ETS data, CO_2	CO_2	0.0	4055.7	0.5	0.3	0.583
1A Stationary combustion, Coal, no ETS data, CO_2	CO_2	23826.7	105.9	1.7	1.0	1.958
1A Stationary combustion, BKB, CO_2	CO_2	11.3	0.0	2.9	5.0	5.774
1A Stationary combustion, Coke oven coke, CO_2	CO_2	136.5	45.4	1.6	5.0	5.241
1A Stationary combustion, Fossil waste, ETS data, CO_2	CO_2	0.0	1200.1	2.0	3.0	3.606
1A Stationary combustion, Fossil waste, no ETS data, CO_2	CO_2	573.5	523.8	5.0	10.0	11.180
1A Stationary combustion, Petroleum coke, ETS data, CO_2	CO_2	0.0	605.1	0.5	0.5	0.707
1A Stationary combustion, Petroleum coke, no ETS data, CO_2	CO_2	414.7	38.2	2.0	5.0	5.385
1A Stationary combustion, Residual oil, ETS data, CO_2	CO_2	0.0	187.1	0.5	0.5	0.707
1A Stationary combustion, Residual oil, no ETS data, CO_2	CO_2	2526.6	20.4	1.2	2.0	2.340
1A Stationary combustion, Gas oil, CO_2	CO_2	5442.5	865.0	1.9	1.3	2.339
1A Stationary combustion, Kerosene, CO_2	CO_2	367.6	1.6	2.6	3.0	3.999
1A Stationary combustion, LPG, CO_2	CO_2	195.4	175.7	1.8	4.0	4.401
1A1b Stationary combustion, Petroleum refining, Refinery gas, CO_2	CO_2	816.1	889.5	1.0	0.5	1.118
1A Stationary combustion, Natural gas, onshore, CO_2	CO_2	3810.4	3900.5	1.4	0.4	1.503
1A1c_ii Stationary combustion, Oil and gas extraction, Off shore gas turbines, Natural gas, CO_2	CO_2	524.8	873.1	0.5	0.5	0.707
1A1 Stationary Combustion, Solid fuels, CH_4	CH_4	6.0	1.0	1	100	100.005
1A1 Stationary Combustion, Liquid fuels, CH_4	CH_4	0.8	0.6	1	100	100.005
1A1 Stationary Combustion, not engines, gaseous fuels, CH_4	CH_4	0.9	1.2	1	100	100.005
1A1 Stationary Combustion, Waste, CH_4	CH_4	0.2	0.4	3	100	100.045
1A1 Stationary Combustion, not engines, Biomass, CH_4	CH_4	3.7	17.6	3	100	100.045
1A2 Stationary Combustion, solid fuels, CH_4	CH_4	4.2	1.5	2	100	100.020
1A2 Stationary Combustion, Liquid fuels, CH_4	CH_4	1.0	0.7	2	100	100.020
1A2 Stationary Combustion, not engines, gaseous fuels, CH_4	CH_4	0.7	0.7	2	100	100.020
1A2 Stationary Combustion, Waste, CH_4	CH_4	0.0	2.7	3	100	100.045
1A2 Stationary Combustion, not engines, Biomass, CH_4	CH_4	1.8	1.3	3	100	100.045
1A4 Stationary Combustion, Solid fuels, CH_4	CH_4	7.0	0.0	3	100	100.045
1A4 Stationary Combustion, Liquid fuels, CH_4	CH_4	3.4	0.4	3	100	100.045
1A4 Stationary Combustion, not engines, gaseous fuels, CH_4	CH_4	18.5	20.1	3	100	100.045
1A4 Stationary Combustion, Waste, CH_4	CH_4	0.8	0.0	3	100	100.045
1A4 Stationary Combustion, not engines, not residential wood and not residential/agricultural straw, Biomass, CH_4	CH_4	0.1	6.0	3	100	100.045
1A4b_i Stationary combustion, Residential wood combustion, CH_4	CH_4	81.0	39.7	10	150	150.333
1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion, CH_4	CH_4	71.2	43.4	10	150	150.333
1A Stationary combustion, Natural gas fuelled engines, gaseous fuels, CH_4	CH_4	6.2	64.3	1	2	2.236
1A Stationary combustion, Biogas fuelled engines,	CH_4	2.4	82.1	3	10	10.440

IPCC Source category	Gas	Base year emission	2021 emission	Activity data uncertainty	Emission factor uncertainty	Approach 1 Combined uncertainty
		kt CO_2 eqv.	kt CO_2 eqv.	%	%	% of total emissions
Biomass, CH_4						
1A1 Stationary Combustion, Solid fuels, N_2O	N_2O	51.1	8.3	1	400	400.001
1A1 Stationary Combustion, Liquid fuels, N_2O	N_2O	2.5	1.3	1	1000	1000.000
1A1 Stationary Combustion, Gaseous fuels, N_2O	N_2O	10.5	8.0	1	750	750.001
1A1 Stationary Combustion, Waste, N_2O	N_2O	4.6	11.9	3	400	400.011
1A1 Stationary Combustion, Biomass, N_2O	N_2O	7.4	45.9	3	400	400.011
1A2 Stationary Combustion, Solid fuels, N_2O	N_2O	6.0	6.4	2	400	400.005
1A2 Stationary Combustion, Liquid fuels, N_2O	N_2O	26.1	5.3	2	1000	1000.002
1A2 Stationary Combustion, Gaseous fuels, N_2O	N_2O	6.4	19.1	2	750	750.003
1A2 Stationary Combustion, Waste, N_2O	N_2O	0.0	3.5	3	400	400.011
1A2 Stationary Combustion, Biomass, N_2O	N_2O	10.7	13.4	3	400	400.011
1A4 Stationary Combustion, Solid fuels, N_2O	N_2O	1.3	0.1	3	400	400.011
1A4 Stationary Combustion, Liquid fuels, N_2O	N_2O	10.5	1.0	3	1000	1000.004
1A4 Stationary Combustion, Gaseous fuels, N_2O	N_2O	6.9	7.7	3	750	750.006
1A4 Stationary Combustion, Waste, N_2O	N_2O	1.0	0.0	3	400	400.011
1A4 Stationary Combustion, not residential wood and not residential/agricultural straw, Biomass, N_2O	N_2O	0.4	4.8	3	400	400.011
1A4b_i Stationary Combustion, Residential wood combustion, N_2O	N_2O	9.5	33.0	10	500	500.100
1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion, N_2O	N_2O	9.0	5.5	10	500	500.100
1.A.2.g Industry (mobile)	CO_2	529.9	627.9	41	5	41.304
1.A.3.a Civil aviation	CO_2	225.9	85.4	10	5	11.180
1.A.3.b Road Transport	CO_2	9338.3	11262.3	2	5	5.385
1.A.3.c Railways	CO_2	297.1	184.8	2	5	5.385
1.A.3.d Navigation (large vessels)	CO_2	715.4	542.5	11	5	12.083
1.A.4.a Commercial/Institutional (mobile)	CO_2	150.9	173.0	35	5	35.355
1.A.4.b Residential (mobile)	CO_2	25.6	26.7	35	5	35.355
1.A.4.c ii Agriculture (mobile)	CO_2	558.6	639.7	24	5	24.515
1.A.4.c ii Forestry (mobile)	CO_2	35.9	43.6	30	5	30.414
1.A.4.c iii Fisheries	CO_2	640.1	370.0	2	5	5.385
1.A.5.b Other (military)	CO_2	48.0	91.5	41	5	41.304
1.A.5.b Other (small boats)	CO_2	119.0	127.1	2	5	5.385
1.A.2.g Industry (mobile)	CH_4	1.3	0.6	41	100	108.079
1.A.3.a Civil aviation	CH_4	0.1	0.0	10	100	100.499
1.A.3.b Road Transport	CH_4	87.8	8.9	2	40	40.050
1.A.3.c Railways	CH_4	0.3	0.1	2	100	100.020
1.A.3.d Navigation (large vessels)	CH_4	0.3	0.9	11	100	100.603
1.A.4.a Commercial/Institutional (mobile)	CH_4	0.9	0.8	35	100	105.948
1.A.4.b Residential (mobile)	CH_4	1.3	0.6	35	100	105.948
1.A.4.c ii Agriculture (mobile)	CH_4	1.3	0.8	24	100	102.840
1.A.4.c ii Forestry (mobile)	CH_4	4.5	0.4	30	100	104.403
1.A.4.c iii Fisheries	CH_4	0.2	0.2	2	100	100.020
1.A.5.b Other (military)	CH_4	2.1	0.2	41	100	108.079
1.A.5.b Other (small boats)	CH_4	0.1	0.1	2	100	100.020
1.A.2.g Industry (mobile)	N_2O	5.4	7.8	41	1000	1000.840
1.A.3.a Civil aviation	N_2O	2.8	1.1	10	1000	1000.050
1.A.3.b Road Transport	N_2O	77.4	110.9	2	50	50.040
1.A.3.c Railways	N_2O	2.4	1.5	2	1000	1000.002
1.A.3.d Navigation (large vessels)	N_2O	4.7	3.7	11	1000	1000.060
1.A.4.a Commercial/Institutional (mobile)	N_2O	1.5	1.8	35	1000	1000.612

IPCC Source category	Gas	Base year emission	2021 emission	Activity data uncertainty	Emission factor uncertainty	Approach 1 Combined uncertainty % of total emissions
		kt CO_2 eqv.	kt CO_2 eqv.	%	%	
1.A.4.b Residential (mobile)	N_2O	0.1	0.1	35	1000	1000.612
1.A.4.c ii Agriculture (mobile)	N_2O	5.6	8.1	24	1000	1000.288
1.A.4.c ii Forestry (mobile)	N_2O	0.1	0.5	30	1000	1000.450
1.A.4.c iii Fisheries	N_2O	4.2	2.4	2	1000	1000.002
1.A.5.b Other (military)	N_2O	0.3	0.9	41	1000	1000.840
1.A.5.b Other (small boats)	N_2O	1.0	1.3	2	1000	1000.002
1.B.2.a.1 Exploration	CO_2	4.7	0.0	2	10	10.198
1.B.2.a.2 Production	CO_2	0.0	0.0	2	100	100.020
1.B.2.a.4 Refining/storage	CO_2	0.0	0.1	2	40	40.050
1.B.2.b.1 Exploration	CO_2	8.2	0.0	2	10	10.198
1.B.2.b.2 Production	CO_2	0.1	0.0	2	50	50.040
1.B.2.b.4 Transmission and storage	CO_2	0.0	0.0	15	2	15.133
1.B.2.b.5 Distribution	CO_2	0.0	0.0	25	10	26.926
1.B.2.c.1.ii Venting	CO_2	0.0	0.1	15	2	15.133
1.B.2.c.2.i Flaring, oil	CO_2	22.9	12.8	11	2	11.180
1.B.2.c.2.ii Flaring, gas	CO_2	2.1	1.3	7.5	2	7.762
1.B.2.c.2.iii Flaring, combined	CO_2	302.6	97.0	7.5	2	7.762
1.B.2.a.1 Exploration	CH_4	0.0	0.0	2	125	125.016
1.B.2.a.2 Production	CH_4	0.1	0.1	2	100	100.020
1.B.2.a.3 Transport	CH_4	13.8	0.9	2	50	50.040
1.B.2.a.4 Refining/storage	CH_4	34.3	19.8	1	200	200.002
1.B.2.b.1 Exploration	CH_4	0.9	0.0	2	125	125.016
1.B.2.b.2 Production	CH_4	54.7	14.1	2	100	100.020
1.B.2.b.4 Transmission and storage	CH_4	4.0	7.8	15	2	15.133
1.B.2.b.5 Distribution	CH_4	7.1	5.9	25	10	26.926
1.B.2.c.1.ii Venting	CH_4	1.9	1.0	15	2	15.133
1.B.2.c.2.i Flaring, oil	CH_4	0.2	0.1	11	15	18.601
1.B.2.c.2.ii Flaring, gas	CH_4	0.3	0.0	7.5	2	7.762
1.B.2.c.2.iii Flaring, combined	CH_4	32.0	11.6	7.5	125	125.225
1.B.2.a.1 Exploration, oil	N_2O	0.0	0.0	2	1000	1000.002
1.B.2.c.2.i Flaring, oil	N_2O	0.1	0.0	11	1000	1000.060
1.B.2.c.2.ii Flaring, gas	N_2O	0.0	0.0	7.5	1000	1000.028
1.B.2.c.2.iii Flaring, combined	N_2O	0.1	0.0	7.5	1000	1000.028
2A1 Cement production	CO_2	774.7	1214.6	2	2	2.561
2A2 Lime production	CO_2	105.4	48.4	1	4	4.228
2A3 Glass production	CO_2	16.5	11.2	1	2	2.236
2A4a Ceramics	CO_2	46.1	53.4	5	2	5.385
2A4b Other uses of soda ash	CO_2	13.8	17.4	5	2	5.385
2A4d Other process uses of carbonates	CO_2	17.0	13.7	4	2	4.472
2B10 Production of catalysts	CO_2	0.6	1.2	5	5	7.071
2C1a Steel	CO_2	30.3	0.0	5	10	11.180
2C5 Lead production	CO_2	0.2	0.1	10	50	50.990
2D1 Lubricant use	CO_2	49.7	31.7	5	10	11.180
2D2 Paraffin wax use	CO_2	21.7	65.5	10	20	22.361
Paint Application	CO_2	12.9	7.6	10	15	18.028
Degreasing, dry cleaning and electronics	CO_2	0.0	0.0	10	15	18.028
Chemical products manufacturing or processing	CO_2	19.4	14.4	10	15	18.028
Other use of solvents and related activities	CO_2	52.0	39.8	10	20	22.361
Printing industry	CO_2	0.0	0.0	10	15	18.028
Domestic solvent use (other than paint application)	CO_2	9.4	8.6	10	15	18.028
2D3 Road paving with asphalt	CO_2	0.6	0.8	5	75	75.166
2D3 Asphalt roofing	CO_2	0.0	0.0	5	75	75.166

IPCC Source category	Gas	Base year emission	2021 emission	Activity data uncertainty	Emission factor uncertainty	Approach 1 Combined uncertainty % of total emissions
		kt CO_2 eqv.	kt CO_2 eqv.	%	%	
2D3 Urea based catalysts	CO_2	0.0	9.5	5	10	11.180
2G4 Fireworks	CO_2	0.1	0.2	5	50	50.249
2D2 Paraffin wax use	CH_4	0.0	0.1	10	20	22.361
2D3 Road paving with asphalt	CH_4	0.3	0.4	5	75	75.166
2G4 Fireworks	CH_4	0.0	0.1	5	50	50.249
2G4 Tobacco	CH_4	1.2	0.5	5	50	50.249
2G4 Charcoal	CH_4	1.2	2.1	5	100	100.125
2B2 Nitric acid production	N_2O	891.5	0.0	2	25	25.080
2D2 Paraffin wax use	N_2O	0.0	0.1	10	20	22.361
2G3a Medical application of N_2O	N_2O	10.1	10.1	25	20	32.016
2G3b N_2O as propellant for pressure and aerosol products	N_2O	4.7	5.9	100	150	180.278
2G4 Fireworks	N_2O	0.7	2.6	5	50	50.249
2G4 Tobacco	N_2O	0.2	0.1	5	50	50.249
2G4 Charcoal	N_2O	0.1	0.1	5	100	100.125
2E Electronics industry	HFCs	0.0	0.0	0	0	0.000
2F1 Refrigeration and air conditioning	HFCs	45.4	264.4	10	50	50.990
2F2 Foam blowing agents	HFCs	192.2	0.6	10	50	50.990
2F4 Aerosols	HFCs	0.0	10.1	10	50	50.990
2E Electronics industry	PFCs	0.0	0.0	10	50	50.990
2F1 Refrigeration and air conditioning	PFCs	0.6	0.0	10	50	50.990
2C4 Magnesium production	SF_6	35.3	0.0	10	30	31.623
2G1 Electrical equipment	SF_6	3.8	13.5	10	50	50.990
2G2 SF_6 and PFCs from other product use	SF_6	67.9	1.5	10	50	50.990
3A Enteric Fermentation	CH_4	4488.8	4142.4	2	20	20.100
3B Manure Management	CH_4	2521.8	3063.9	5	20	20.616
3F Field Burning of Agricultural Residues	CH_4	1.9	2.8	25	50	55.902
3B Manure Management	N_2O	684.9	498.7	20	100	101.980
3B5 Atmospheric deposition	N_2O	174.6	97.1	15	100	101.119
3Da1 Inorganic N fertilizer	N_2O	1667.4	952.0	3	300	300.015
3Da2a Animal manure applied to soils	N_2O	881.3	829.2	25	300	301.040
3Da2b Sewage sludge applied to soils	N_2O	13.0	20.1	15	300	300.375
3Da2c Other organic fertilizer applied to soils	N_2O	6.4	23.4	20	300	300.666
3Da3 Urine and dung deposited by grazing animals	N_2O	54.8	33.5	10	300	300.167
3Da4 Crop Residues	N_2O	666.6	892.6	25	300	301.040
3Da5 Mineralization	N_2O	179.5	38.6	50	300	304.138
3Da6 Cultivation of organic soils	N_2O	727.3	531.8	50	300	304.138
3Db1 Atmospheric deposition	N_2O	334.3	157.6	15	500	500.225
3Db2 Leaching	N_2O	880.0	514.7	20	300	300.666
3F Field Burning of Agricultural Residues	N_2O	0.3	0.4	25	50	55.902
3G Liming	CO_2	565.5	271.0	5	100	100.125
3H Urea application	CO_2	14.7	1.2	3	100	100.045
3I Other carbon-containing fertilizers	CO_2	33.3	3.5	3	100	100.045
4.A.1 Forest land remaining forest land, Living biomass	CO_2	-244.4	-1284.3	5	2	5.385
4.A.1 Forest land remaining forest land, Dead organic matter	CO_2	-127.0	-635.8	5	3	5.983
4.A.1 Forest land remaining forest land, Mineral soils	CO_2	0.0	0.0	5	2	5.385
4.A.1 Forest land remaining forest land, Organic soils	CO_2	147.4	126.9	10	50	50.990
4.A.2 Land converted to forest land	CO_2	-1036.8	-1173.6	10	9	13.280
4.B.1 Cropland remaining cropland, Living biomass	CO_2	74.6	539.4	3	15	15.207
4.B.1 Cropland remaining cropland, Mineral soils	CO_2	932.2	-546.2	3	75	75.042
4.B.1 Cropland remaining cropland, Organic soils	CO_2	3959.1	2520.8	3	50	50.109

IPCC Source category	Gas	Base year emission	2021 emission	Activity data uncertainty	Emission factor uncertainty	Approach 1 Combined uncertainty % of total emissions
		kt CO_2 eqv.	kt CO_2 eqv.	%	%	
4.B.2 Forest land converted to cropland	CO_2	2.2	96.8	10	50	50.990
4.B.2 Other land uses converted to cropland	CO_2	86.3	-26.8	10	50	50.990
4(II) Cropland on organic soils	CO_2	106.7	69.8	3	40	40.136
4.C.1 Grassland remaining grassland, Living biomass	CO_2	7.5	86.9	3	7	7.433
4.C.1 Grassland remaining grassland, Organic soils	CO_2	1974.2	1892.6	3	50	50.109
4.C.2 Forest land converted to grassland	CO_2	2.4	13.4	10	50	50.990
4.C.2 Other land uses converted to grassland	CO_2	53.7	123.8	10	50	50.990
4(II) Grassland on organic soils	CO_2	72.9	70.1	3	40	40.136
4.D.1.1 Peat extraction remaining peat extraction	CO_2	99.5	42.6	10	75	75.664
4.D.1.2 Flooded land remaining flooded land	CO_2	0.0	0.0	10	75	75.664
4.D.2. Land converted to wetlands	CO_2	3.2	11.8	10	75	75.664
4.E.2 Forest land converted to settlements	CO_2	4.4	25.0	10	75	75.664
4.E.2 Other land uses converted to settlements	CO_2	424.0	191.6	10	75	75.664
4.G Harvested wood products	CO_2	-2.4	-55.9	25	75	79.057
4(II) Cropland on organic soils	CH_4	153.1	102.8	10	90	90.554
4(II) Grassland on organic soils	CH_4	133.3	128.2	10	90	90.554
4(II) A. Forest land, organic soils	CH_4	4.5	24.4	10	90	90.554
4(II) Land converted to wetlands	CH_4	0.5	34.4	10	90	90.554
4(II) Peatland	CH_4	1.5	0.7	10	90	90.554
4(V) Biomass Burning	CH_4	0.7	0.0	10	30	31.623
4(III) Mineralization/immobilization, Forest land	N_2O	0.0	0.0	10	90	90.554
4(III) Mineralization/immobilization, Cropland	N_2O	0.0	2.3	10	90	90.554
4(III) Mineralization/immobilization, Grassland	N_2O	0.0	0.1	10	90	90.554
4(III) Mineralization/immobilization, Land converted to Settlements	N_2O	39.0	16.0	10	90	90.554
4(V) Biomass burning	N_2O	0.4	0.0	10	30	31.623
4(II) Drainage and rewetting, Forest soils	N_2O	23.6	21.7	10	50	50.990
4(II) Peat extraction remaining peat extraction	N_2O	0.2	0.1	10	50	50.990
5.E Accidental fires	CO_2	21.8	21.6	10	300	300.167
5.A Solid waste disposal	CH_4	1526.2	433.5	10	105	105.000
5.B.1 Composting	CH_4	29.9	94.2	20	100	101.980
5.B.2. Anaerobic digestion at biogas facilities	CH_4	6.3	402.5	5	20	20.616
5.C.1 Incineration of corpses	CH_4	0.0	0.0	1	150	150.003
5.C.2 Incineration of carcasses	CH_4	0.0	0.0	40	150	155.242
5.D.1 Domestic wastewater	CH_4	67.0	87.5	30	50	58.310
5.E Accidental fires	CH_4	3.0	2.9	10	500	500.100
5.B.1 Composting	N_2O	19.8	65.2	20	100	101.980
5.C.1 Incineration of corpses	N_2O	0.2	0.2	1	150	150.003
5.C.2 Incineration of carcasses	N_2O	0.0	0.1	40	150	155.242
5.D.1 Domestic wastewater	N_2O	104.4	118.6	30	50	58.310
5.D.2 Industrial wastewater	N_2O	196.2	8.0	30	50	58.310

1.7.2 Results of the Approach 1 uncertainty estimation

The estimated uncertainties for total GHG and for CO_2, CH_4, N_2O and F-gases are shown in Table 1.6. The base year for F-gases is 1995 and for all other sources, the base year is 1990. The total Danish net GHG emission is estimated with an uncertainty of ±12.4 % and the trend in net GHG emission since the base year has been estimated to be -40.7 % ± 3.1 %-age points. The GHG uncertainty estimates do not take into account the uncertainty of the GWP factors.

The uncertainty of N_2O emissions from synthetic fertiliser, animal waste applied to soil and crop residues and CH_4 emission from solid waste disposal, are the largest sources of uncertainty for the Danish GHG inventory (excluding LULUCF). For LULUCF the largest sources of uncertainty are organic soil emissions from cropland.

The uncertainty of the GHG emission from combustion (sector 1A) is 2.8 % and the trend uncertainty is -45.5 % ±1.4 %-age points.

Table 1.6 Uncertainties 1990-2021.

	Uncertainty Base year [%]	Uncertainty 2021 [%]	Trend [%]	Uncertainty in trend [%-age points]
GHG	10.2	12.4	-40.7	3.1
CO_2	4.2	5.7	-47.2	1.9
CH_4	20.5	13.1	-5.5	11.7
N_2O	91.9	102.0	-34.2	23.3
F-gases	31.0	46.5	-15.9	42.4
CO_2 excl. LULUCF	1.8	2.5	-44.6	1.2
GHG excl. LULUCF	10.6	12.5	-38.3	3.0

The overall increase in the uncertainty from the base year to the latest year is caused by less uncertain emission sources (such as CO_2 emission from fossil fuels) declining significantly. This causes more uncertain emission sources such as agriculture and LULUCF to influence the overall uncertainty more.

1.7.3 Tier 2 uncertainties

On the recommendation of the UNFCCC expert review team (ERT) in 2009 Denmark undertook a tier 2 uncertainty analysis. However, due to a reduction in resources, the tier 2 uncertainty analysis will no longer be carried out. For a description on the methodology and results of the tier 2 uncertainty estimation, please refer to Nielsen et al. (2016).

1.8 General assessment of the completeness

The present Danish greenhouse gas emission inventory includes all sources identified by the 2006 IPPC Guidelines. Please see Annex 5 for discussion on minor sources that are not included.

1.9 ESR emissions

The table below includes data for the emissions covered by the EU ETS (not including aviation), the CO_2 emissions from domestic aviation and resulting ESR emissions for 2021. As neither Greenland nor the Faroe Islands are members of the EU, the data in Table 1.7 refer to Denmark only.

Table 1.7 ESR emissions.

	kt CO_2 equivalents	2021
A	Total greenhouse gas emissions without LULUCF	43 851.1
B	Total ETS emissions	11 618.4
C	CO_2 emissions from 1.A.3.a civil aviation	85.4
D	Total ESR emissions (= A-B-C)	32 147.4
E	Annual Emission Allocation	32 127.5
F	Difference (= E-D)	-19.8

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2 Trends in greenhouse gas emissions

The trends presented in this Chapter cover the emissions from Denmark. Due to the small emissions originating from Greenland and the Faroe Islands, the trends are very similar in fact close to identical.

2.1 Description and interpretation of emission trends for aggregated greenhouse gas emissions

2.1.1 Greenhouse Gas Emissions

The greenhouse gas emissions are estimated according to the IPCC guidelines and are aggregated into five main sectors. The greenhouse gases include CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3. Figure 2.1 shows the estimated total greenhouse gas emissions in CO_2 equivalents (without indirect CO_2) from 1990 to 2021. The emissions are not corrected for electricity trade or temperature variations.

CO_2 is the most important greenhouse gas contributing in 2021 to the national total in CO_2 equivalents excluding LULUCF (Land Use and Land Use Change and Forestry) and excluding indirect CO_2 emissions with 67.9%, followed by CH_4 with 19.7 %, N_2O with 11.7 %, and f-gases (HFCs, PFCs, SF_6 and NF_3) with 0.7 %. If including LULUCF and indirect CO_2, the CO_2 emissions account for 69.0%, followed by CH_4 with 19.2 %, N_2O with 11.1 %, and f-gases (HFCs, PFCs, SF_6 and NF_3) with 0.6 %.

The energy sector and agricultural sector represent the largest sources, followed by LULUCF, industrial processes and product use and waste, see Figure 2.1. The total national greenhouse gas emission in CO_2 equivalents excluding LULUCF has decreased by 38.7 % from 1990 to 2021 when considering indirect CO_2, if excluding indirect CO_2 the emissions have decreased by 38.1 %. The emissions including LULUCF and indirect CO_2 have decreased by 41.0 % from 1990 to 2021. Comments on the overall trends etc. seen in Figure 2.1 are given in the sections below on the individual greenhouse gases.

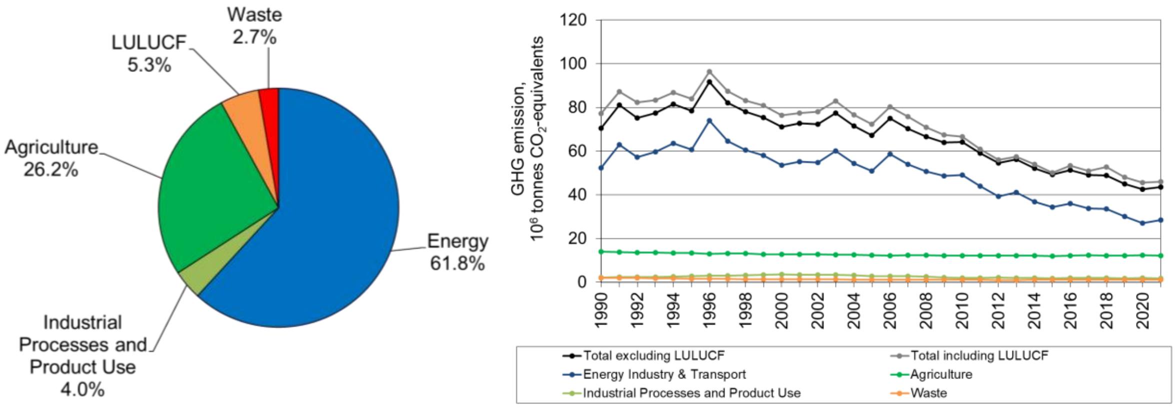


Figure 2.1 Greenhouse gas emissions in CO_2 equivalents distributed on main sectors for 2021 (excluding LULUCF and indirect CO_2) and time series for 1990 to 2021.

2.2 Description and interpretation of emission trends by gas

2.2.1 Carbon dioxide

The largest source to the emission of CO_2 is the energy sector, which includes combustion of fossil fuels like oil, coal and natural gas (Figure 2.2). The transport sector (dominated by road transport) is the largest sector in 2021 and contributes with 41 %, followed by energy industries with 27 %. The CO_2 emission (excl. LULUCF) increased by 4.9 % from 2020 to 2021. The main reason for the increase is increasing emissions from energy industries due to an increase in the consumption of fossil fuels. In general, CO_2 emissions fluctuate significantly as a result of the electricity trade with neighbouring countries.

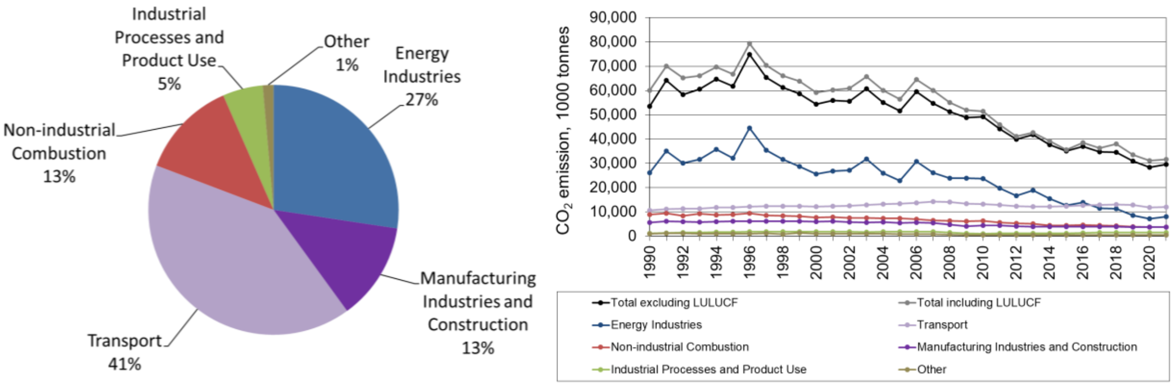


Figure 2.2 CO_2 emissions. Distribution according to the main sectors for 2021 and time series for 1990 to 2021.

2.2.2 Methane

The largest sources of anthropogenic CH_4 emissions are agricultural activities contributing with 83.9 % in 2021, waste (11.9 %) and the remaining emission sources covers 4.2 % - see Figure 2.3. The emission from agriculture derives from enteric fermentation (48.2 %) and management of animal manure (35.7 %).

Since 1990, the emission of CH_4 from enteric fermentation has decreased 7.7 % mainly due to the decrease in the number of cattle. However, this reduction is countered by an increase of 21.5 % in emissions from manure management caused by a change in housing type towards slurry-based systems. In later years, the emission from manure management has decreased due to changes in manure management, e.g. more biogas treatment and acidification of slurry. The emission of CH_4 from solid waste disposal has decreased significantly (71.6 %) from 1990 to 2021 due to an increase in the incineration of waste and extensive recycling thereby causing a decrease in the waste disposal on land. The CH_4 emission from the energy sector increases from mid 1990ties from public power and district heating plants increases due to the increasing use of gas engines in the decentralised cogeneration plant sector. Due to the liberalisation of the electricity market the use of gas engines declined from 2005 onwards. The high emission from gas engines is caused by the fact that up to 3 % of the natural gas in the gas engines is not combusted.

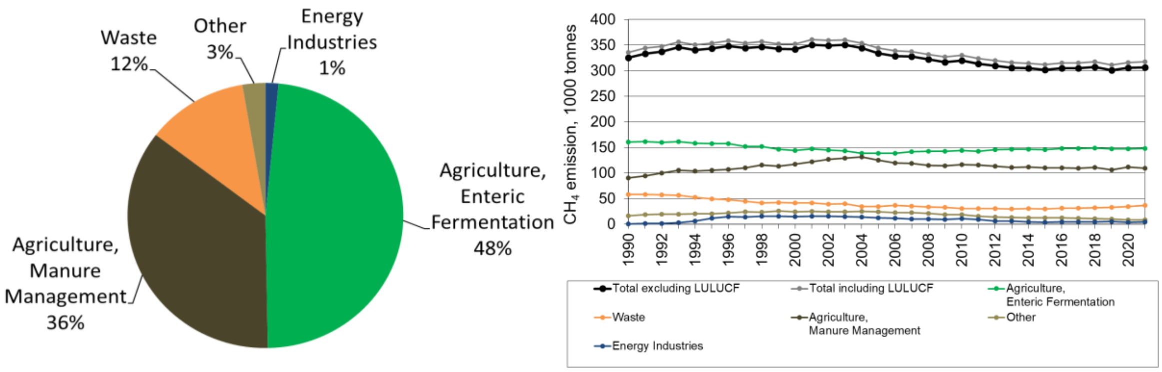


Figure 2.3 CH_4 emissions. Distribution according to the main sectors for 2021 and time series for 1990 to 2021.

2.2.3 Nitrous oxide

Agriculture is the most important N_2O emission source in 2021 contributing with 89.7 % (Figure 2.4) of which N_2O from soils dominates (78.1 % of total N_2O). Substantial emissions come from drainage water and coastal waters where nitrogen is converted to N_2O through bacterial processes. However, the nitrogen converted in these processes originates mainly from the agricultural use of manure and fertilisers.

The main reason for the decrease of N_2O emission is due to the agricultural sector, which has decreased with 26.8 % since 1990 caused by legislation to improve the utilisation of nitrogen in manure. Combustion of fuels contributes 6.2 % to the total whereof the N_2O emission from transport contributes with 2.3 % to the national total in 2021. Emission from industrial processes decreased significantly in 2004 due to the closure of the only nitric acid plant operating in Denmark and the emission from this emission source is therefore close to zero since then.

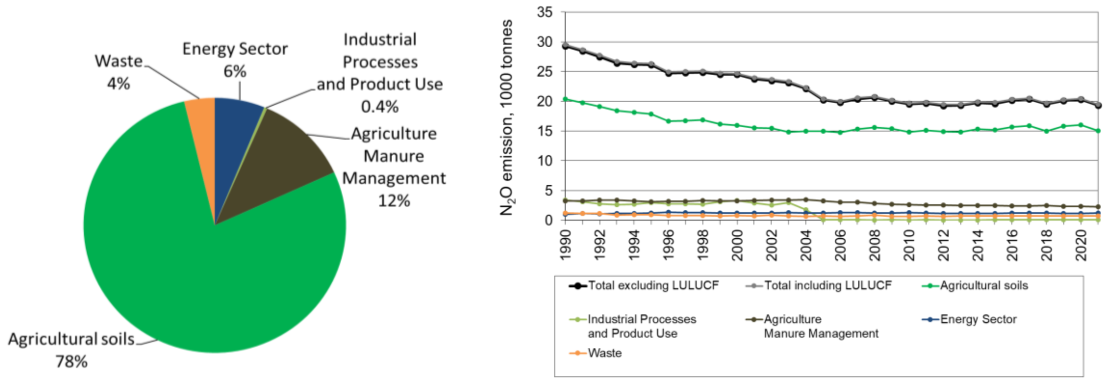


Figure 2.4 N_2O emissions. Distribution according to the main sectors for 2021 and time series for 1990 to 2021.

2.2.4 HFCs, PFCs, SF_6 and NF_3

This part of the Danish inventory only comprises a full data set for all substances from 1995 - see Figure 2.5. From 1995 to 2000, there was a continuous and substantial increase in the contribution from the range of f-gases as a whole (134.6 %), calculated as the sum of emissions in CO_2 equivalents. In 2000-2009, the increase of f-gas emissions continues with a lower increasing rate than for the years 1995 to 2000. Hereafter, the f-gas emission decreases.

The use of HFCs has increased several folds and HFCs have become the dominant f-gases, comprising 68.8 % in 1995 but 94.8 % in 2021. HFCs are mainly used as a refrigerant. SF_6 contributed considerably to the f-gas sum in earlier years, with 31.0 % in 1995 and reduced to 5.2 % in 2021. Due to environmental awareness the Danish legislation regulates the use of f-gases, e.g. since January 1, 2007 new HFC-based refrigerant stationary systems are forbidden. Refill of old systems are still allowed and the use of air conditioning in mobile systems increases.

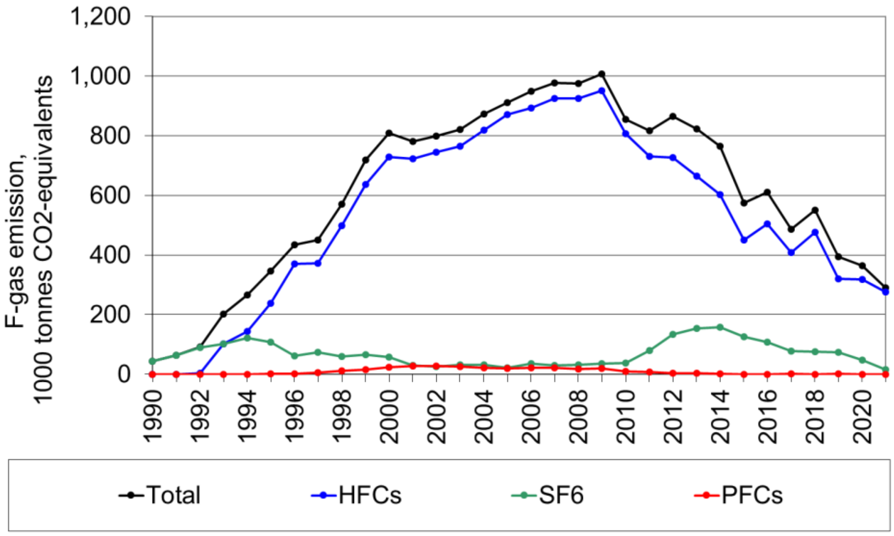


Figure 2.5 F-gas emissions. Time series for 1990 to 2021.

2.3 Description and interpretation of emission trends by source

2.3.1 Energy

The emission from the energy sector in 2021 covers 61.5 % of the total emission in CO_2 equivalents (incl. LULUCF and indirect CO_2). The emission of CO_2 equivalents from energy industries (CRF 1A1) has decreased by 68.3 % from 1990 to 2021. The relatively large fluctuations in the emission through the time-series 1990-2021 is due to inter-country electricity trade. Thus, the high emissions in 1991, 1996, 2003 and 2006 reflect a large electricity export and the low emission in 1990, 2005, 2008, 2011 and 2012 is due to import of electricity. In general, CO_2 emissions are decreasing due to a lower consumption of fossil fuels and a higher electricity production based on renewable energy, mainly wind power.

The increasing emission of CH_4 is due to the increasing use of gas engines in decentralised cogeneration plants. However, in later years the CH_4 emission has decreased due to less use of natural gas in gas engines. The CH_4 emission from residential combustion (mainly wood) increased as a result of increased use of wood. However, the wood consumption has decreased substantially over the last years, so that emission is decreasing. The emission of CO_2 equivalents from the transport sector (CRF 1A3) increased by 13.5 % from 1990 to 2021, mainly due to increasing road traffic. A large decrease in transport emissions occurred between 2019 and 2020, which can to a large extend be attributed to the restrictions to mobility in battling the COVID-19 pandemic.

2.3.2 Industrial processes and product use

The emissions from industrial processes and product use, i.e. emissions from processes other than fuel combustion, amount in 2021 to 4.0 % of the total emission in CO_2 equivalents (incl. LULUCF and indirect CO_2). The main sources are cement production and f-gases used in refrigeration and air conditioning.

The largest source is CO_2 emissions from cement production, which in 2021 contributes with 1214.6 kt CO_2, i.e. 2.6 % of the national greenhouse gas emissions (incl. LULUCF and indirect CO_2). The CO_2 emission from cement production has increased by 56.8 % since 1990. The second largest source is the emission from consumption of HFCs mainly from refrigeration and air condition equipment. This source contributes with 275.2 kt CO_2 equivalents, i.e. 0.6 % of the national total. Historically (1990-2004), the emission of N_2O from the production of nitric acid has been the second largest source (after cement), with up to 1002.5 kt CO_2 equivalents (1990). However, the production of nitric acid ceased in 2004, which reduced the N_2O emission from industrial processes drastically.

2.3.3 Agriculture

The agricultural sector contributes in 2021 with 26.1 % of the total emission in CO_2 equivalents (incl. LULUCF and indirect CO_2) and the major part is related to the livestock production. Since 1990, the agricultural emission has decreased 13.1 % mainly due to a decrease in the N_2O emission.

In 2021, the agricultural activities accounts for 83.0 % of the total CH_4 emission (excl. LULUCF). Since 1990, the emission of CH_4 from enteric fermentation has decreased by 7.7 %, which is mainly due to the decrease in the number of dairy cattle. However, the emission from manure management has in the same period increased 21.5 %, which is mainly driven by a change from traditional housing systems towards slurry-based housing systems. In total, the CH_4 emission from the agriculture sector 1990 – 2021 has increased by 2.8 %.

In 2021, the agricultural activities accounts for 89.7 % of the total N_2O emission (excl. LULUCF). Since 1990, the N_2O emission has decreased 26.8 %. A string of measures have been introduced by action plans to prevent the loss of nitrogen from agriculture to the aquatic environment. These actions have brought a decrease in animal nitrogen excretion, improvement in use of nitrogen in manure and a fall in the use of inorganic N fertiliser, which all have led to reductions of the N_2O emission.

2.3.4 Land use, Land-use change and forestry

The total sector has been estimated to be a net source of 4.3 % of the total Danish emission incl. LULUCF (average previous 10 years (2012-2021) (variation 1.7-7.2 % depending of year). The average emission over the past 10 years (2012-2021) has been estimated to 2148 kt CO_2-eq. with an emission of 2420 kt CO_2 equivalents in 2021. Emissions/removals from the sector fluctuate based on specific conditions in the given year. In general, the forest sector is a net sink or around in its equilibrium state, while Cropland and Grassland are net sources. The latter due to a large area with drained organic soils. CO_2 emissions from drained organic soils within cropland and grassland accounts for 9.6 % of the total Danish emission incl. LULUCF and indirect CO_2 in 2021.

In 2021, Cropland has been estimated to be a net source of 6.0% of the total Danish emission incl. LULUCF and indirect CO_2. Grassland is a net source contributing to 5.0 % of the total Danish emission, also due to a large area with drained organic soils. Emissions from Cropland and Grassland have shown a continuous decrease since 1990. However, large variations occur between years.

2.3.5 Waste

The waste sector contributes in 2021 to 2.7 % of the total emission in CO_2 equivalents (incl. LULUCF and indirect CO_2). The emission from the sector has decreased by 37.5 % since 1990. Historically, the most important activity in the sector is solid waste disposal on land. In 2021, the emissions contributed by 35.1 % of the sectoral total GHG emission. The CH_4 emission from solid waste disposal has been decreasing since 1990 by 71.6 % due to banning of deposing organic waste and an overall decrease in waste deposited because waste has increasingly been used for power and heat production and/or recycled.

Biological treatment of solid waste (5.B) has in the later years become the largest contributor to the sectoral total GHG emission. It contributes to the sectoral total in CO_2 equivalents in 2021 with 45.5 %. The emissions from biological treatment of solid waste have increased by 1273 % for CH_4 and 230 % for N_2O since 1990, due to an increase in the number of biogas plants and the amount of bio-waste composted in Denmark.

Wastewater handling contributes to the sectoral total in CO_2 equivalents in 2021 with 17.3 %. The CH_4 emissions from wastewater handling have increased by 30.5 % from 1990 to 2021 while the N_2O emission has decreased by 57.9 %.

Since all incinerated waste (municipal, industrial, hazardous) is used for power and heat production, the emissions are included in the 1A1a category.

3 Energy

3.1 Overview of the sector

The data presented in Chapter 3 relates to Denmark only, whereas information for Greenland is included in Chapter 16 and for the Faroe Islands in Annex 7.

The energy sector has been reported in four main chapters:

3.2 Stationary combustion plants (CRF sector 1A1, 1A2 and 1A4)
3.3 Transport and other mobile sources (CRF sector 1A2, 1A3, 1A4 and 1A5)
3.4 Additional information, fuel combustion (Reference approach, feedstocks and non-energy use of fuels)
3.5 Fugitive emissions (CRF sector 1B)

Summary tables for the energy sector are shown below.

Table 3.1.1 CO_2 emissions from the energy sector.

Greenhouse gas source categories	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	kt									
1. Energy	51,672	62,200	56,364	58,659	62,617	59,411	72,665	63,143	59,086	56,509
1A. Fuel Combustion (Sectoral Approach)	51,331	61,550	55,688	58,077	62,042	58,957	72,167	62,445	58,563	55,402
1A1. Energy Industries	26,156	35,026	30,099	31,675	35,675	32,183	44,478	35,351	31,699	28,610
1A2. Manufacturing Industries and Construction	5,666	6,097	5,917	5,831	5,941	6,069	6,176	6,189	6,127	6,197
1A3. Transport	10,577	11,077	11,269	11,315	11,735	11,867	12,127	12,325	12,332	12,361
1A4. Other Sectors	8,766	9,013	8,207	8,960	8,377	8,520	9,141	8,335	8,123	7,970
1A5. Other	167	338	196	296	314	318	246	245	282	265
1B. Fugitive Emissions from Fuels	341	650	677	582	575	454	498	698	523	1,107
1B1. Solid Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B2. Oil and Natural Gas	341	650	677	582	575	454	498	698	523	1,107
1C. CO_2 transport and storage	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	kt									
1. Energy	52,152	53,815	53,429	58,660	53,066	49,492	57,466	52,671	49,478	47,577
1A. Fuel Combustion (Sectoral Approach)	51,429	53,044	52,755	57,990	52,314	48,944	56,922	52,128	49,091	47,315
1A1. Energy Industries	25,598	26,881	27,103	31,846	25,963	22,780	30,686	26,053	23,935	23,884
1A2. Manufacturing Industries and Construction	5,957	6,068	5,717	5,691	5,783	5,494	5,626	5,369	4,843	4,031
1A3. Transport	12,228	12,284	12,447	12,913	13,142	13,362	13,692	14,244	14,074	13,310
1A4. Other Sectors	7,449	7,624	7,304	7,349	7,083	6,934	6,690	6,185	6,030	5,831
1A5. Other	197	188	184	192	343	374	229	276	208	260
1B. Fugitive Emissions from Fuels	723	771	675	670	752	548	544	544	387	262
1B1. Solid Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B2. Oil and Natural Gas	723	771	675	670	752	548	544	544	387	262
1C. CO_2 transport and storage	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	kt									
1. Energy	48,003	42,860	38,466	40,305	36,104	33,689	35,280	32,914	32,883	29,331
1A. Fuel Combustion (Sectoral Approach)	47,650	42,608	38,248	40,061	35,853	33,442	35,007	32,673	32,650	29,136
1A1. Energy Industries	23,710	19,758	16,654	18,894	15,423	12,731	13,890	11,411	11,313	8,513
1A2. Manufacturing Industries and Construction	4,466	4,353	4,053	3,874	3,866	3,823	3,910	3,983	3,985	3,756
1A3. Transport	13,188	12,878	12,307	12,103	12,209	12,389	12,656	12,840	13,087	12,886
1A4. Other Sectors	6,080	5,330	5,026	4,956	4,131	4,308	4,350	4,141	4,054	3,788
1A5. Other	206	289	209	234	225	191	201	297	210	193
1B. Fugitive Emissions from Fuels	353	252	218	244	251	247	273	242	233	195
1B1. Solid Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B2. Oil and Natural Gas	353	252	218	244	251	247	273	242	233	195
1C. CO_2 transport and storage	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Continued	2020	2021
	kt	
1. Energy	26,501	27,773
1A. Fuel Combustion (Sectoral Approach)	26,374	27,662
1A1. Energy Industries	7,181	8,109
1A2. Manufacturing Industries and Construction	3,648	3,734
1A3. Transport	11,814	12,075
1A4. Other Sectors	3,493	3,525
1A5. Other	238	219
1B. Fugitive Emissions from Fuels	126	111
1B1. Solid Fuels	NO	NO
1B2. Oil and Natural Gas	126	111
1C. CO_2 transport and storage	NO	NO

Table 3.1.2 CH_4 emissions from the energy sector.

Greenhouse gas source categories	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	kt									
1. Energy	16.41	19.56	20.31	22.53	25.85	31.66	36.35	37.58	38.27	40.66
1A. Fuel Combustion (Sectoral Approach)	11.08	12.23	12.84	15.03	18.09	23.88	28.08	27.52	28.76	28.35
1A1. Energy Industries	0.62	0.96	1.36	2.98	6.07	11.40	14.58	13.90	15.29	15.39
1A2. Manufacturing Industries and Construction	0.32	0.34	0.32	0.33	0.33	0.39	0.76	0.76	0.86	0.85
1A3. Transport	3.16	3.28	3.29	3.24	3.17	3.01	2.85	2.71	2.56	2.37
1A4. Other Sectors	6.90	7.56	7.78	8.39	8.43	8.97	9.80	10.05	9.94	9.65
1A5. Other	0.08	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10
1B. Fugitive Emissions from Fuels	5.33	7.33	7.48	7.50	7.76	7.78	8.27	10.06	9.52	12.31
1B1. Solid Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B2. Oil and Natural Gas	5.33	7.33	7.48	7.50	7.76	7.78	8.27	10.06	9.52	12.31

Continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	kt									
1. Energy	39.04	40.10	39.08	38.37	38.74	36.31	34.28	32.05	30.72	27.15
1A. Fuel Combustion (Sectoral Approach)	27.65	28.41	27.71	27.27	26.84	24.95	23.42	21.73	21.42	19.38
1A1. Energy Industries	14.68	15.56	15.13	14.39	14.07	12.43	11.51	9.59	10.10	8.82
1A2. Manufacturing Industries and Construction	1.06	1.12	1.02	0.99	0.99	0.85	0.69	0.48	0.54	0.49
1A3. Transport	2.19	2.03	1.89	1.78	1.64	1.48	1.35	1.22	1.03	0.88
1A4. Other Sectors	9.63	9.61	9.59	10.04	10.06	10.12	9.81	10.39	9.71	9.15
1A5. Other	0.09	0.09	0.08	0.08	0.08	0.07	0.06	0.05	0.04	0.03
1B. Fugitive Emissions from Fuels	11.39	11.69	11.36	11.10	11.89	11.36	10.86	10.32	9.30	7.77
1B1. Solid Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B2. Oil and Natural Gas	11.39	11.69	11.36	11.10	11.89	11.36	10.86	10.32	9.30	7.77

Continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	kt									
1. Energy	29.30	24.85	20.38	18.89	16.40	15.78	16.06	15.74	15.34	14.55
1A. Fuel Combustion (Sectoral Approach)	21.73	18.56	14.84	13.62	11.30	11.04	11.53	11.36	11.55	11.41
1A1. Energy Industries	10.98	9.20	6.37	5.66	4.12	3.50	4.06	4.22	4.72	4.92
1A2. Manufacturing Industries and Construction	0.57	0.52	0.36	0.38	0.38	0.50	0.54	0.68	0.88	0.97
1A3. Transport	0.78	0.69	0.60	0.54	0.50	0.48	0.44	0.42	0.39	0.38
1A4. Other Sectors	9.37	8.13	7.48	7.02	6.30	6.55	6.48	6.02	5.54	5.13
1A5. Other	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1B. Fugitive Emissions from Fuels	7.57	6.29	5.54	5.27	5.10	4.74	4.54	4.38	3.80	3.14
1B1. Solid Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B2. Oil and Natural Gas	7.57	6.29	5.54	5.27	5.10	4.74	4.54	4.38	3.80	3.14

Continued	2020	2021
	kt	
1. Energy	11.98	12.79
1A. Fuel Combustion (Sectoral Approach)	9.76	10.61
1A1. Energy Industries	3.65	4.67
1A2. Manufacturing Industries and Construction	0.96	0.80
1A3. Transport	0.35	0.35
1A4. Other Sectors	4.79	4.78
1A5. Other	0.01	0.01
1B. Fugitive Emissions from Fuels	2.22	2.18
1B1. Solid Fuels	NO	NO
1B2. Oil and Natural Gas	2.22	2.18

Table 3.1.3 N_2O emissions from the energy sector.

Greenhouse gas source categories	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	kt									
1. Energy	1.02	1.14	1.11	1.14	1.18	1.23	1.37	1.30	1.27	1.25
1A. Fuel Combustion (Sectoral Approach)	1.02	1.14	1.11	1.14	1.18	1.23	1.37	1.30	1.27	1.25
1A1. Energy Industries	0.29	0.37	0.34	0.36	0.39	0.38	0.51	0.44	0.42	0.40
1A2. Manufacturing Industries and Construction	0.21	0.22	0.22	0.20	0.20	0.25	0.25	0.25	0.26	0.25
1A3. Transport	0.33	0.35	0.36	0.36	0.38	0.39	0.39	0.40	0.40	0.39
1A4. Other Sectors	0.19	0.20	0.20	0.21	0.20	0.20	0.21	0.20	0.19	0.20
1A5. Other	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1B. Fugitive Emissions from Fuels	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1B1. Solid Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B2. Oil and Natural Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	kt									
1. Energy	1.22	1.24	1.22	1.27	1.23	1.19	1.28	1.26	1.25	1.20
1A. Fuel Combustion (Sectoral Approach)	1.22	1.23	1.22	1.27	1.22	1.19	1.28	1.26	1.25	1.20
1A1. Energy Industries	0.38	0.40	0.40	0.44	0.39	0.36	0.42	0.36	0.35	0.36
1A2. Manufacturing Industries and Construction	0.24	0.24	0.22	0.21	0.22	0.21	0.23	0.24	0.23	0.19
1A3. Transport	0.39	0.38	0.38	0.38	0.38	0.37	0.36	0.38	0.39	0.38
1A4. Other Sectors	0.20	0.21	0.21	0.23	0.23	0.25	0.26	0.28	0.28	0.27
1A5. Other	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1B. Fugitive Emissions from Fuels	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1B1. Solid Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B2. Oil and Natural Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	kt									
1. Energy	1.26	1.21	1.16	1.18	1.14	1.17	1.24	1.23	1.24	1.17
1A. Fuel Combustion (Sectoral Approach)	1.26	1.21	1.16	1.18	1.14	1.17	1.24	1.23	1.24	1.17
1A1. Energy Industries	0.38	0.33	0.31	0.33	0.29	0.28	0.30	0.29	0.29	0.26
1A2. Manufacturing Industries and Construction	0.20	0.20	0.18	0.17	0.15	0.17	0.19	0.19	0.21	0.19
1A3. Transport	0.39	0.41	0.41	0.42	0.43	0.45	0.46	0.46	0.47	0.46
1A4. Other Sectors	0.29	0.26	0.25	0.26	0.24	0.27	0.28	0.27	0.26	0.25
1A5. Other	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1B. Fugitive Emissions from Fuels	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1B1. Solid Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B2. Oil and Natural Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Continued	2020	2021
	kt	
1. Energy	1.12	1.19
1A. Fuel Combustion (Sectoral Approach)	1.12	1.19
1A1. Energy Industries	0.25	0.28
1A2. Manufacturing Industries and Construction	0.19	0.21
1A3. Transport	0.43	0.44
1A4. Other Sectors	0.24	0.25
1A5. Other	0.01	0.01
1B. Fugitive Emissions from Fuels	0.00	0.00
1B1. Solid Fuels	NO	NO
1B2. Oil and Natural Gas	0.00	0.00

Table 3.1.4 Emissions of NO_x, CO, NMVOC and SO_2 from the energy sector in 2021.

	NO_x, kt	CO, kt	NMVOC, kt	SO_2, kt
1. Energy	70.47	185.73	26.62	6.72
A. Fuel Combustion (Sectoral Approach)	70.42	185.63	19.90	6.25
1. Energy Industries	15.23	16.53	1.23	2.46
2. Manufacturing Industries and Construction	8.05	13.62	1.28	2.05
3. Transport	32.37	53.00	6.01	0.32
4. Other Sectors	13.64	99.55	11.12	1.35
5. Other	1.12	2.92	0.25	0.07
B. Fugitive Emissions from Fuels	0.06	0.10	6.72	0.47
1. Solid Fuels	NO	NO	NO	NO
2. Oil and Natural Gas	0.06	0.10	6.72	0.47

3.2 Stationary combustion

Stationary combustion is the largest source of CO_2 emission in Denmark accounting for 42.5 % of the 2021 national total CO_2 emissions including LULUCF. The CO_2 emission from stationary combustion has decreased by 65 % since 1990. The decreased emission since 1990 is a result of both at decreased fuel consumption and a change of fuel types applied; the consumption of coal has decreased whereas the consumption of biomass has increased since 1990. The relatively large fluctuations in the CO_2 emission time series from 1990 to 2021 are due to inter-country electricity trade fluctuations caused mainly by variation in hydropower generation in Norway and Sweden. The CO_2 emission in 2021 was 8 % higher than in 2020. This is related to the lower net electricity import in 2021 compared to 2020.

The methane (CH_4) emission from stationary combustion plants accounted for 3.2 % of the national CH_4 emission in 2021. The CH_4 emission from stationary combustion has increased by 35 % since 1990. The emission increased until 1996 and decreased after 2004. The trend is related to the considerable number of lean-burn gas engines installed in CHP plants in Denmark during the 1990s. The CH_4 emission from gas engines is high compared to other plant types. The deregulation of the electricity market has made production of electricity in gas engines less favourable, therefore the fuel consumption and CH_4 emission has decreased since 2004. The CH_4 emission in 2021 was 9 % higher than in 2020.

The nitrous oxide (N_2O) emission from stationary combustion plants accounted for 3.4 % of the national N_2O emission in 2021. The N_2O emission from stationary combustion was 7 % higher than in 1990, but as for CO_2, fluctuations in emission level due to electricity import/export are considerable. The emission in 2021 was 10 % higher than in 2020.

3.2.1 Source category description

Source category definition

Stationary combustion plants are included in the emission source subcategories:

- 1A1 Energy, Fuel combustion, Energy Industries
    - 1A1a Public electricity and heat production
    - 1A1b Petroleum refining
    - 1A1c Oil and gas extraction

- 1A2 Energy, Fuel combustion, Manufacturing Industries and Construction
  - 1A2a Iron and steel
  - 1A2b Non-ferrous metals
  - 1A2c Chemicals
  - 1A2d Pulp, Paper and Print
  - 1A2e Food processing, beverages and tobacco
  - 1A2f Non-metallic minerals
  - 1A2 g viii Other manufacturing industry
- 1A4 Energy, Fuel combustion, Other Sectors
  - 1A4a i Commercial/institutional plants.
  - 1A4b i Residential plants.
  - 1A1c i Agriculture/forestry.

The emission and fuel consumption data included in tables and figures in Chapter 3.2 only include emissions originating from stationary combustion plants of a given CRF sector.

The consumption of fuel for military use in stationary combustion plants has been included in commercial/institutional plants.

All pipeline compressors on the natural gas grid are electric compressors. Hence fuel consumption and emissions are NO in the sector 1A3e i Pipeline transport. The fuel consumption in the Danish gas treatment plant is included in sector 1A1cii Oil and gas extraction.

In the Danish emission database, all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution) according the CORINAIR system. The emission inventories are prepared from a complete emission database based on the SNAP source categories. Danish Centre for Environment and Energy, Aarhus University (DCE) has modified the SNAP categorisation to enable direct reporting of the disaggregated data for manufacturing industries and construction. Aggregation to the IPCC source category codes is based on a correspondence list enclosed in Annex 3A-1. Stationary combustion is defined as combustion activities in the SNAP sectors 01 – 03, not including SNAP 0303.

The CO_2 emission from calcinations is not part of the source category Energy. This emission is included in the source category Industrial Processes.

Methodology overview, tier

The type of emission factor and the applied tier level for each emission source are shown in Table 3.2.1 below. The tier level has been determined based on the IPCC Guidelines (IPCC, 2006).

The fuel consumption data for transformation are technology specific. For end-use of fuels, the disaggregation to specific technologies is less detailed. However, for residential wood combustion the technology disaggregation is technology specific.

The distinction between tier 2 and 3 has been based on the emission factor. The tier level definitions have been interpreted as follows:

- Tier 1: The emission factor is an IPCC default tier 1 value.

- Tier 2: The emission factors are country-specific and based on a limited number of emission measurements or a technology specific IPCC tier 2 emission factor.
- Tier 3: Emission data are based on:
  - Plant specific emission measurements or
  - Technology specific fuel consumption data and country-specific emission factors based on a considerable number of emission measurements from Danish plants.

Table 3.2.1 gives an overview of the calculation methods and type of emission factor. The table also shows which of the source categories are key in any of the key category analysis[1] (including LULUCF, approach 1/approach 2, level/trend).

This year, two source categories based on tier 1 approach have been identified as key sources. The total emission from these emission sources adds up to 35 ktonnes CO_2 equivalent or 0.08 % of the national total in 2021. In 1990, the emission from the two emission sources adds up to 377 ktonnes or 0.5 % of national total. Additional information is included in Chapter 3.2.5.

[1] Key category according to the KCA approach 1 or approach 2 for Denmark (excluding Greenland and Faroe Islands), including LULUCF, level 1990/level 2021/trend.

Table 3.2.1 Methodology and type of emission factor.

		Tier	EMF[1)]	Key category[2)]
1A Stationary combustion, Coal, ETS data	CO_2	Tier 3	PS	Yes
1A Stationary combustion, Coal, no ETS data	CO_2	Tier 3 [3)]	CS	Yes
1A Stationary combustion, BKB	CO_2	Tier 1	D	No
1A Stationary combustion, Coke oven coke	CO_2	Tier 1/Tier 3	D/PS	No
1A Stationary combustion, Fossil waste, ETS data	CO_2	Tier 3	PS/CS	Yes
1A Stationary combustion, Fossil waste, no ETS data	CO_2	Tier 2	CS	Yes
1A Stationary combustion, Petroleum coke, ETS data	CO_2	Tier 3	PS	Yes
1A Stationary combustion, Petroleum coke, no ETS data	CO_2	Tier 2	CS	Yes
1A Stationary combustion, Residual oil, ETS data	CO_2	Tier 3	PS	Yes
1A Stationary combustion, Residual oil, no ETS data	CO_2	Tier 2 [4)]	CS	Yes
1A Stationary combustion, Gas oil	CO_2	Tier 2/Tier 3 [5)]	CS / PS	Yes
1A Stationary combustion, Kerosene	CO_2	Tier 1	D	Yes
1A Stationary combustion, LPG	CO_2	Tier 2/Tier 3 [6)]	CS / PS	Yes
1A1b Stationary combustion, Petroleum refining, Refinery gas	CO_2	Tier 3	CS	Yes
1A Stationary combustion, Natural gas, onshore	CO_2	Tier 3	CS	Yes
1A1c_ii Stationary combustion, Oil and gas extraction, Offshore gas turbines, Natural gas	CO_2	Tier 3	CS	Yes
1A1 Stationary Combustion, solid fuels	CH_4	Tier 2	D(2)	No
1A1 Stationary Combustion, liquid fuels	CH_4	Tier/Tier 2	D / D(2) / CS	No
1A1 Stationary Combustion, not engines, gaseous fuels	CH_4	Tier 2	CS / D(2)	No
1A1 Stationary Combustion, waste	CH_4	Tier 2	CS	No
1A1 Stationary Combustion, not engines, biomass	CH_4	Tier 3/Tier 2/Tier 1	CS / D(2) / D	No
1A2 Stationary Combustion, solid fuels	CH_4	Tier 1	D	No
1A2 Stationary Combustion, liquid fuels	CH_4	Tier 1/Tier 2	D / D(2) / CS	No
1A2 Stationary Combustion, not engines, gaseous fuels	CH_4	Tier 2	CS / D(2)	No
1A2 Stationary Combustion, waste	CH_4	Tier 1	D	No
1A2 Stationary Combustion, not engines, biomass	CH_4	Tier 2/Tier 1	D(2) / D	No
1A4 Stationary Combustion, solid fuels	CH_4	Tier 1	D	No
1A4 Stationary Combustion, liquid fuels	CH_4	Tier 1/Tier 2	D / D(2)	No
1A4 Stationary Combustion, not engines, gaseous fuels	CH_4	Tier 2	CS	No
1A4 Stationary Combustion, waste	CH_4	Tier 1	D	No
1A4 Stationary Combustion, not engines, not residential wood and not residential/agricultural straw, biomass	CH_4	Tier 1/Tier 2	D / D(2) / CS	No
1A4b_i Stationary combustion, Residential wood combustion	CH_4	Tier 2	CS	Yes
1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion	CH_4	Tier 1	D	No
1A Stationary combustion, Natural gas fuelled engines, gaseous fuels	CH_4	Tier 3	CS	No
1A Stationary combustion, Biogas fuelled engines, biomass	CH_4	Tier 3	CS	No
1A1 Stationary Combustion, solid fuels	N_2O	Tier 2	CS / D(2)	Yes
1A1 Stationary Combustion, liquid fuels	N_2O	Tier 2/Tier 1	D(2) / CS / D	No
1A1 Stationary Combustion, gaseous fuels	N_2O	Tier 3/Tier 2	CS / D(2)	No
1A1 Stationary Combustion, waste	N_2O	Tier 2	CS	Yes
1A1 Stationary Combustion, biomass	N_2O	Tier 2/Tier 1	CS / D(2) / D	Yes
1A2 Stationary Combustion, solid fuels	N_2O	Tier 1/Tier 3	D/PS	No
1A2 Stationary Combustion, liquid fuels	N_2O	Tier 2/Tier 1	D(2) / CS / D	Yes
1A2 Stationary Combustion, gaseous fuels	N_2O	Tier 3/Tier 2	CS / D(2)	Yes
1A2 Stationary Combustion, waste	N_2O	Tier 1	D	No
1A2 Stationary Combustion, biomass	N_2O	Tier 1/Tier 2	D / CS	No
1A4 Stationary Combustion, solid fuels	N_2O	Tier 1	D	No
1A4 Stationary Combustion, liquid fuels	N_2O	Tier 2/Tier 1	D(2) / CS / D	Yes
1A4 Stationary Combustion, gaseous fuels	N_2O	Tier 3/Tier 2	CS / D(2)	No
1A4 Stationary Combustion, waste	N_2O	Tier 1	D	No
1A4 Stationary Combustion, not residential wood and not residential/agricultural straw, biomass	N_2O	Tier 1/Tier 2	D / CS	No
1A4b_i Stationary Combustion, Residential wood combustion	N_2O	Tier 1	D	Yes
1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion	N_2O	Tier 1	D	No

1. D: IPCC (2006) default, tier 1. D(2): IPCC (2006) default, tier 2. CS: Country specific. PS: Plant specific.
2. KCA approach 1 or approach 2 for Denmark (excluding Greenland and Faroe Islands), including LULUCF, level 1990 or level 2021 or trend 1990-2021.
3. Only 2.5 % of the total coal consumption is included in the non-ETS category in 2021.
4. Only 10 % of the total residual oil consumption is included in the non-ETS category in 2021.
5. Tier 3 for less than 1 % of the gas oil consumption in 2021.
6. Tier 3 for less than 1 % of the LPG consumption in 2021.

Key Categories

Key Category Analysis (KCA) approach 1 and approach 2 for the years 1990 and 2021 and for the trend 1990-2021 for Denmark has been carried out in accordance with the IPCC Guidelines (IPCC, 2006). Table 3.2.2 shows the 22 stationary combustion key categories. The table is based on the analysis including LULUCF. Detailed key category analysis is shown in NIR Chapter 1.5 and Annex 1.

The CO_2 emissions from stationary combustion are key categories for all the major fuels. CH_4 from residential wood combustion is a key category for 1990. Due to the relatively high uncertainty for N_2O, emission factors the N_2O emission from several emission sources are key categories in the approach 2 analysis.

Table 3.2.2 Key categories[2], stationary combustion.

		Approach 1			Approach 2		
		1990	2021	1990-2021	1990	2021	1990-2021
1A Stationary combustion, Coal, ETS data, CO_2	CO_2		Level	Trend			
1A Stationary combustion, Coal, no ETS data, CO_2	CO_2	Level		Trend	Level		Trend
1A Stationary combustion, Fossil waste, ETS data, CO_2	CO_2		Level	Trend			Trend
1A Stationary combustion, Fossil waste, no ETS data, CO_2	CO_2	Level	Level	Trend			
1A Stationary combustion, Petroleum coke, ETS data, CO_2	CO_2		Level	Trend			
1A Stationary combustion, Petroleum coke, no ETS data, CO_2	CO_2	Level		Trend			
1A Stationary combustion, Residual oil, ETS data, CO_2	CO_2		Level	Trend			
1A Stationary combustion, Residual oil, no ETS data, CO_2	CO_2	Level		Trend			Trend
1A Stationary combustion, Gas oil, CO_2	CO_2	Level	Level	Trend	Level		Trend
1A Stationary combustion, Kerosene, CO_2	CO_2	Level		Trend			
1A Stationary combustion, LPG, CO_2	CO_2	Level	Level				
1A1b Stationary combustion, Petroleum refining, Refinery gas, CO_2	CO_2	Level	Level	Trend			
1A Stationary combustion, Natural gas, onshore, CO_2	CO_2	Level	Level	Trend			
1A1c_ii Stationary combustion, Oil and gas extraction, Offshore gas turbines, Natural gas, CO_2	CO_2	Level	Level	Trend			
1A4b_i Stationary combustion, Residential wood combustion, CH_4	CH_4				Level		
1A1 Stationary Combustion, Solid fuels, N_2O	N_2O				Level		Trend
1A1 Stationary Combustion, Waste, N_2O	N_2O						Trend
1A1 Stationary Combustion, Biomass, N_2O	N_2O					Level	Trend
1A2 Stationary Combustion, Liquid fuels, N_2O	N_2O				Level		Trend
1A2 Stationary Combustion, Gaseous fuels, N_2O	N_2O					Level	Trend
1A4 Stationary Combustion, Liquid fuels, N_2O	N_2O						Trend
1A4b_i Stationary Combustion, Residential wood combustion, N_2O	N_2O					Level	Trend

3.2.2 Fuel consumption data

In 2021, the total fuel consumption for stationary combustion plants was 389 PJ of which 189 PJ was fossil fuels and 201 PJ was biomass. Fuel consumption distributed according to the stationary combustion subcategories is shown in Figure 3.2.1 and Figure 3.2.2. The fuel consumption in Public electricity and heat production adds up to 55 % of the fuel consumption in stationary combustion plants. Other source categories with high fuel consumption are Residential and Industry.

[2] For Denmark, not including Greenland & Faroe Island. Based on the KCA including LULUCF.

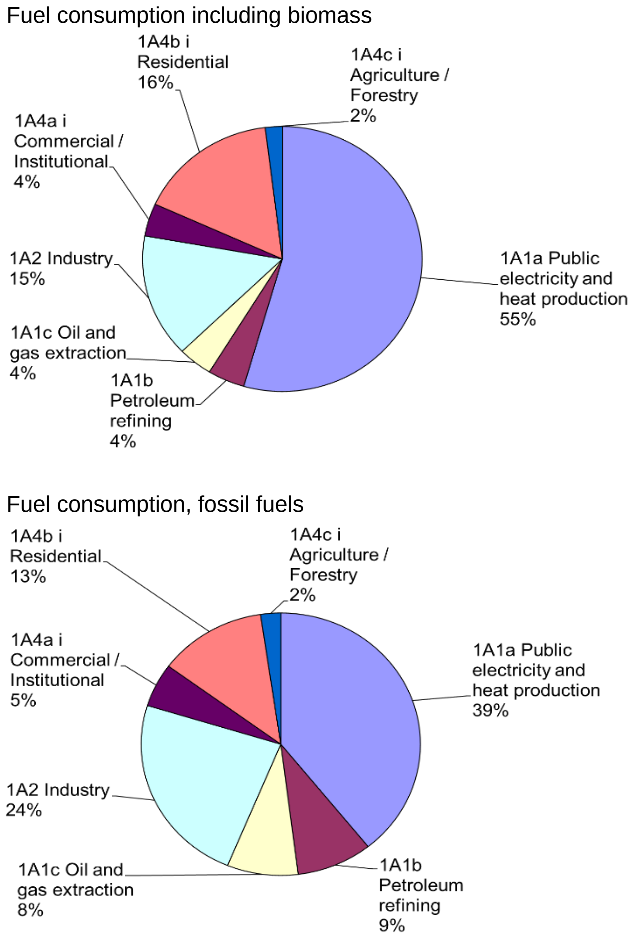
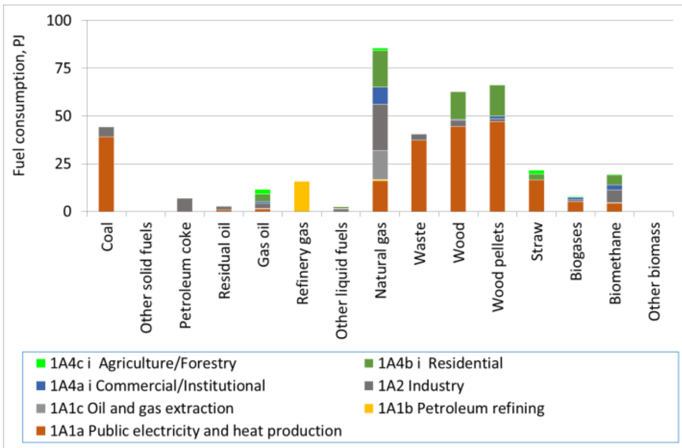


Figure 3.2.1 Fuel consumption of stationary combustion source categories, 2021. Based on DEA (2022a).

Natural gas, wood pellets, wood, coal, and waste are the most utilised fuels for stationary combustion plants. Natural gas is used in all plant (see Figure 3.2.2). Wood and wood pellets are mainly applied for public electricity and heat production and in residential plants. Coal is mainly used in power plants.

Detailed fuel consumption rates are shown in Annex 3A-2.



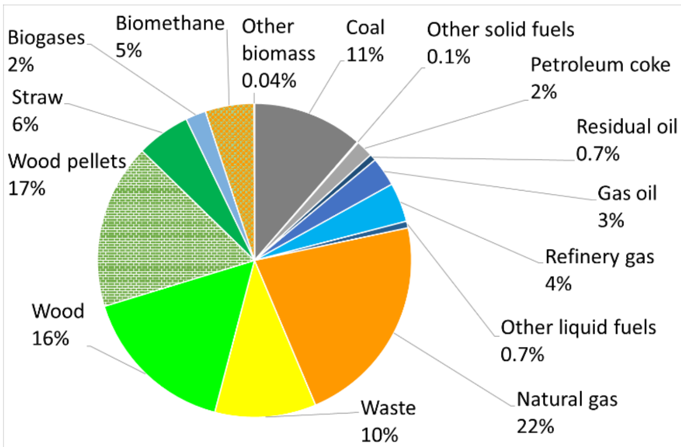


Figure 3.2.2 Fuel consumption of stationary combustion 2021, disaggregated to fuel type. Based on DEA (2022a).

Time series for fuel consumption for stationary combustion plants are presented in Figure 3.2.3. The fuel consumption for stationary combustion was 24 % lower in 2021 than in 1990, while the fossil fuel consumption was 60 % lower and the biomass fuel consumption 4.9 times the level in 1990.

The consumption of waste and biomass has increased since 1990 whereas the consumption of coal and oil has decreased.

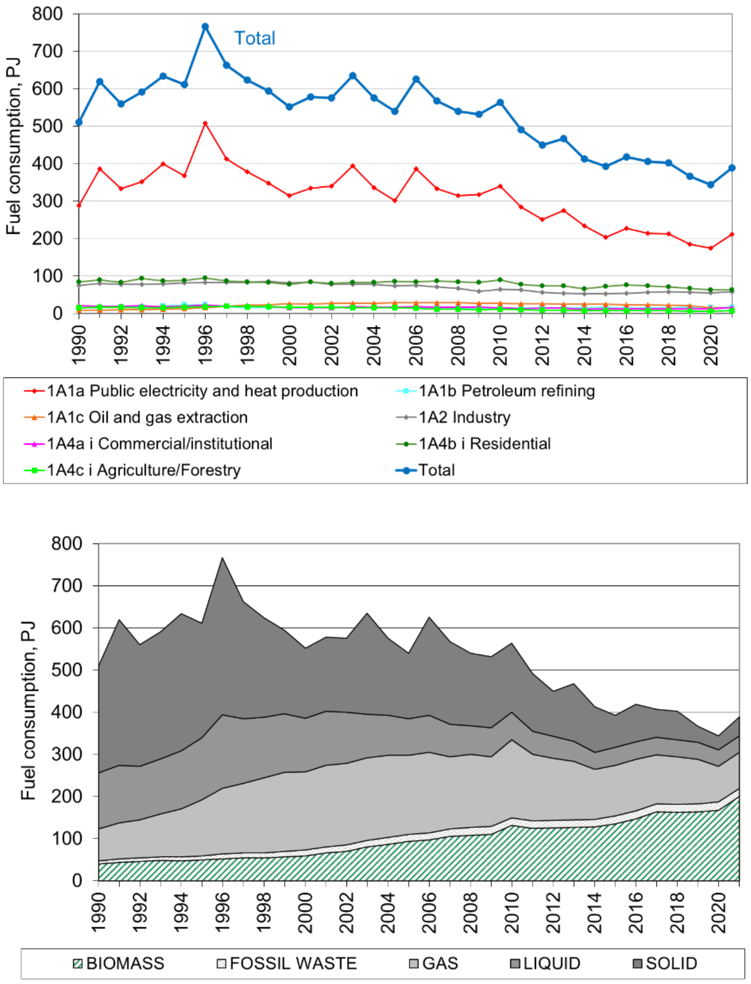


Figure 3.2.3 Fuel consumption time series, stationary combustion. Based on DEA (2022a).

The fluctuations in the time series for fuel consumption are mainly a result of electricity import/export, but also of outdoor temperature variations from year to year. This, in turn, leads to fluctuations in emission levels. The fluctuations in electricity trade, fuel consumption, CO_2 and NO_x emission are illustrated and compared in Figure 3.2.4. In 1990, the Danish net electricity import was large causing relatively low fuel consumption, whereas the fuel consumption was high in 1996, 2003 and 2006 due to a large net electricity export. In 2021, the net electricity import was 18 PJ, whereas there was a 25 PJ net electricity import in 2020. The large net electricity export that occurs some years is a result of low rainfall in Norway and Sweden causing insufficient hydropower production in both countries.

The Danish electricity production is highly dependent on the electricity trade with especially Sweden and Norway. Denmark has a number of central coal-fuelled power plants that consists of a number of blocks. These do not under normal conditions, operate at max load, i.e., there is free capacity for peak situations. In addition, there are blocks, which are mothballed but can be reopened in situations where there is a significant increase in the electricity demand. Three Danish plants will stay in operation longer than planned or taken out of mothball status due to the energy crisis[3].

To be able to follow the national energy consumption, the Danish Energy Agency (DEA) produces a correction of the observed fuel consumption and CO_2 emission without random variations in electricity import/export and in ambient temperature. This fuel consumption trend is also illustrated in Figure 3.2.4. The estimates are based on DEA (2016) and updated data (DEA, 2022d). The corrections are included here to explain the fluctuations in the time series for fuel rates and emissions.

[3] Fall 2022, not relevant for emissions in 2021

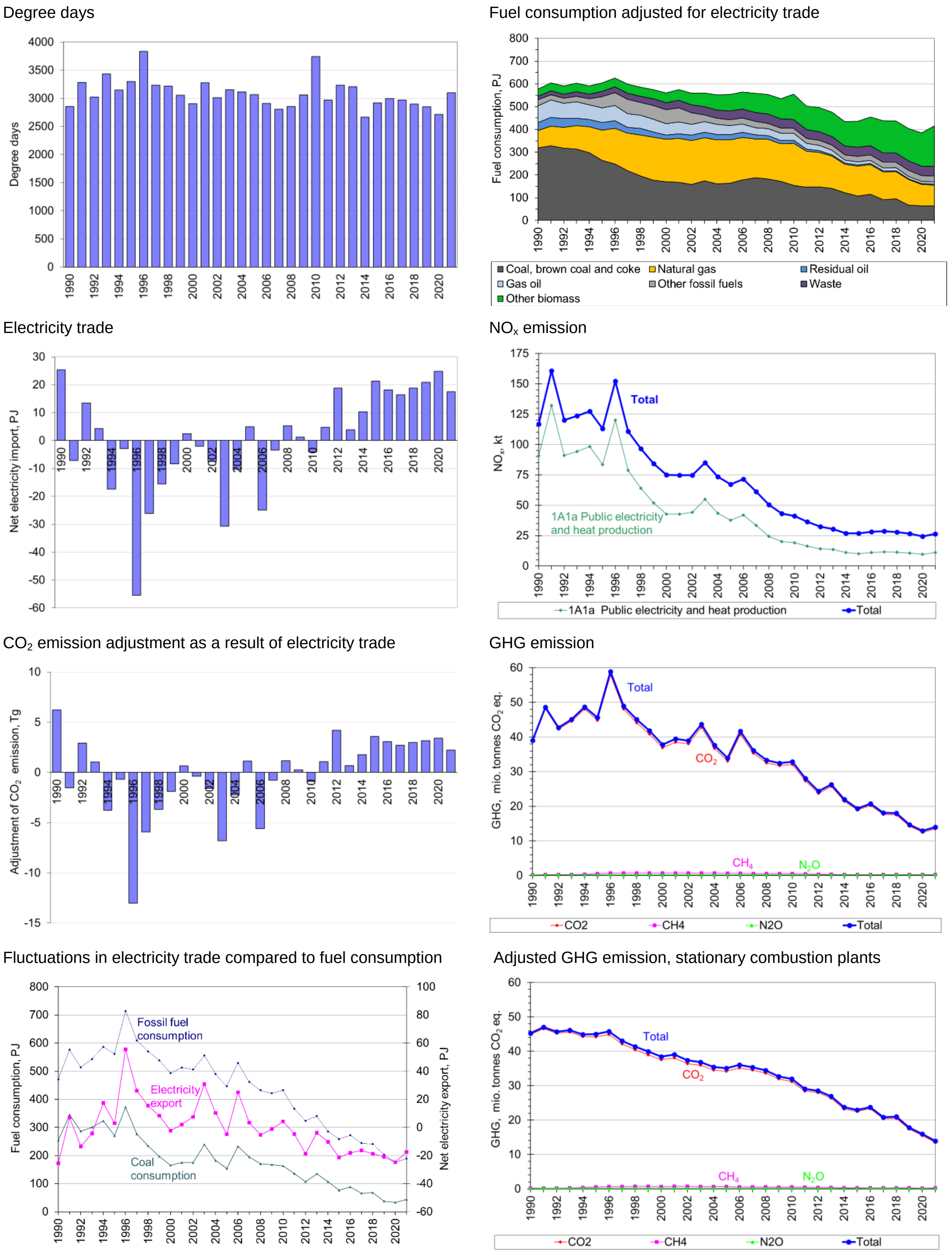


Figure 3.2.4 Comparison of time series fluctuations for net electricity import, fuel consumption, CO_2 emission and NO_x emission. Based on DEA (2022a).

Time series for fuel consumption for the subcategories to stationary combustion are shown in Figure 3.2.5, 3.2.6 and 3.2.7.

Fuel consumption for Energy industries fluctuates due to electricity trade as discussed above. The fuel consumption in 2021 was 22 % lower than in 1990 and the fossil fuel consumption was 64 % lower. The fluctuation in electricity production is based on fossil fuel consumption in the subcategory Public electricity and heat production. The energy consumption in Oil and gas extraction is mainly natural gas used in gas turbines in the offshore industry. The biomass fuel consumption in Energy industries in 2021 added up to 138 PJ, which is 8.5 times the level in 1990 and 24 % higher than in 2020.

The fuel consumption in Industry was 22 % lower in 2021 than in 1990 (Figure 3.2.6) and the fossil fuel consumption was 36 % lower. The fuel consumption in industrial plants decreased considerably after 2006 as a result of the financial crisis. The biomass fuel consumption in Industry in 2021 added up to 14 PJ, which is 2.4 times the consumption in 1990.

The fuel consumption in Other Sectors decreased 29 % since 1990 (Figure 3.2.7) and increased 5 % since 2020. The fossil fuel consumption decreased 63 % since 1990. The biomass fuel consumption in Other sectors in 2021 added up to 48 PJ, which is 2.6 times the consumption in 1990. The consumption of wood and wood pellets in residential plants in 2021 was 3.6 times the consumption in 1990.

Time series for subcategories are shown in Chapter 3.2.4.

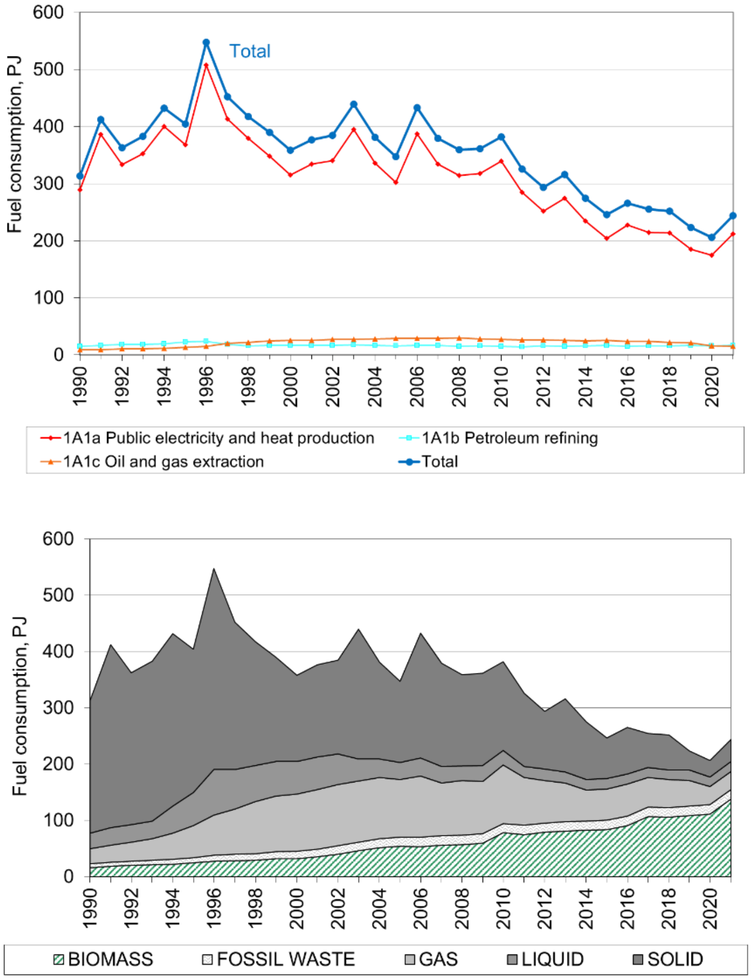


Figure 3.2.5 Fuel consumption time series for subcategories - 1A1 Energy Industries.

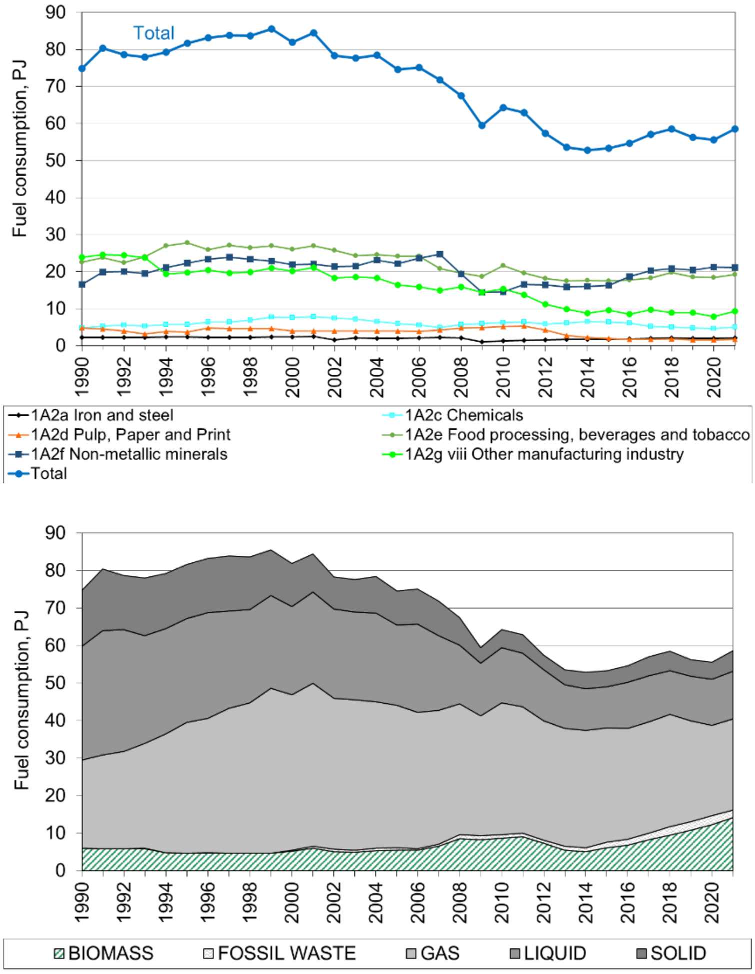


Figure 3.2.6 Fuel consumption time series for subcategories - 1A2 Industry.

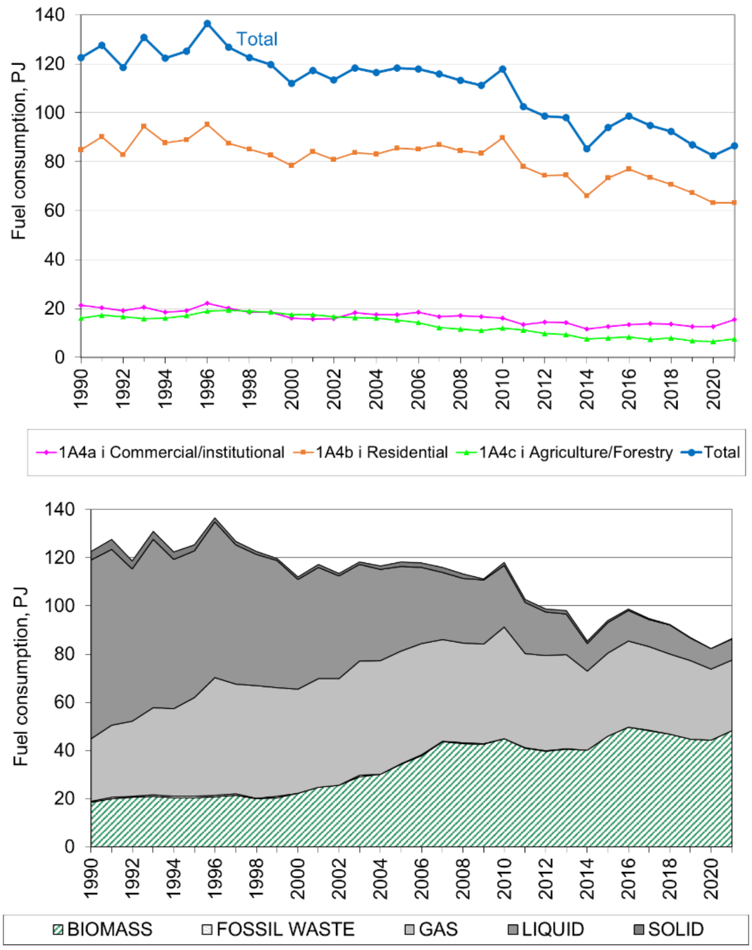


Figure 3.2.7 Fuel consumption time series for subcategories - 1A4 Other Sources.

3.2.3 Emissions

Greenhouse gas emission

The greenhouse gas emissions from stationary combustion are listed in Table 3.2.3. The emission from stationary combustion accounted for 30.3 % of the national greenhouse gas emission (including LULUCF) in 2021.

The CO_2 emission from stationary combustion plants accounts for 43 % of the national CO_2 emission (including LULUCF). The CH_4 emission accounts for 3.2 % of the national CH_4 emission and the N_2O emission for 3.4 % of the national N_2O emission.

Table 3.2.3 Greenhouse gas emission, 2021 [1)].

	CO_2	CH_4	N_2O
	kt CO_2 equivalent		
1A1 Fuel combustion, Energy industries	8109	131	75
1A2 Fuel combustion, Manufacturing industries and construction[1)]	3106	22	48
1A4 Fuel combustion, Other sectors [1)]	2272	131	52
Emission from stationary combustion plants	13487	284	175
Emission share for stationary combustion (LULUCF included)	42.5%	3.2%	3.4%

[1)] Only stationary combustion sources of the category are included.

CO_2 is the most important greenhouse gas for stationary combustion accounting for 96.7 % of the greenhouse gas emission (CO_2 equivalents) from stationary combustion. CH_4 accounts for 2.0 % and N_2O for 1.3 % of the greenhouse gas emission (CO_2 equivalents) from stationary combustion (Figure 3.2.8).

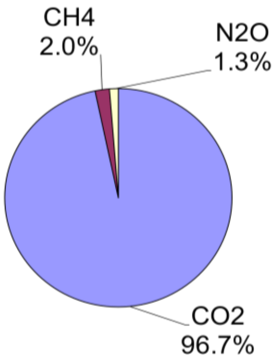
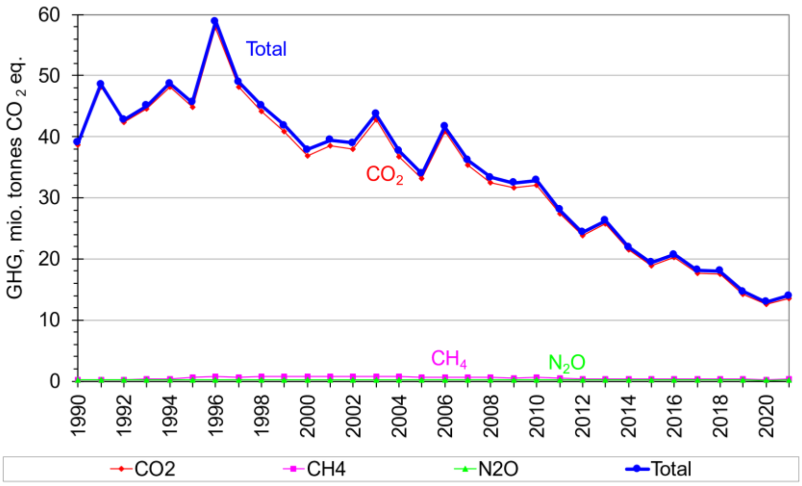


Figure 3.2.8 Greenhouse gas emission from stationary combustion (CO_2 equivalents), contribution from each pollutant.

Figure 3.2.9 shows the time series of greenhouse gas emissions (CO_2 equivalents) from stationary combustion. The development of the greenhouse gas emission follows the CO_2 emission development very closely. Both the CO_2 and the total greenhouse gas emission are lower in 2021 than in 1990, CO_2 is 65.1 % lower and greenhouse gas emissions are 64.3 % lower. However, fluctuations in the GHG emission level are large.



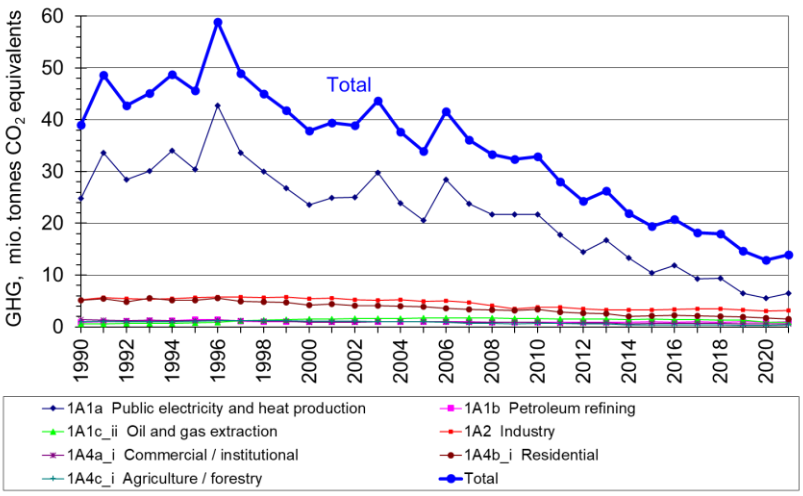


Figure 3.2.9 GHG emission time series for stationary combustion.

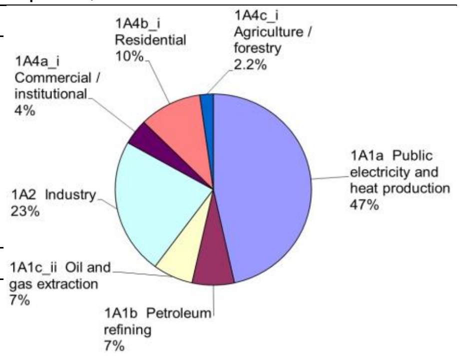
The fluctuations in the time series are largely a result of electricity import/export, but also of outdoor temperature variations from year to year. The fluctuations follow the fluctuations in fuel consumption discussed in Chapter 3.2.2. As mentioned in Chapter 3.2.2, the Danish Energy Agency estimates a correction of the observed CO_2 emission without random variations in electricity imports/exports and in ambient temperature. The greenhouse gas emission corrected for electricity import/export and ambient temperature has decreased by 69.2 % since 1990, and the CO_2 emission by 69.9 %. These data are included here to explain the fluctuations in the emission time series.

CO_2

The carbon dioxide (CO_2) emission from stationary combustion plants is one of the most important sources of greenhouse gas emissions. Thus, the CO_2 emission from stationary combustion plants accounts for 42.5% of the national CO_2 emission (LULUCF included). Table 3.2.4 lists the CO_2 emission inventory for stationary combustion plants for 2021. Public electricity and heat production accounts for 47 % of the CO_2 emission from stationary combustion. Other large CO_2 emission sources are Industry[4] and Residential plants. These are the source categories, which also account for a considerable share of fuel consumption.

Table 3.2.4 CO_2 emission from stationary combustion plants, 2021[1)].

	CO_2 kt
1A1a Public electricity and heat production	6277
1A1b Petroleum refining	938
1A1c Oil and gas extraction	894
1A2 Industry	3106
1A4a Commercial/Institutional	581
1A4b Residential	1392
1A4c Agriculture/Forestry	299
Total	13487

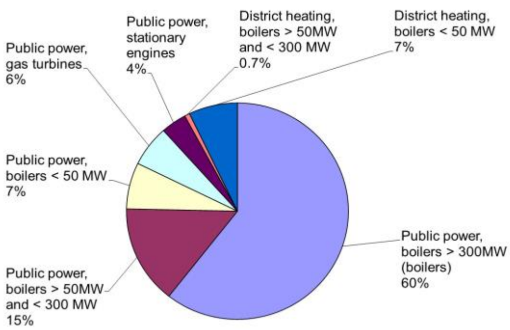


1) Only emissions from stationary combustion plants in the categories are included.

In the Danish inventory, the source category Public electricity and heat production is further disaggregated. The CO_2 emission from each of the subcategories is shown in Table 3.2.5. The largest subcategory is power plant boilers >300MW.

Table 3.2.5 CO_2 emission from subcategories to 1A1a Public electricity and heat production.

SNAP name	$CO_{2,}$ kt
Public power	
Combustion plants ≥ 300MW (boilers)	3804
Combustion plants ≥ 50MW and < 300 MW (boilers)	925
Combustion plants <50 MW (boilers)	435
Gas turbines	384
Stationary engines	236
District heating plants	
Combustion plants ≥ 50MW and < 300 MW (boilers)	47
Combustion plants <50 MW (boilers)	447



[4] Includes only stationary combustion, whereas CO_2 from industrial processes e.g. calcination in cement production is included elsewhere.

CO_2 emission from combustion of biomass fuels is not included in the total CO_2 emission data, because biomass fuels are considered CO_2 neutral. The CO_2 emission from biomass combustion is reported as a memo item in the Climate Convention reporting. In 2021, the CO_2 emission from biomass combustion from stationary combustion was 19 298 kt.

In Figure 3.2.10, the fuel consumption share (fossil fuels) is compared to the CO_2 emission share disaggregated to fuel origin. Due to the higher CO_2 emission factor for coal than oil and gas, the CO_2 emission share from coal combustion is higher than the fuel consumption share.

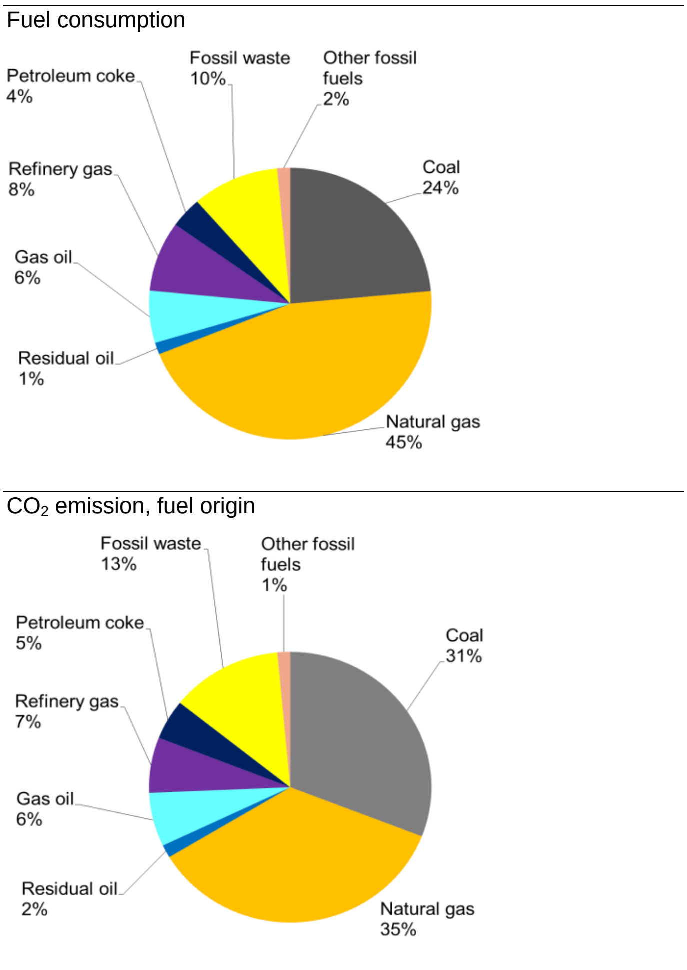


Figure 3.2.10 CO_2 emission, fuel origin.

The time series for CO_2 emission is provided in Figure 3.2.11. Despite a decrease in fuel consumption of 24 %[5] since 1990, the CO_2 emission from stationary combustion has decreased by 65 % due to the change of fuel type used.

The fluctuations in total CO_2 emission follow the fluctuations in CO_2 emission from Public electricity and heat production (Figure 3.2.11) and in coal consumption (Figure 3.2.4). The fluctuations are a result of electricity import/export as discussed in Chapter 3.2.2.

[5] The consumption of fossil fuels has decreased 60 %.

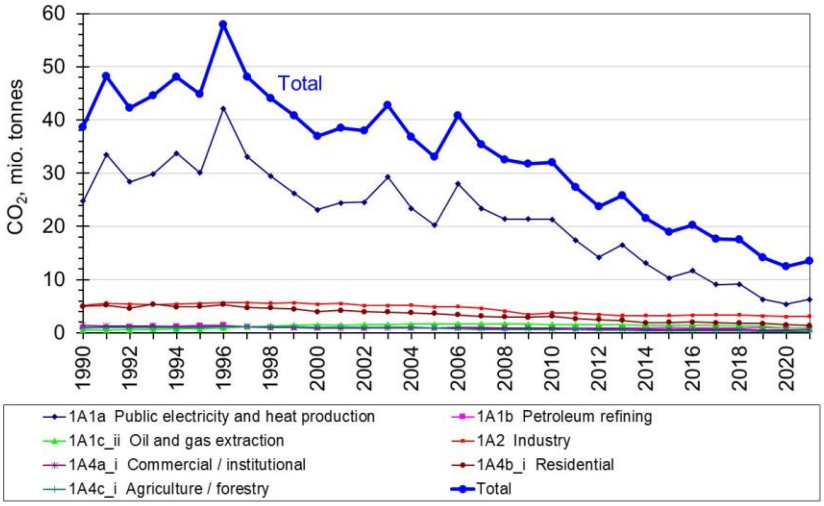


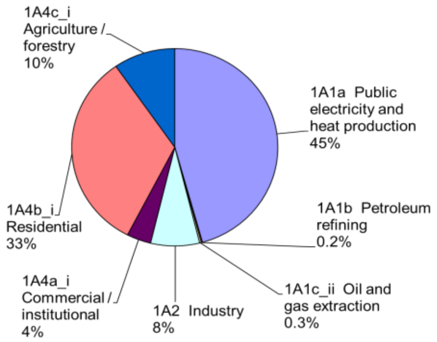
Figure 3.2.11 CO_2 emission time series for stationary combustion plants.

CH_4

The methane (CH_4) emission from stationary combustion plants accounts for 3.2 % of the national CH_4 emission. Table 3.2.6 lists the CH_4 emission inventory for stationary combustion plants in 2021. Public electricity and heat production accounts for 45 % of the CH_4 emission from stationary combustion. The emission from residential plants adds up to 33 % of the emission.

Table 3.2.6 CH_4 emission from stationary combustion plants, 2021[1)].

	CH_4, tonnes
1A1a Public electricity and heat production	4626
1A1b Petroleum refining	18
1A1c Oil and gas extraction	26
1A2 Industry	777
1A4a Commercial/Institutional	386
1A4b Residential	3315
1A4c Agriculture/Forestry	981
Total	10129



1) Only emission from stationary combustion plants in the source categories is included.

The CH_4 emission factor for reciprocating gas engines is much higher than for other combustion plants due to the continuous ignition/burn-out of the gas. Lean-burn gas engines have an especially high emission factor. A considerable number of lean-burn gas engines are in operation in Denmark and in 2021, these plants accounted for 52 % of the CH_4 emission from stationary combustion plants (Figure 3.2.12). Most engines are installed in CHP plants and the fuel used is either natural gas or biogas. Residential wood combustion is also a large emission source accounting for 14 % of the emission in 2021. Other large emission sources are residential gas boilers and straw combustion in residential/agricultural boilers.

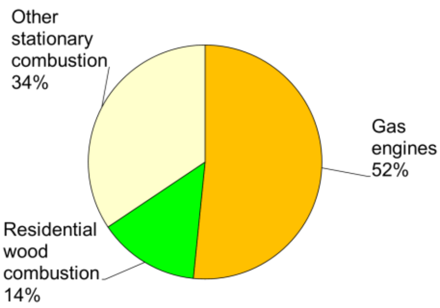


Figure 3.2.12 CH_4 emission share for gas engines and residential wood combustion, 2021.

Figure 3.2.13 shows the time series for CH_4 emission. The CH_4 emission from stationary combustion was 35 % higher in 2021 than in 1990. The emission increased until 1996 and decreased after 2004. This time series is related to the considerable number of lean-burn gas engines installed in CHP plants in Denmark during the 1990s. Figure 3.2.14 provides time series for the fuel consumption rate in gas engines and the corresponding increase of CH_4 emission. The decline in later years is due to structural changes in the Danish electricity market, which means that the fuel consumption in gas engines has been decreasing.

The CH_4 emission from residential plants was 38 % lower in 2021 than in 1990. For residential plants, the main emission source is combustion of biomass. The consumption of wood in residential plants has increased, whereas the emission factor for residential wood combustion has decreased due to implementation of new improved stoves and boilers. Combustion of wood (including wood pellets) accounted for 43 % of the CH_4 emission from residential plants in 2021.

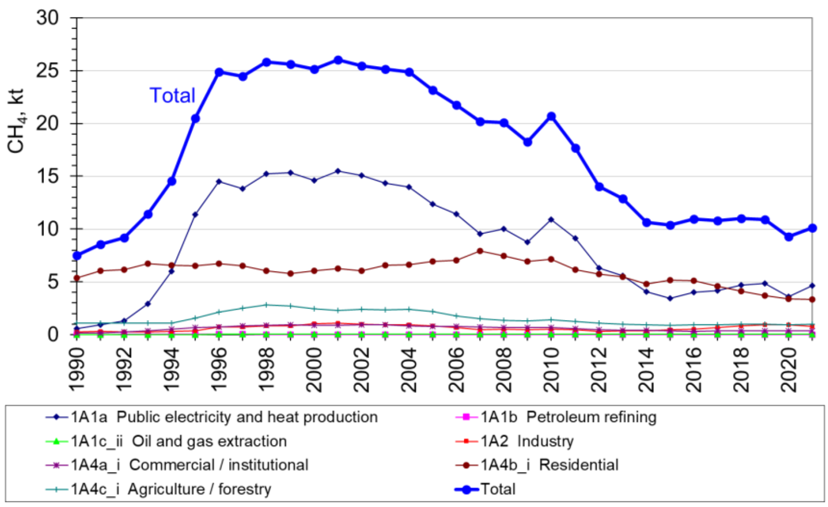


Figure 3.2.13 CH_4 emission time series for stationary combustion plants.

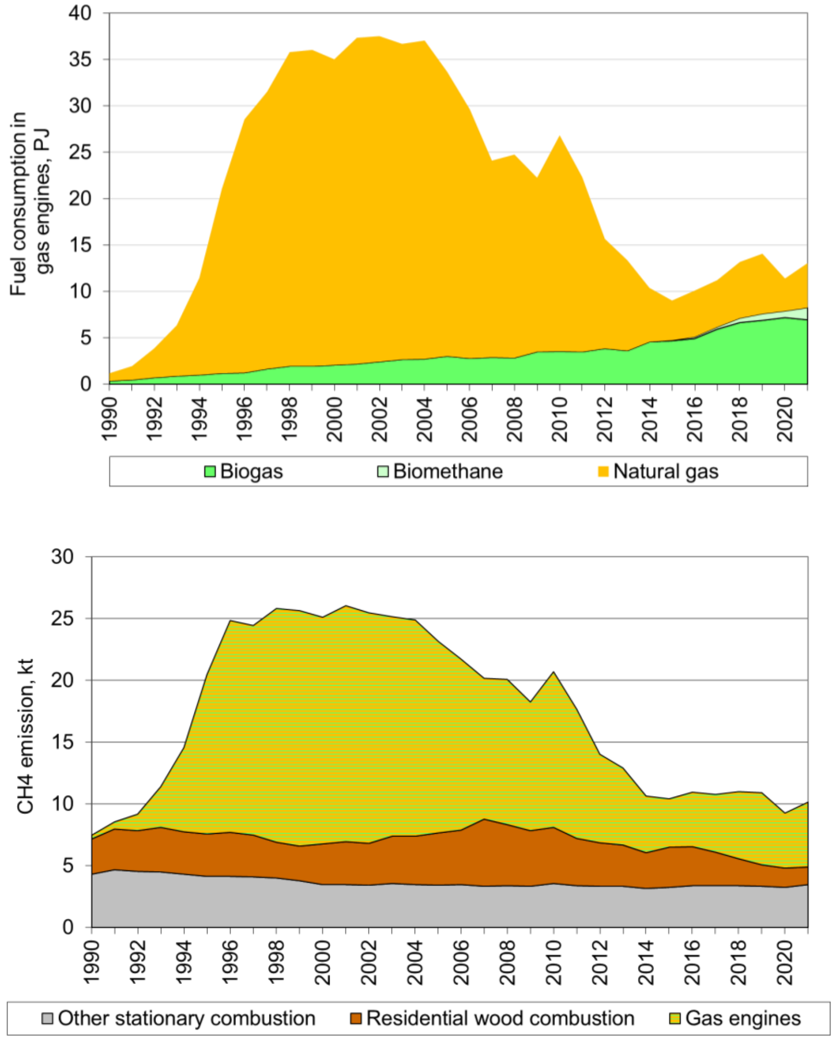


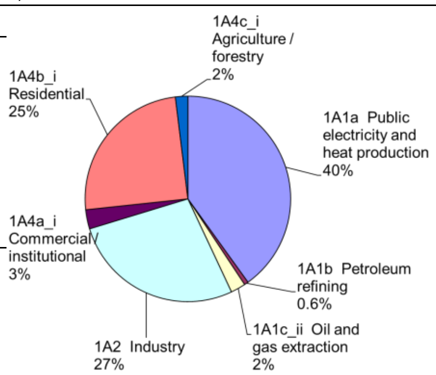
Figure 3.2.14 Time series for a) fuel consumption in gas engines and b) CH_4 emission from gas engines, residential wood combustion and other plants.

N_2O

The nitrous oxide (N_2O) emission from stationary combustion plants accounts for 3.4 % of the national N_2O emission. Table 3.2.7 lists the N_2O emission inventory for stationary combustion plants in the year 2021. Public electricity and heat production accounts for 40 % of the N_2O emission from stationary combustion.

Table 3.2.7 N_2O emission from stationary combustion plants, 2021[1)].

	N_2O, tonnes
1A1a Public electricity and heat production	265
1A1b Petroleum refining	4
1A1c Oil and gas extraction	15
1A2 Industry	180
1A4a Commercial/Institutional	20
1A4b Residential	164
1A4c Agriculture/Forestry	13
Total	661



1) Only emission from stationary combustion plants in the source categories is included.

Figure 3.2.15 shows the time series for N_2O emission. The N_2O emission from stationary combustion was 7 % higher in 2021 than in 1990, but again fluctuations in emission level due to electricity import/export are considerable.

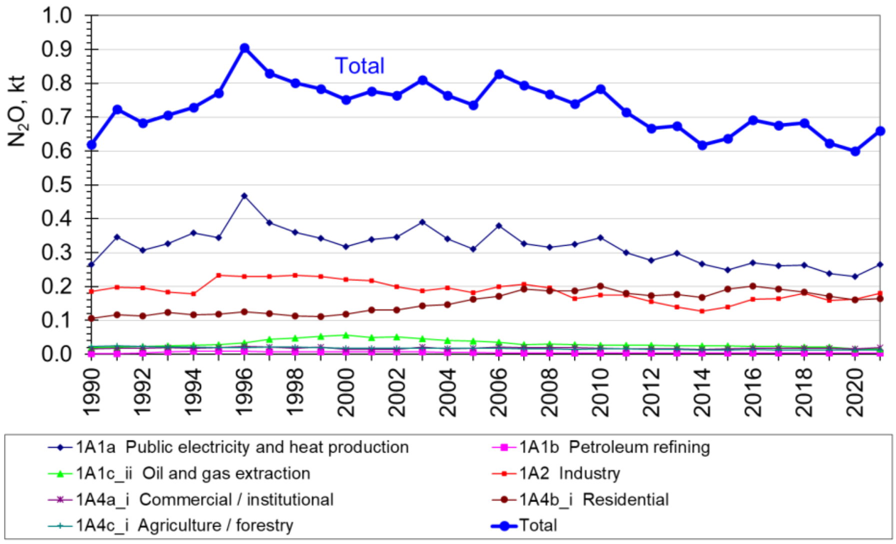


Figure 3.2.15 N_2O emission time series for stationary combustion plants.

SO_2, NO_x, NMVOC and CO

The emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x), non-volatile organic compounds (NMVOC) and carbon monoxide (CO) from Danish stationary combustion plants are included in the Danish IIR (Nielsen et al., 2023). Please refer to the Danish IIR for data presentation and references for SO_2, NO_x, NMVOC and CO.

3.2.4 Trend for subsectors

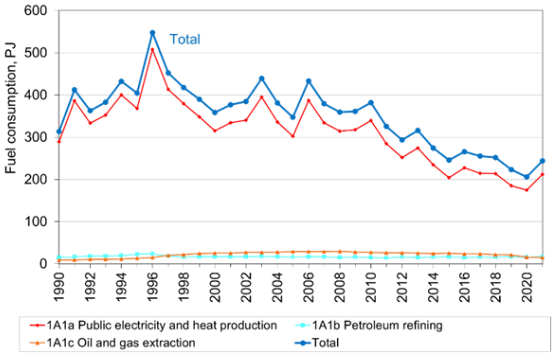
In addition to the data for stationary combustion, this chapter presents and discusses data for each of the subcategories in which stationary combustion is included. Time series are presented for fuel consumption and emissions.

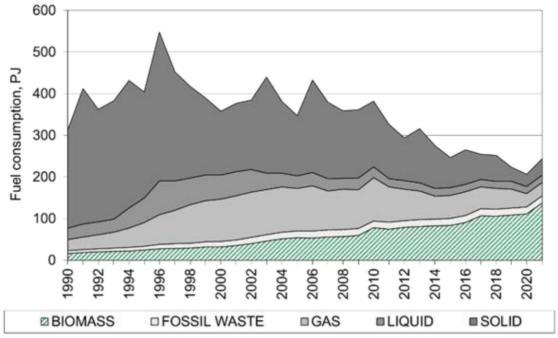
1A1 Energy industries

The emission source category 1A1 Energy Industries consists of the subcategories:

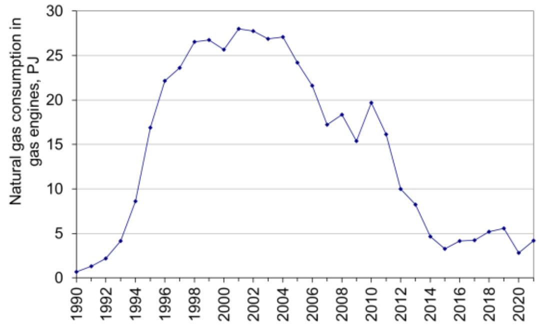
- 1A1a Public electricity and heat production
- 1A1b Petroleum refining
- 1A1c Oil and gas extraction

Figure 3.2.16 – 3.2.17 present time series for the Energy Industries. Public electricity and heat production is the largest subcategory accounting for the main part of all emissions. Time series are discussed below for each subcategory.

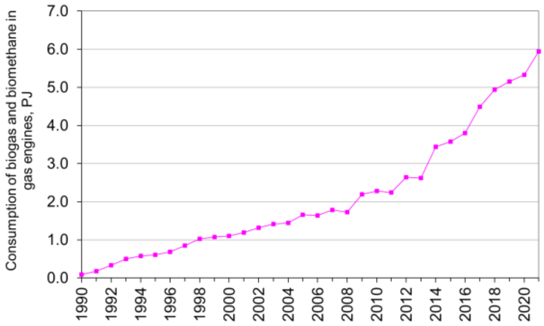




Natural gas fuelled engines



Biogas fuelled engines (biogas, bio gasification gas and biomethane)



Residual oil in petroleum refining

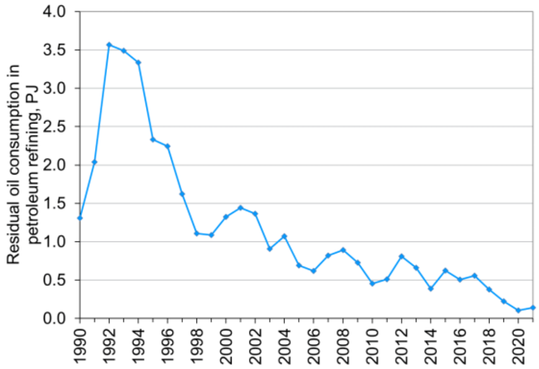


Figure 3.2.16 Time series for fuel consumption, 1A1 Energy industries.

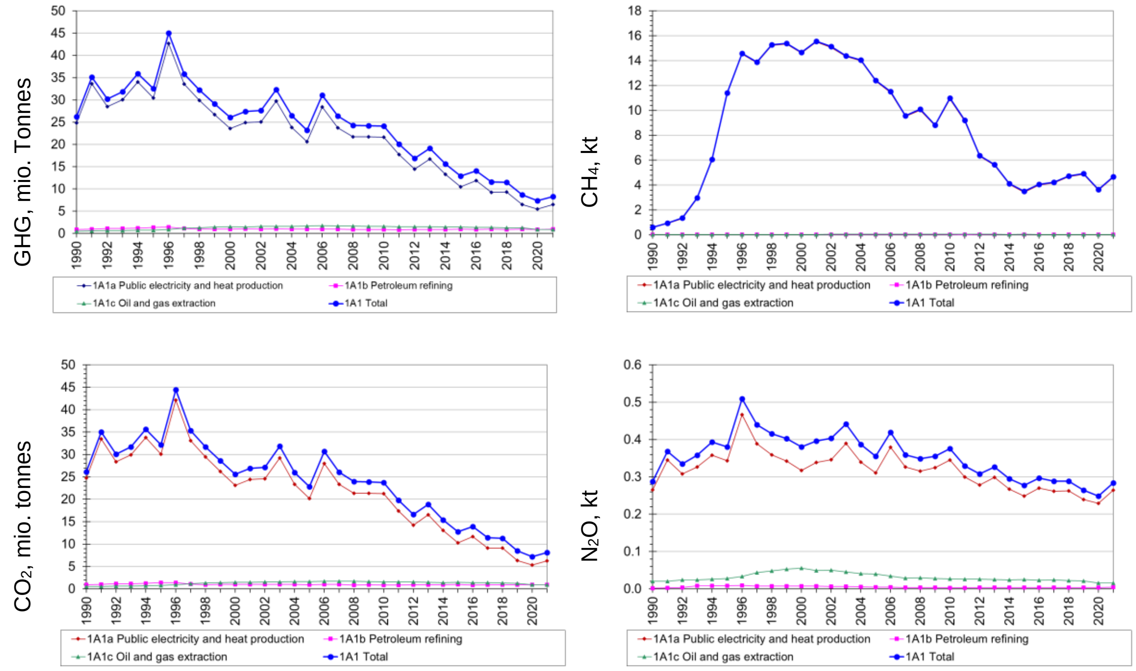


Figure 3.2.17 Time series for greenhouse gas emissions, 1A1 Energy industries.

1A1a Public electricity and heat production

Public electricity and heat production is the largest source category regarding both fuel consumption and greenhouse gas emissions for stationary combustion. Figure 3.2.18 shows the time series for fuel consumption and emissions.

The fuel consumption in public electricity and heat production was 27 % lower in 2021 than in 1990. In addition to fuel type changes, the total fuel consumption is also influenced by the fact that the Danish wind power production has increased. The increase of fuel consumption from 2020 to 2021 is related to a lower import of electricity in 2021 and lower temperatures in 2021 (a higher number of degree days).

As discussed in Chapter 3.2.2 the fuel consumption fluctuates mainly because of electricity trade. Coal is the fuel that is affected the most by the fluctuating electricity trade.

Coal was the main fuel in the source category in the 1990s, but the consumption has been decreasing in later years. The coal consumption in 2021 was only 17 % of the 1990 consumption in this sector. Natural gas is also an important fuel and the consumption of natural gas increased in 1990-2000 but has decreased since 2010. A considerable part of the natural gas is combusted in gas engines (Figure 3.2.17). The consumption of waste, biogas and biomass has increased.

The CO_2 emission was 75 % lower in 2021 than in 1990. This decrease – in spite of only a 27 % decrease in fuel consumption - is a result of the change of fuel types used.

The CH_4 emission has increase until the mid-nineties as a result of the considerable number of lean-burn gas engines installed in CHP plants in Denmark in this period. The decline after 2004 is due to structural changes in the Danish electricity market, which means that the fuel consumption in gas engines has been decreasing (Figure 3.2.17). The emission in 2021 was 7.9 times the 1990 emission level.

The N_2O emission in 2021 was the same as in 1990. The emission fluctuates similar to the fuel consumption.

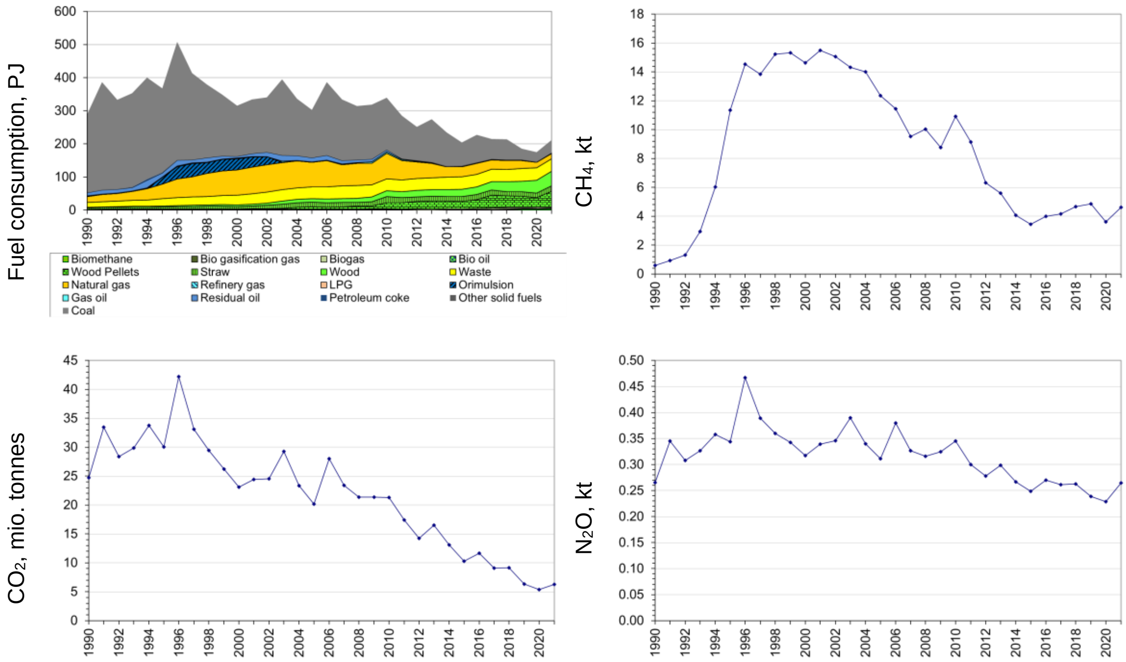


Figure 3.2.18 Time series for 1A1a Public electricity and heat production.

1A1b Petroleum refining

Petroleum refining is a small source category regarding both fuel consumption and emissions for stationary combustion. There are presently two refineries operating in Denmark. Figure 3.2.19 shows the time series for fuel consumption and emissions.

The significant decrease in both fuel consumption and emissions in 1996 is a result of the closure of a third refinery.

The fuel consumption has increased 9 % since 1990 and the CO_2 emission has increased 3 %.

The CH_4 emission has increased 3 % since 1990. The reduction in CH_4 emission from 1995 to 1996 is caused by the closure of a refinery.

The N_2O emission was 94 % higher in 2021 than in 1990. The emission increased in 1993 as a result of the installation of a gas turbine in one of the refineries (DEA, 2021b).

The N_2O emission factor for the refinery gas fuelled gas turbine has been assumed equal to the emission factor for natural gas fuelled turbines. This emission factor decreases in the years 2000-2007. This cause the decrease of the N_2O emission in 2000-2007.

Emissions from refineries are further discussed in Chapter 3.5 and in Plejdrup et al. (2021).

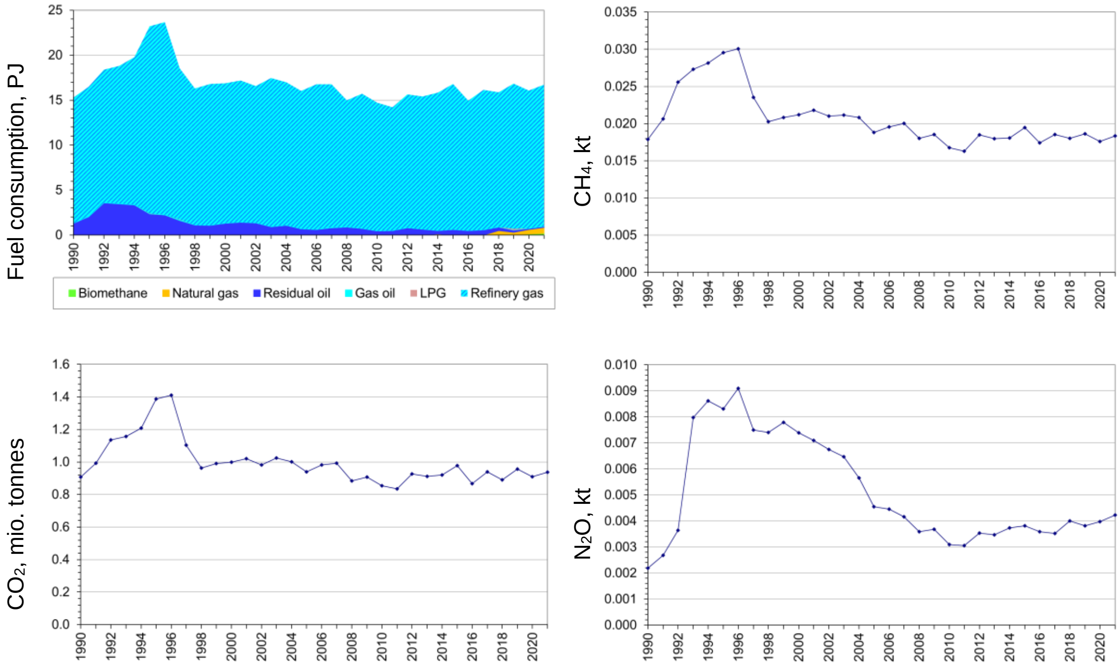


Figure 3.2.19 Time series for 1A1b Petroleum refining.

1A1c Oil and gas extraction

The source category Oil and gas extraction comprises natural gas consumption in the offshore industry. Gas turbines are the main plant type. In addition, a small consumption of gas oil in offshore plants and the fuel consumption in the Danish gas treatment plant[6] are included in this subsector. Fugitive emissions from fuels are not included in the sector. Venting and flaring are included in the sector 1B2c Venting and Flaring.

Figure 3.2.20 shows the time series for fuel consumption and emissions.

The fuel consumption in 2021 was 69 % higher than in 1990. The fuel consumption has decreased since 2008. The large decrease between 2019 and 2020 is related to renovation of the largest gas field, Tyra. The CO_2 emission follows the fuel consumption and the emission in 2021 was 69 % higher than in 1990.

The time series for N_2O emission follows the decreasing emission factor for gas turbines applied in CHP plants.

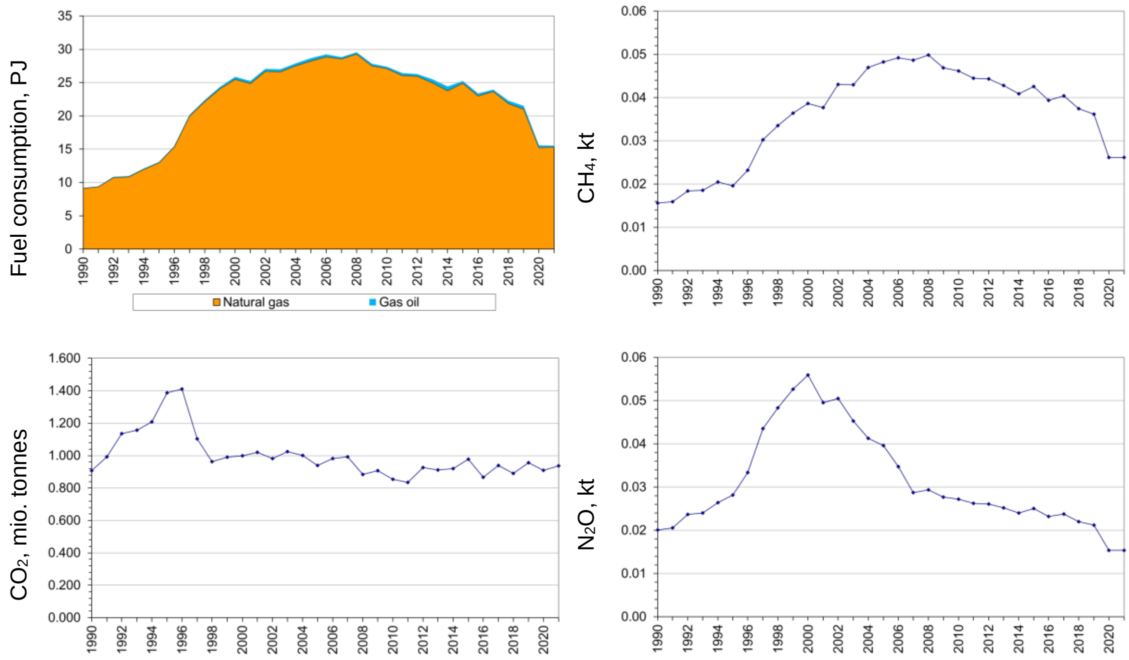


Figure 3.2.20 Time series for 1A1c Oil and gas extraction.

[6] Nybro.

1A2 Industry

Manufacturing industries and construction (Industry) consists of both stationary and mobile sources. In this chapter, only stationary sources are included. Emissions from industrial processes e.g. calcination are not included in the sector stationary combustion.

The emission source category 1A2 Industry consists of the subcategories:

- 1A2a Iron and steel
- 1A2b Non-ferrous metals
- 1A2c Chemicals
- 1A2d Pulp, Paper and Print
- 1A2e Food processing, beverages and tobacco
- 1A2f Non-metallic minerals
- 1A2 g viii Other manufacturing industry

The figures 3.2.21-3.2.22 show the time series for fuel consumption and emissions. The subsectors Non-metallic minerals, Other manufacturing industry and Food processing, beverages and tobacco are the main subsectors for fuel consumption and emissions.

The total fuel consumption in industrial combustion was 22 % lower in 2021 than in 1990. The consumption of fossil fuels was 36 % lower. The consumption of coal and liquid fossil fuels have decreased since 1990. The biomass consumption in 2021 was 2.4 times the consumption in 1990.

The greenhouse gas emission and the CO_2 emission are both rather stable until 2006 following the small fluctuations in fuel consumption. The emission decreased in 2006-2009. Due to change of applied fuels, the greenhouse gas and CO_2 emissions have decreased more than the fuel consumption since 1990; The GHG emission has decreased 39 % since 1990 and the CO_2 emission has decreased 40 %.

The CH_4 emission has increased from 1994-2001, decreased from 2001 – 2007 and increased again from 2013-2019. In 2021, the emission was 2.8 times the emission level in 1990. The CH_4 emission follows the consumption of natural gas and biogas in gas engines (Figure 3.2.21). Most industrial CHP plants based on gas engines came in operation in the years 1995 to 1999. The decrease after 2004 is a result of the liberalisation of the electricity market. The increased emission after 2013 is related to new biogas fuelled gas engines in the food industry.

The N_2O emission has decreased 3 % since 1990. The emission from mineral wool production[7] is a large emission source, and the production of mineral wool production has increased in recent years (see Chapter 4.2.9). This causes the increase of the N_2O emission in 2014-2018.

The increase of N_2O emission from 1994 to 1995 is related to combustion of coke oven coke in mineral wool production. Plant specific fuel consumption data are only available from 1995 onwards for the mineral wool production plants.

[7] Included in sector 1A2f Non-metallic minerals.

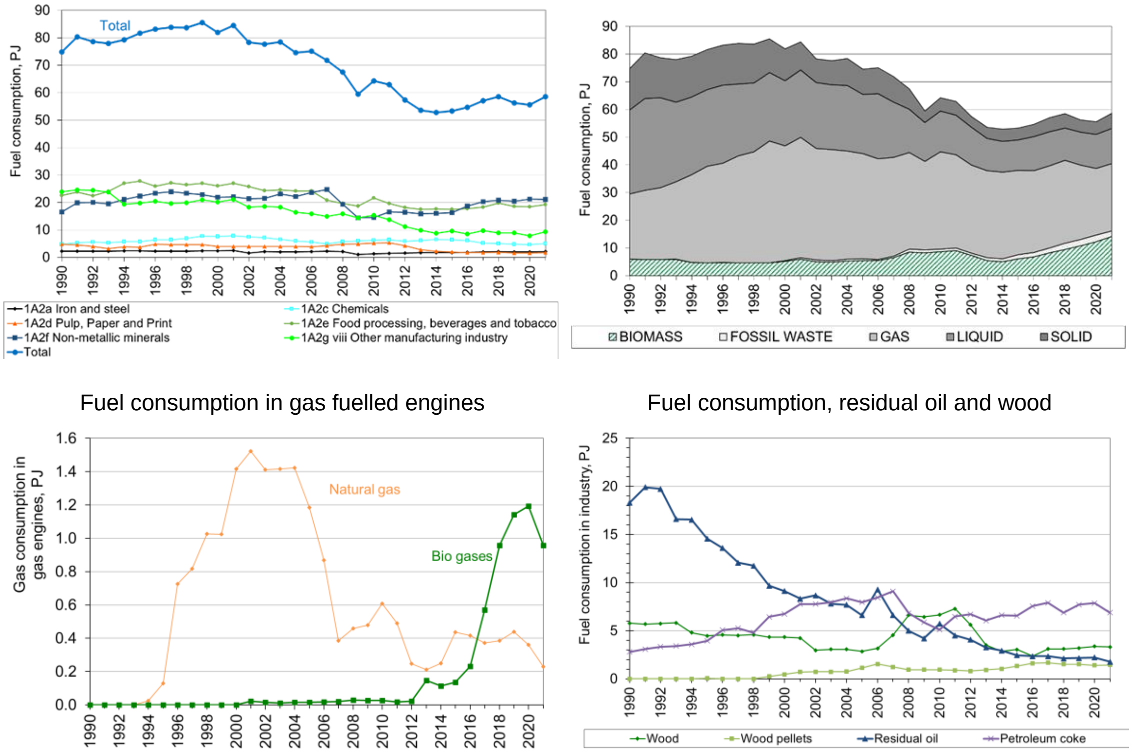


Figure 3.2.21 Time series for fuel consumption, 1A2 Industry.

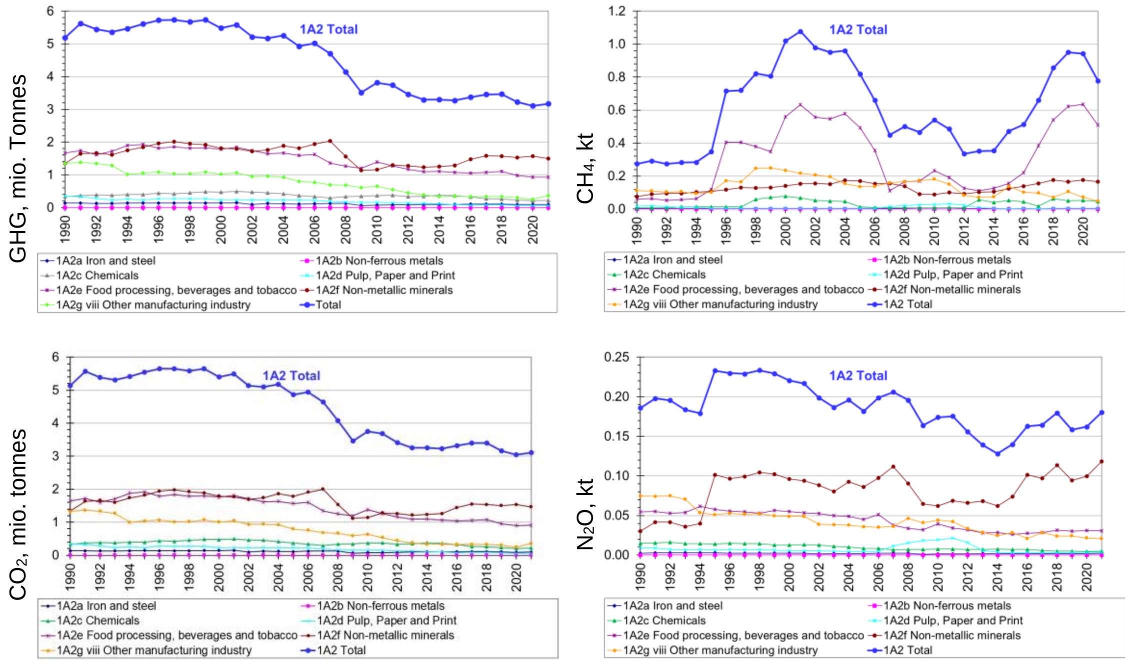


Figure 3.2.22 Time series for greenhouse gas emission, 1A2 Industry.

1A2a Iron and steel

Iron and steel is a very small emission source category. Figure 3.2.23 shows the time series for fuel consumption and emissions.

Natural gas is the main fuel in the subsector. In recent years, the consumption of biomethane is also considerable.

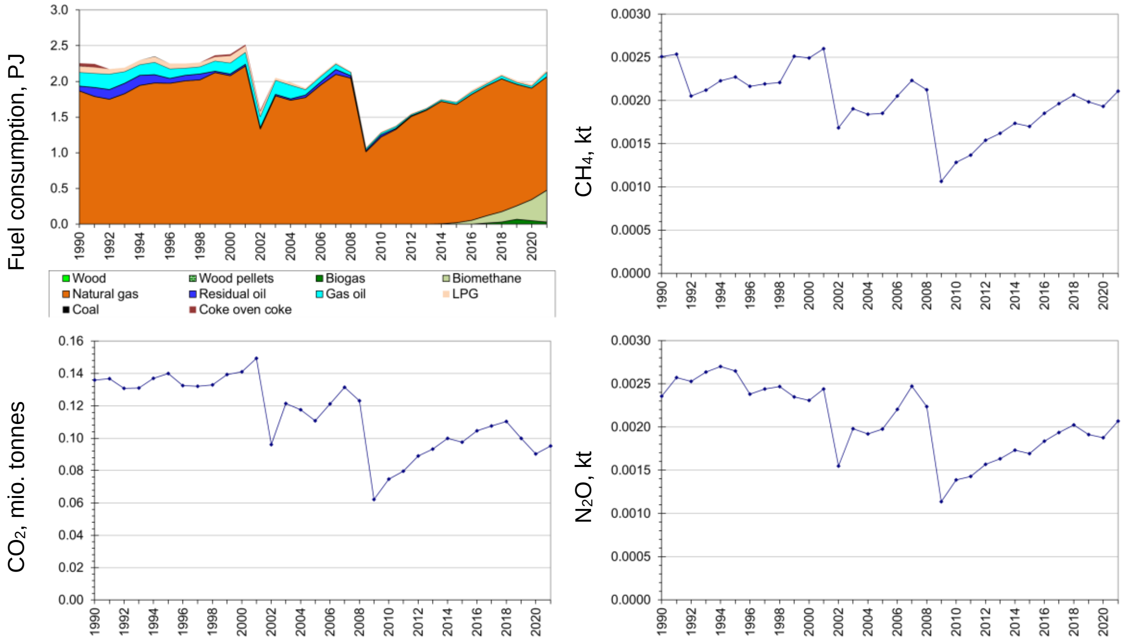


Figure 3.2.23 Time series for 1A2a Iron and steel.

1A2b Non-ferrous metals

No fuel consumption is reported for non-ferrous metals in the Danish energy statistics.

1A2c Chemicals

Chemicals is a minor emission source category. Figure 3.2.24 shows the time series for fuel consumption and emissions.

Natural gas and in recent years also biomethane are the main fuels in this subsector. The CO_2 emission time series follow the time series for fuel consumption. The time series for CH_4 emission 1997-2006 is related to consumption of natural gas in gas engines. The higher and fluctuating CH_4 emission in 2012 to 2021 is related to a few biogas fuelled engines in the industry. The decreasing time series for N_2O emission is related to the decreasing consumption of residual oil.

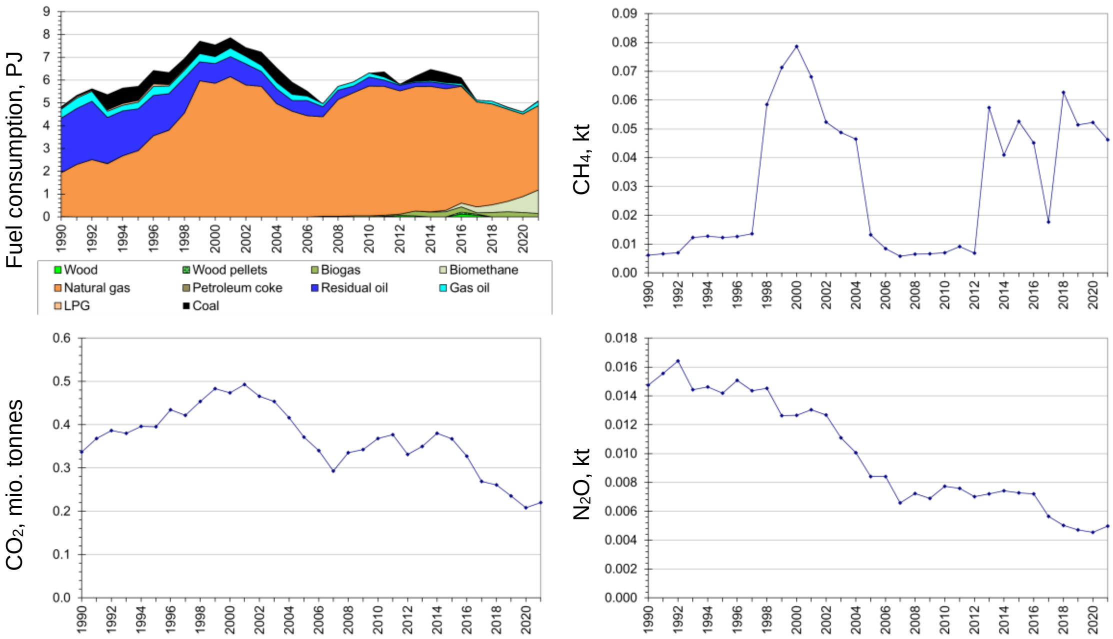


Figure 3.2.24 Time series for 1A2c Chemicals.

1A2d Pulp, paper and print

Pulp, paper and print is a minor emission source category. Figure 3.2.25 shows the time series for fuel consumption and emissions.

The fuel consumption decreased 65 % from 1990. The time series is related to both closure of plants and new combustion units in exiting plants. In addition, the liberalisation of the electricity market caused less operational hours of a natural gas fuelled gas turbine. Natural gas, and in 2007-2013 also wood, are the main fuels in the subsector.

The increased consumption of wood in 2007-2013 is reflected in the CH_4 and N_2O emission time series.

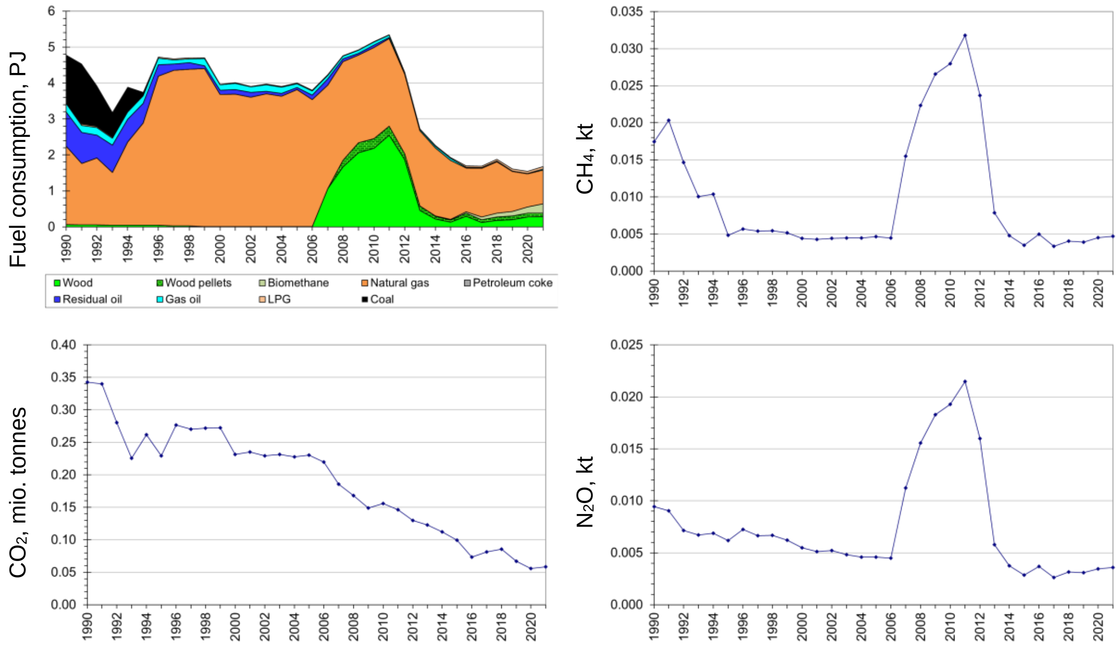


Figure 3.2.25 Time series for 1A2d Pulp, paper and print.

1A2e Food processing, beverages and tobacco

Food processing, beverages and tobacco is a considerable industrial subsector. Figure 3.2.26 shows the time series for fuel consumption and emissions.

Natural gas, biomethane, residual oil and coal are the main fuels in the subsector. The consumption of coal and residual oil has decreased.

The time series for CH_4 emission follows the consumption of natural gas in gas engines.

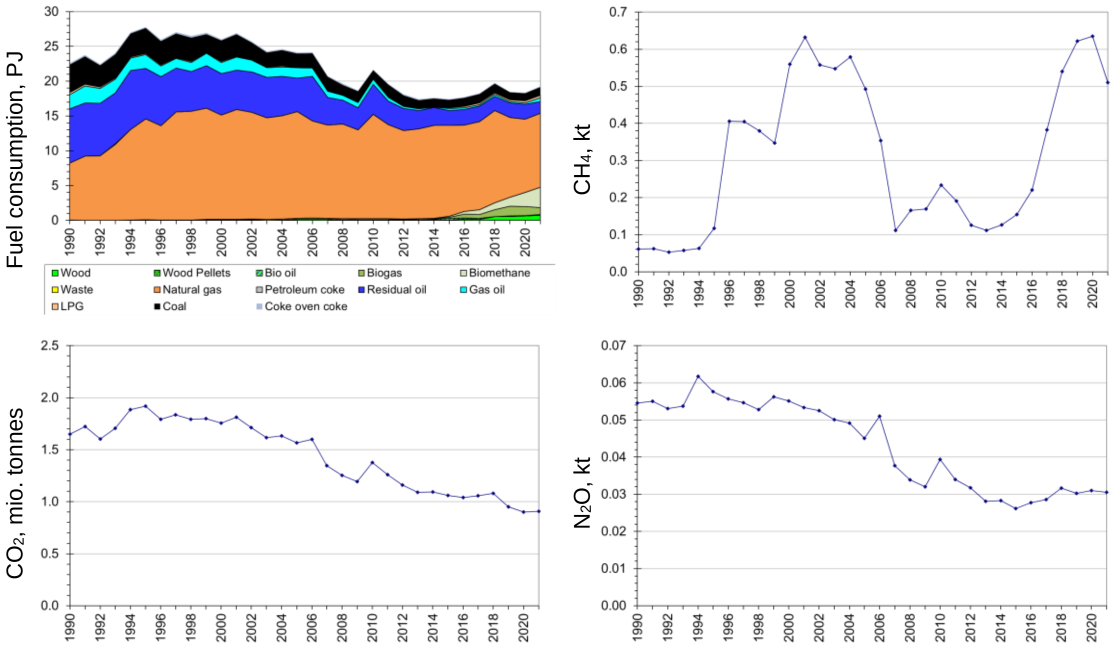


Figure 3.2.26 Time series for 1A2e Food processing, beverages and tobacco.

1A2f Non-metallic minerals

Non-metallic minerals is a considerable industrial subsector. The subsector includes cement production that is a major industrial emission source in Denmark. Production of mineral wool and glass is also included in the subsector. Figure 3.2.27 shows the time series for fuel consumption and emissions.

Petroleum coke, natural gas, waste and coal are the main fuels in the subsector in recent years. The consumption of coal has decreased.

Due to the global recession, cement production decreased in 2008 and 2009, but then increased again. This is reflected in the time series.

Combustion of coke oven coke in mineral wool production is a large emission source for N_2O. Plant specific fuel consumption rates for the mineral wool production plants are available from 1995. This causes the increase in N_2O emission between 1994 and 1995.

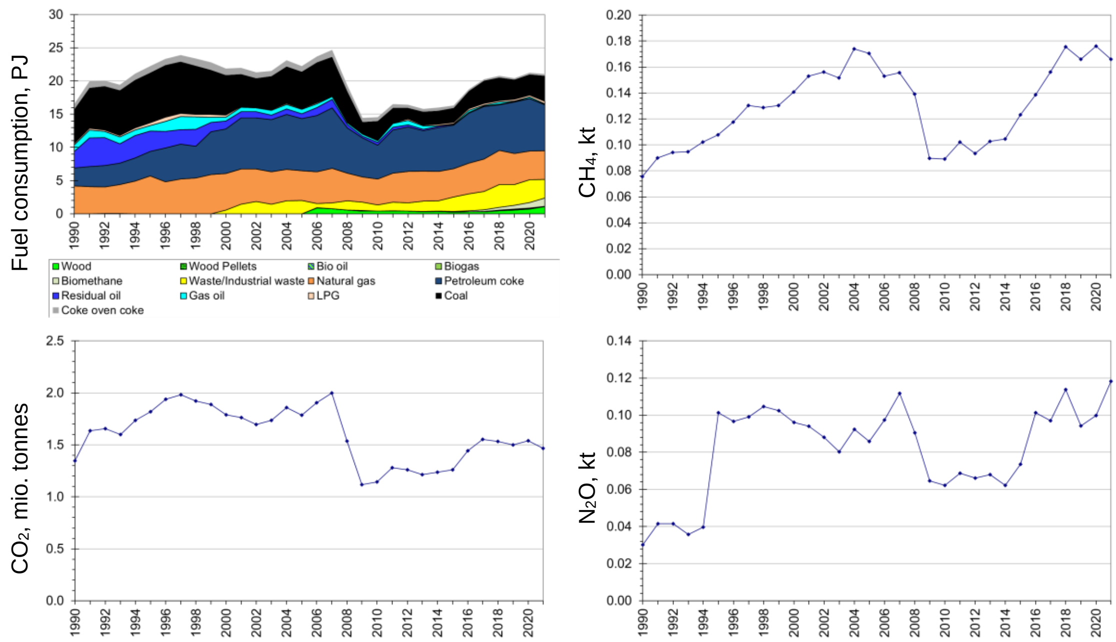


Figure 3.2.27 Time series for 1A2f Non-metallic minerals.

1A2g Other manufacturing industry

Other manufacturing industry is a considerable industrial subsector. Figure 3.2.28 shows the time series for fuel consumption and emissions.

Natural gas, wood, wood pellets and gas oil are the main fuels in the subsector in recent years. The consumption of coal and oil has decreased.

The time series for CH_4 is related to the consumption of natural gas in gas engines.

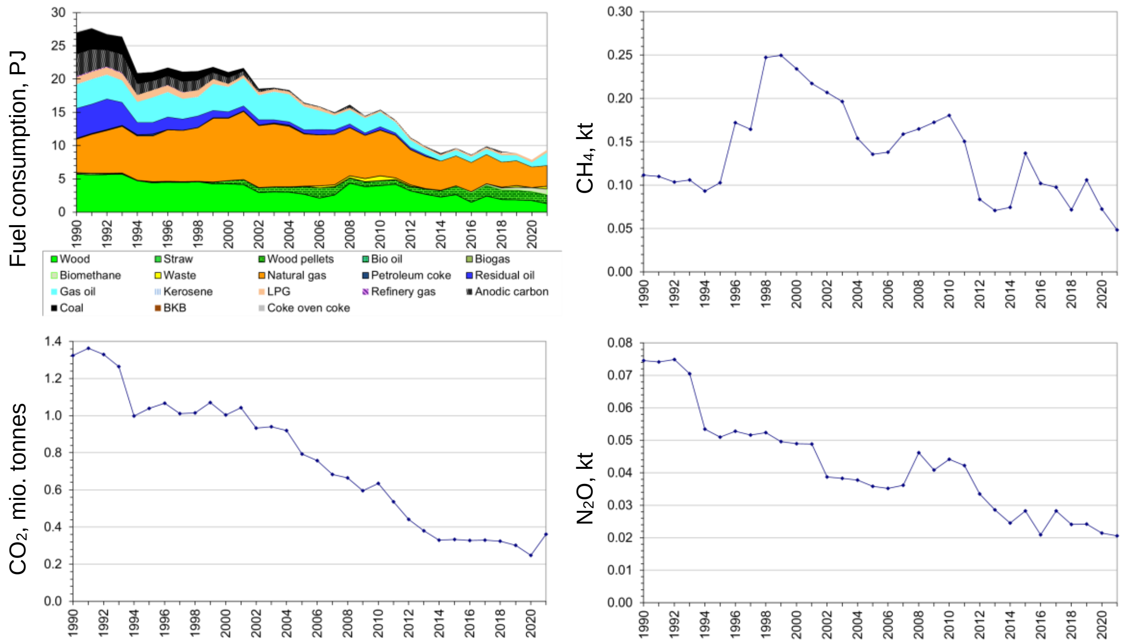


Figure 3.2.28   Time series for 1A2g Industry - other.

1A4 Other Sectors

The emission source category 1A4 Other Sectors consists of the subcategories:

- 1A4a Commercial/Institutional plants.
- 1A4b Residential plants.
- 1A1c Agriculture/Forestry.

The Figures 3.2.29-30 present time series for this emission source category. Residential plants are the dominant subcategory accounting for the largest part of all emissions. Time series are discussed below for each subcategory.

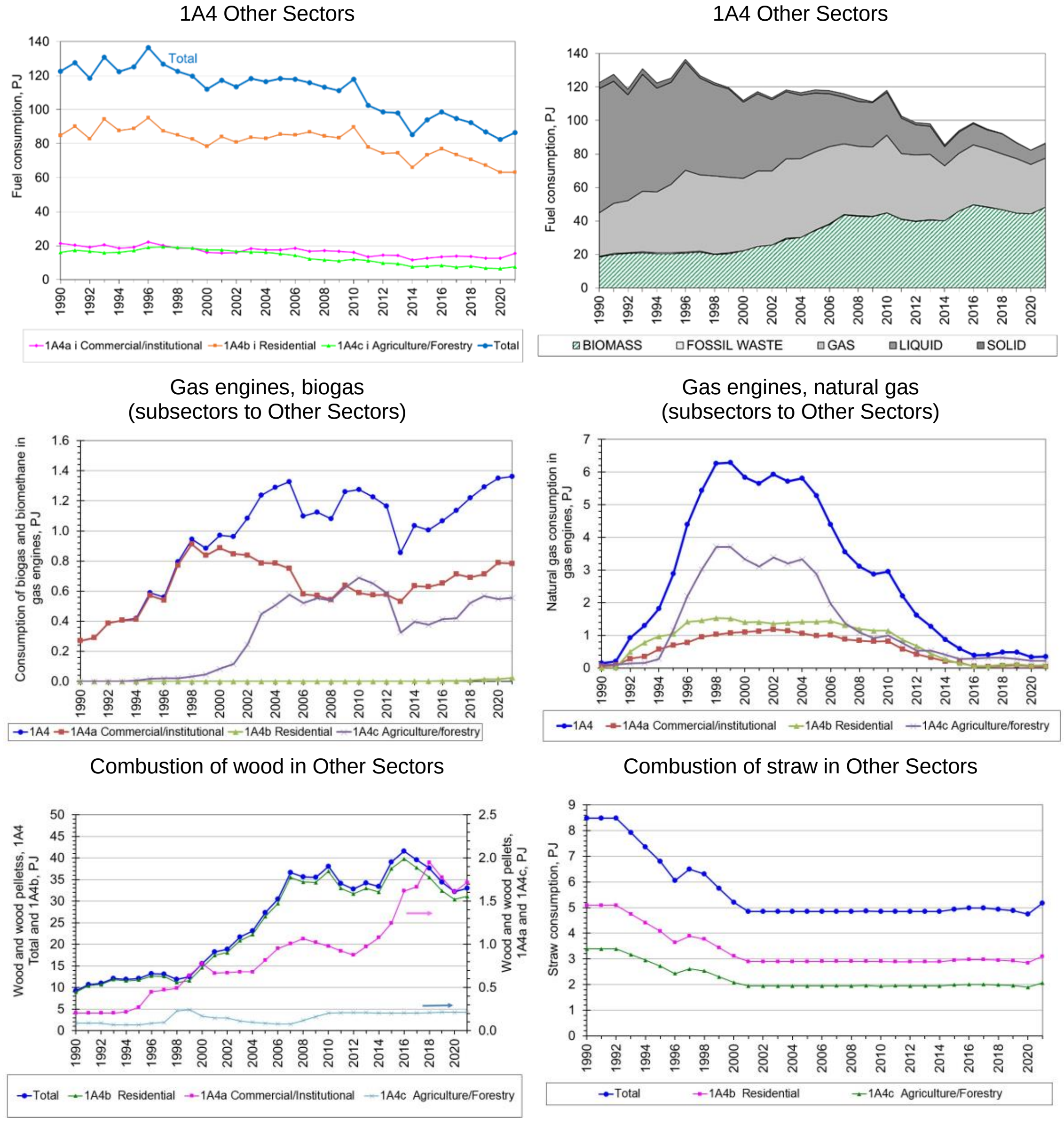


Figure 3.2.29 Time series for fuel consumption, 1A4 Other Sectors.

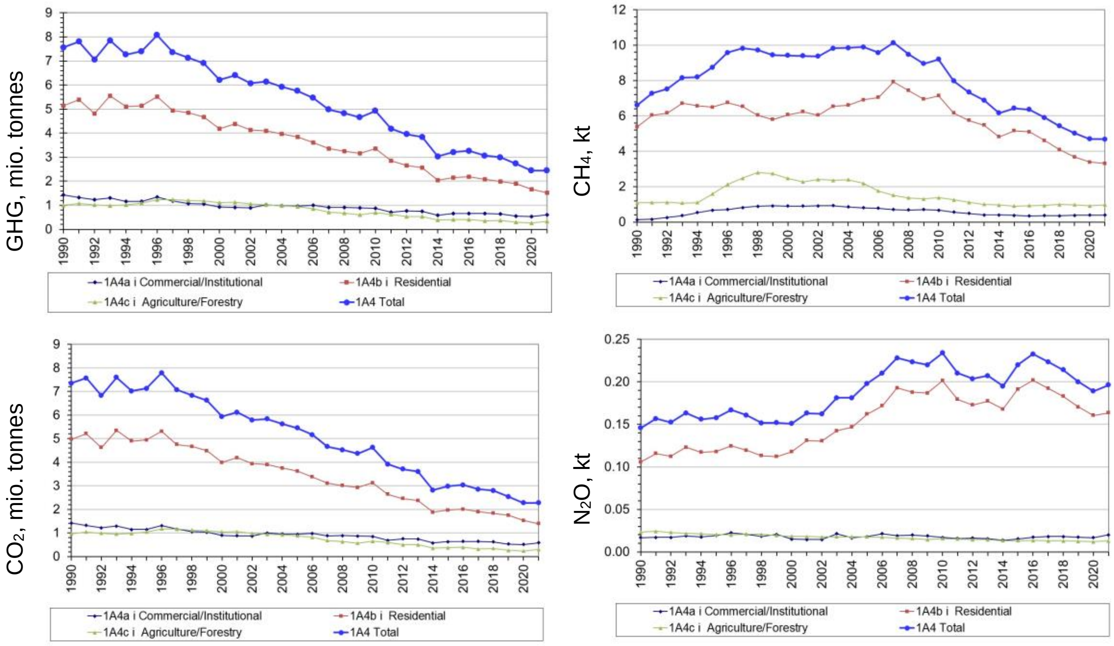


Figure 3.2.30 Time series for greenhouse gas emission, 1A4 Other Sectors.

1A4a Commercial and institutional plants

The subcategory Commercial and institutional plants consists of both stationary and mobile sources. In this chapter, only stationary sources are included. Figure 3.2.31 shows the time series for fuel consumption and emissions.

The subcategory Commercial and institutional plants has low fuel consumption and emissions compared to the other stationary combustion emission source categories.

The fuel consumption in Commercial/institutional plants has decreased 28 % since 1990 and the fuels applied have changed. In later years, the main fuel is natural gas. The consumption of gas oil has decreased since 1990. The consumptions of wood, wood pellets, biogas, and biomethane have increased.

The CO_2 emission has decreased 59 % since 1990. Both the decrease of fuel consumption and the change of fuels contribute to the decreased CO_2 emission.

The CH_4 emission in 2021 was 3.0 times the 1990 level. The increase is mainly a result of the increased emission from natural gas fuelled engines. The emissions from biogas-fuelled engines and from combustion of wood also contribute to the increase. The time series for consumption of natural gas and biogas are shown in Figure 3.2.29.

The N_2O emission in 2021 was 18 % higher than in 1990. The fluctuations of the N_2O emission are mainly a result of fluctuations in consumption of natural gas and waste.

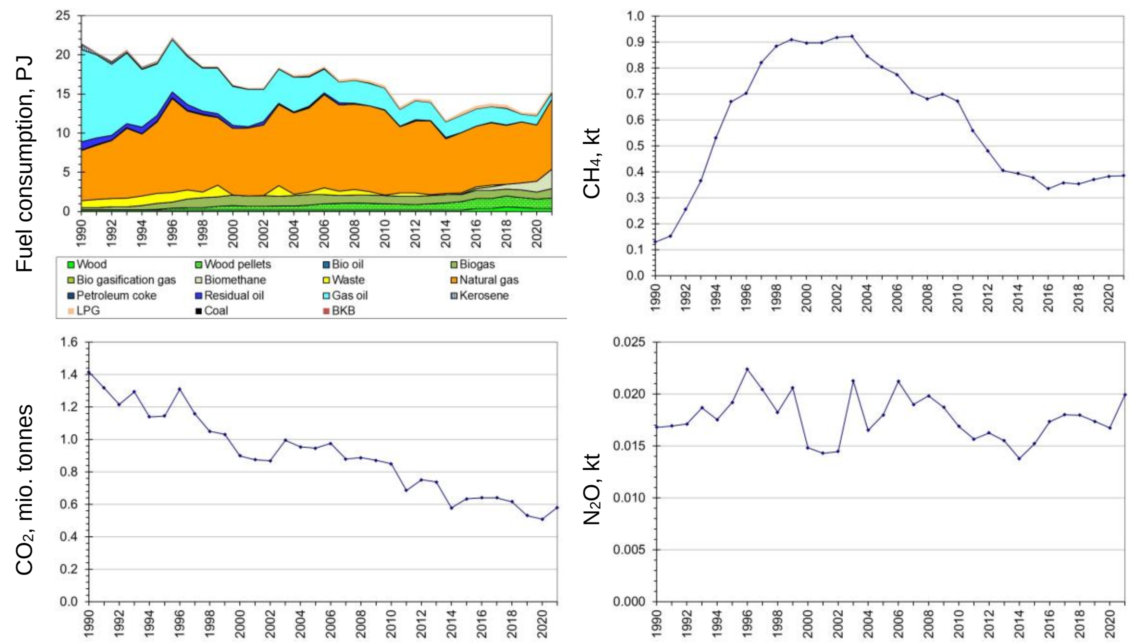


Figure 3.2.31 Time series for 1A4a Commercial /institutional.

1A4b Residential plants

The emission source category Residential plants consists of both stationary and mobile sources. In this chapter, only stationary sources are included. Figure 3.2.32 shows the time series for fuel consumption and emissions.

For residential plants, the total fuel consumption was 26 % lower in 2021 than in 1990. The large decrease from 2010 to 2011 was caused by high temperature in the winter season of 2011 compared to the cold winter of 2010. The consumption of gas oil has decreased since 1990 whereas the consumption of wood, wood pellets and biomethane has increased considerably.

The CO_2 emission has decreased by 72 % since 1990. This decrease is mainly a result of the considerable change in fuels used from gas oil to log wood, wood pellets, biomethane and natural gas.

The CH_4 emission from residential plants was 38 % lower in 2021 than in 1990. Residential wood combustion is a large source of CH_4 emission, and the consumption of wood has increased whereas the emission factor has decreased since 1990. Replacement of older stoves and boilers with new improved stoves and boilers cause a lower CH_4-emission factor for residential wood combustion, see also Chapter 3.2.5.

The change of fuel from gas oil to wood has resulted in a 54 % increase of N_2O emission since 1990 due to a higher emission factor for wood than for gas oil.

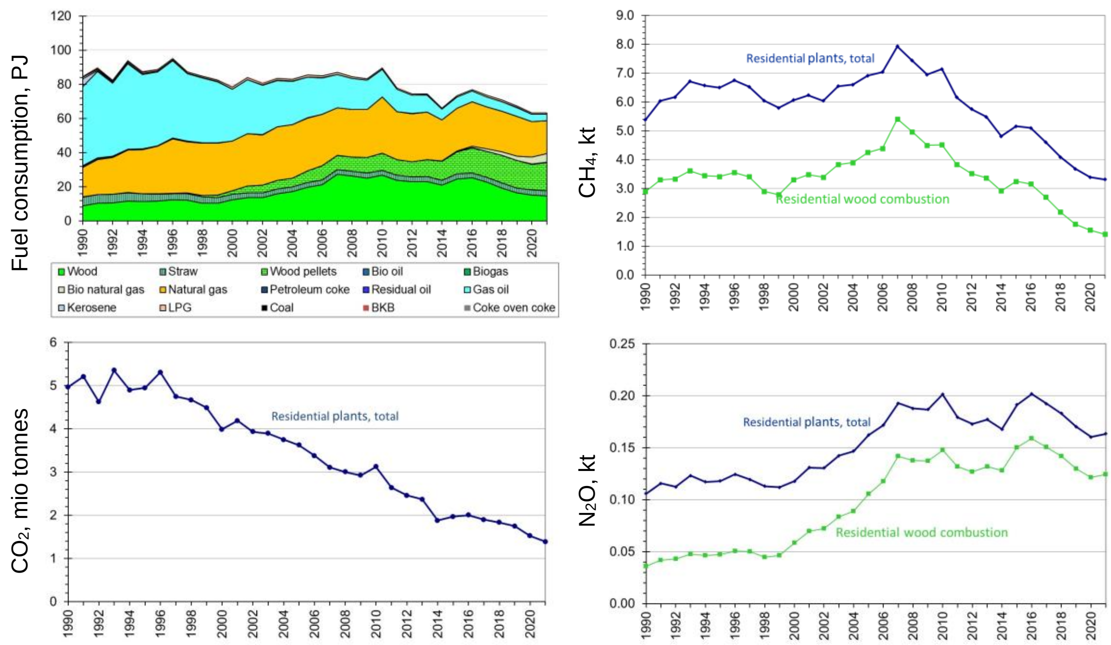


Figure 3.2.32 Time series for 1A4b Residential plants.

1A4c Agriculture/forestry

The emission source category Agriculture/forestry consists of both stationary and mobile sources. In this chapter, only stationary sources are included. Figure 3.2.33 shows the time series for fuel consumption and emissions.

For plants in Agriculture/forestry, the fuel consumption has decreased 53 % since 1990.

The type of fuel that has been applied has changed since 1990. In the years 1994-2004, the consumption of natural gas was high, but after 2004, the consumption decreased again. A large part of the natural gas consumption has been applied in gas engines (Figure 3.2.29). Most CHP plants in Agriculture/forestry based on gas engines came in operation in 1995-1999. The decrease after 2004 is a result of the liberalisation of the electricity market.

The consumption of coal, residual oil and straw has decreased since 1990. The consumption of biogas has increased.

The CO_2 emission in 2021 was 69 % lower than in 1990. The CO_2 emission increased from 1990 to 1996 due to increased fuel consumption. Since 1996, the CO_2 emission has decreased in line with the decrease in fuel consumption.

The CH_4 emission in 2020 was 10 % lower than in 1990. The emission follows the time series for natural gas combusted in gas engines (Figure 3.2.29). The emission from combustion of straw has decreased as a result of the decreasing consumption of straw in the sector.

The emission of N_2O has decreased by 44 % since 1990. The decrease is a result of the lower fuel consumption as well as the change of fuel. The decreasing consumption of straw contributes considerably to the decrease of emission.

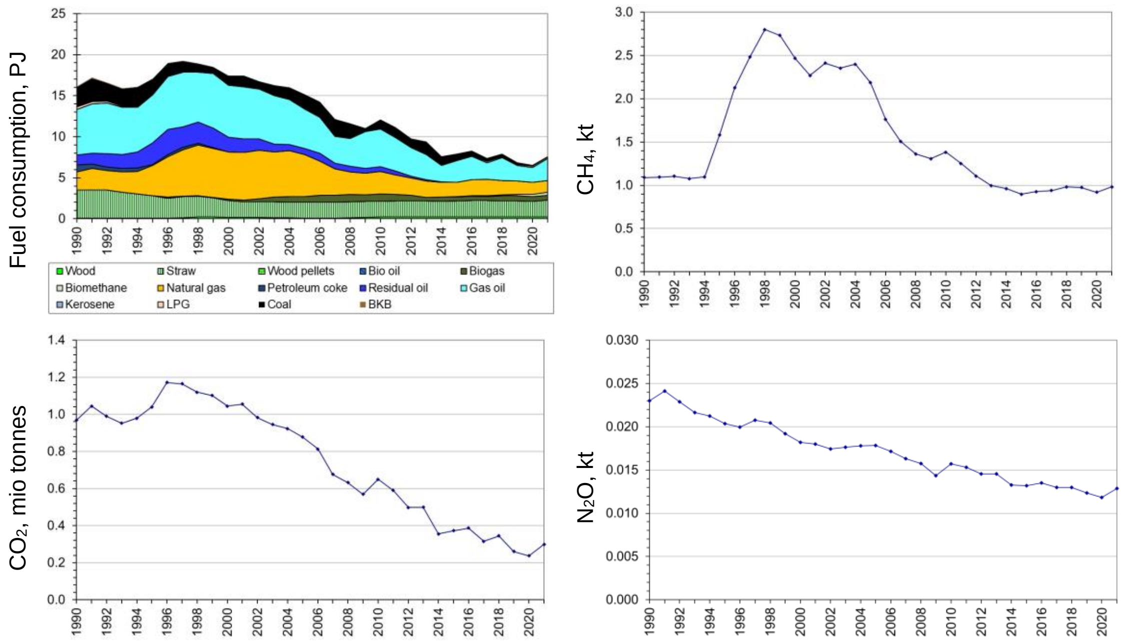


Figure 3.2.33 Time series for 1A4c Agriculture/Forestry.

3.2.5 Methodological issues

The Danish emission inventory is based on the CORINAIR (CORe INventory on AIR emissions) system, which is a European program for air emission inventories. CORINAIR includes methodology structure and software for inventories. The methodology is described in the EEA Guidebook (EEA, 2019). Emission data are stored in MS Access databases, from which data are transferred to the reporting formats.

In the Danish emission database, all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution) according the CORINAIR system. The emission inventories are prepared from a complete emission database based on the SNAP source categories. Aggregation to the source category codes used in CRF is based on a correspondence list enclosed in Annex 3A-1.

The emission inventory for stationary combustion is based on activity rates from the Danish energy statistics. General emission factors for various fuels, plants and sectors have been determined. Some large plants, such as power plants, are registered individually as large point sources and plant-specific emission data are used.

Recalculations and improvements are shown in Chapter 3.2.8 and 3.2.9

Tiers

The type of GHG emission factor and the applied tier level for each emission source are shown in Table 3.2.8 below. The tier levels have been determined based on the IPCC Guidelines (IPCC, 2006). The fuel consumption data for transformation are technology specific. For end-use of fuels, the disaggregation to specific technologies is less detailed. However, for residential wood combustion technology specific fuel consumption rates have been estimated.

The tier level definitions have been interpreted as follows:

- Tier 1: The emission factor is an IPCC default tier 1 value.
- Tier 2: The emission factors are country-specific and based on a limited number of emission measurements or a technology specific IPCC tier 2 emission factor.
- Tier 3: Emission data are based on:
  - plant specific emission measurements or
  - technology specific fuel consumption data and country-specific emission factors based on a considerable number of emission measurements from Danish plants.

Table 3.2.8 gives an overview of the calculation methods and type of emission factor. The table also shows which of the source categories are key in any of the key category analysis (including LULUCF, approach 1/approach 2, level/trend)[8].

This year, two source categories based on tier 1 approach have been identified as key sources. The total emission from these emission sources adds up to 35 ktonnes CO_2 equivalent or 0.08 % of the national total in 2021. In 1990, the

[8] Key category according to the KCA approach 1 or approach 2 for Denmark (excluding Greenland and Faroe Islands), including LULUCF, level 1990/ level 2020/ trend.

emission from the two emission sources adds up to 377 ktonnes or 0.5 % of national total.

The 1990 CO_2 emission from kerosene was also identified as a key category in earlier emission reporting, and thus implementation of a tier 2 methodology has been considered. The consumption of kerosene in stationary combustion plants was high in 1990 compared to the years before and after. The high consumption is related to the time series in the Danish energy statistics for kerosene consumption in Single family houses. In 1990, this consumption was 6 times the consumption in 1989 and 9 times the consumption in 1991. The Danish Energy Agency has explained that they have not been able to confirm that the 1990-data are incorrect, and thus data will not be revised (Zarnaghi, 2021).

N_2O emission from residential wood combustion is a key source, and if possible, a tier 2 emission factor will be implemented in future inventories. At present, a national referenced emission factor for N_2O is not available for residential wood combustion.

Three key category emission sources (N_2O from 1A1 biomass, N_2O from 1A2 liquid fuels and N_2O from 1A4 liquid fuels) are partly based on a tier 1 approach. However, a large part of the emission from these source categories are based on higher tiers.

Table 3.2.8 Methodology and type of emission factor, 2021.

		Tier	EMF[1)]	Key category[2)]
1A Stationary combustion, Coal, ETS data	CO_2	Tier 3	PS	Yes
1A Stationary combustion, Coal, no ETS data	CO_2	Tier 3 [3)]	CS	Yes
1A Stationary combustion, BKB	CO_2	Tier 1	D	No
1A Stationary combustion, Coke oven coke	CO_2	Tier 1/Tier 3	D/PS	No
1A Stationary combustion, Fossil waste, ETS data	CO_2	Tier 3	PS/CS	Yes
1A Stationary combustion, Fossil waste, no ETS data	CO_2	Tier 2	CS	Yes
1A Stationary combustion, Petroleum coke, ETS data	CO_2	Tier 3	PS	Yes
1A Stationary combustion, Petroleum coke, no ETS data	CO_2	Tier 2	CS	Yes
1A Stationary combustion, Residual oil, ETS data	CO_2	Tier 3	PS	Yes
1A Stationary combustion, Residual oil, no ETS data	CO_2	Tier 2 [4)]	CS	Yes
1A Stationary combustion, Gas oil	CO_2	Tier 2/Tier 3 [5)]	CS / PS	Yes
1A Stationary combustion, Kerosene	CO_2	Tier 1	D	Yes
1A Stationary combustion, LPG	CO_2	Tier 2/Tier 3 [6)]	CS / PS	Yes
1A1b Stationary combustion, Petroleum refining, Refinery gas	CO_2	Tier 3	CS	Yes
1A Stationary combustion, Natural gas, onshore	CO_2	Tier 3	CS	Yes
1A1c_ii Stationary combustion, Oil and gas extraction, Offshore gas turbines, Natural gas	CO_2	Tier 3	CS	Yes
1A1 Stationary Combustion, solid fuels	CH_4	Tier 2	D(2)	No
1A1 Stationary Combustion, liquid fuels	CH_4	Tier/Tier 2	D / D(2) / CS	No
1A1 Stationary Combustion, not engines, gaseous fuels	CH_4	Tier 2	CS / D(2)	No
1A1 Stationary Combustion, waste	CH_4	Tier 2	CS	No
1A1 Stationary Combustion, not engines, biomass	CH_4	Tier 3/Tier 2/Tier 1	CS / D(2) / D	No
1A2 Stationary Combustion, solid fuels	CH_4	Tier 1	D	No
1A2 Stationary Combustion, liquid fuels	CH_4	Tier 1/Tier 2	D / D(2) / CS	No
1A2 Stationary Combustion, not engines, gaseous fuels	CH_4	Tier 2	CS / D(2)	No
1A2 Stationary Combustion, waste	CH_4	Tier 1	D	No
1A2 Stationary Combustion, not engines, biomass	CH_4	Tier 2/Tier 1	D(2) / D	No
1A4 Stationary Combustion, solid fuels	CH_4	Tier 1	D	No
1A4 Stationary Combustion, liquid fuels	CH_4	Tier 1/Tier 2	D / D(2)	No
1A4 Stationary Combustion, not engines, gaseous fuels	CH_4	Tier 2	CS	No
1A4 Stationary Combustion, waste	CH_4	Tier 1	D	No
1A4 Stationary Combustion, not engines, not residential wood and not residential/agricultural straw, biomass	CH_4	Tier 1/Tier 2	D / D(2) / CS	No
1A4b_i Stationary combustion, Residential wood combustion	CH_4	Tier 2	CS	Yes
1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion	CH_4	Tier 1	D	No
1A Stationary combustion, Natural gas fuelled engines, gaseous fuels	CH_4	Tier 3	CS	No
1A Stationary combustion, Biogas fuelled engines, biomass	CH_4	Tier 3	CS	No
1A1 Stationary Combustion, solid fuels	N_2O	Tier 2	CS / D(2)	Yes
1A1 Stationary Combustion, liquid fuels	N_2O	Tier 2/Tier 1	D(2) / CS / D	No
1A1 Stationary Combustion, gaseous fuels	N_2O	Tier 3/Tier 2	CS / D(2)	No
1A1 Stationary Combustion, waste	N_2O	Tier 2	CS	Yes
1A1 Stationary Combustion, biomass	N_2O	Tier 2/Tier 1	CS / D(2) / D	Yes
1A2 Stationary Combustion, solid fuels	N_2O	Tier 1/Tier 3	D/PS	No
1A2 Stationary Combustion, liquid fuels	N_2O	Tier 2/Tier 1	D(2) / CS / D	Yes
1A2 Stationary Combustion, gaseous fuels	N_2O	Tier 3/Tier 2	CS / D(2)	Yes
1A2 Stationary Combustion, waste	N_2O	Tier 1	D	No
1A2 Stationary Combustion, biomass	N_2O	Tier 1/Tier 2	D / CS	No
1A4 Stationary Combustion, solid fuels	N_2O	Tier 1	D	No
1A4 Stationary Combustion, liquid fuels	N_2O	Tier 2/Tier 1	D(2) / CS / D	Yes
1A4 Stationary Combustion, gaseous fuels	N_2O	Tier 3/Tier 2	CS / D(2)	No
1A4 Stationary Combustion, waste	N_2O	Tier 1	D	No
1A4 Stationary Combustion, not residential wood and not residential/agricultural straw, biomass	N_2O	Tier 1/Tier 2	D / CS	No
1A4b_i Stationary Combustion, Residential wood combustion	N_2O	Tier 1	D	Yes
1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion	N_2O	Tier 1	D	No

1. D: IPCC (2006) default, tier 1. D(2): IPCC (2006) default, tier 2. CS: Country specific. PS: Plant specific.
2. KCA approach 1 or approach 2 for Denmark (excluding Greenland and Faroe Islands), including LULUCF, level 1990 or level 2021 or trend 1990-2021.
3. Only 2.5 % of the total coal consumption is included in the non-ETS category in 2021.
4. Only 10 % of the total residual oil consumption is included in the non-ETS category in 2021
5. Tier 3 for less than 1 % of the gas oil consumption in 2021.
6. Tier 3 for less than 1 % of the LPG consumption in 2021.

Table 3.2.9 Emission data for key sources for which the estimated emissions are based on the tier 1 approach.

Source category	CO_2 emission 1990, ktonne CO_2 equivalent	CO_2 emission 2021, ktonne CO_2 equivalent	Key source (KCA approach)
1A Stationary combustion, Kerosene, CO_2	368	2	Level 1990 (KCA 1), Trend (KCA 1)
1A4b_i Stationary Combustion, Residential wood combustion, N_2O	9	33	Level 2021 (KCA 2), Trend (KCA 2)
Key sources for which the estimated emissions are based on the tier 1 approach, total	377	35	

Large point sources

Large emission sources such as power plants, industrial plants and refineries are included as large point sources in the Danish emission database. Each point source may consist of more than one part, e.g. a power plant with several units. By registering the plants as point sources in the database, it is possible to use plant-specific emission factors.

In the inventory for the year 2021, 71 stationary combustion plants are specified as large point sources. Plant specific emission data[9] are available from 65 of the plants. The point sources include:

- Power plants and decentralised CHP plants.
- Waste incineration plants.
- Large industrial combustion plants.
- Petroleum refining plants.

The criteria for selection of point sources are:

- All centralized power plants, including smaller units.
- All units with a capacity of above 25 MW_e.
- All district heating plants with an installed effect of 50 MW_{th} or above and significant fuel consumption.
- All waste incineration plants obligated to report environmental data annually according to Danish law (DEPA, 2010b; DEPA, 2015).
- Industrial plants,
  - With an installed effect of 50 MW_{th} or above and significant fuel consumption.
  - With a significant process related emission.

The fuel consumption of stationary combustion plants registered as large point sources in the 2021 inventory was 208 PJ. This corresponds to 53 % of the overall fuel consumption for stationary combustion.

A list of the large point sources for 2021 is provided in Annex 3A-5. The number of large point sources registered in the databases increased from 1990 to 2021. Aggregated fuel consumption rates for the large point sources are also shown in Annex 3A-5.

The emissions from a point source are based either on plant specific emission data or, if plant specific data are not available, on fuel consumption data and the general Danish emission factors.

[9] For CO_2 or other pollutants.

The plant-specific emission data from the EU ETS data represent 59 % of the total fossil CO_2 emission from stationary combustion. CO_2 emission factors are plant specific for the major power plants, refineries, offshore gas turbines, large municipal waste incineration plants and for cement production. Plant-specific emission data are obtained from CO_2 data reported under the EU Emission Trading Scheme (ETS). The EU ETS data are discussed below.

Emission measurement data for CH_4 and N_2O are applied for estimating emission factors but not implemented as plant specific data.

Annual environmental reports for the plants include a considerable number of emission data sets. In general, emission data from annual environmental reports are based on emission measurements, but some emissions have potentially been calculated from general emission factors.

If plant-specific emission factors are not available, emission factors for area sources are used.

Area sources

Fuels not combusted in large point sources are included as source category specific area sources in the emission database. Plants such as residential boilers, small district heating plants, small CHP plants and some industrial boilers are defined as area sources. Emissions from area sources are based on fuel consumption data and emission factors. Further information on emission factors is provided below in the chapter Emission factors.

Fuels used for non-energy purposes

The Danish national energy statistics includes three fuels used for non-energy purposes; bitumen, white spirit and lubricants. The total consumption for non-energy purposes is relatively low, e.g. 9.5 PJ in 2021. The use of fuels for non-energy purposes is included in the inventory in sector 2D Non-energy products from fuels and solvent use; see Chapter 4.5.3.

The non-energy use of fuels is included in the reference approach for Climate Convention reporting and appropriately corrected in line with the IPCC Guidelines (IPCC, 2006). The reference approach is included in Chapter 3.4.

Activity rates, fuel consumption

The fuel consumption rates are based on the official Danish energy statistics prepared by the Danish Energy Agency (DEA). DCE aggregates fuel consumption rates to SNAP categories. Some fuel types in the official Danish energy statistics are added to obtain a less detailed fuel aggregation level cf. Annex 3A-3. The calorific values on which the energy statistics are based are also enclosed in Annex 3A-3. The correspondence list between the energy statistics and SNAP categories is enclosed in Annex 4.

The fuel consumption of the CRF category Manufacturing industries and construction (corresponding to SNAP category 03) is disaggregated into industrial subsectors based on the DEA data set aggregated for the Eurostat reporting (DEA, 2021c). The fuel consumption data flow is shown in Figure 3.2.34.

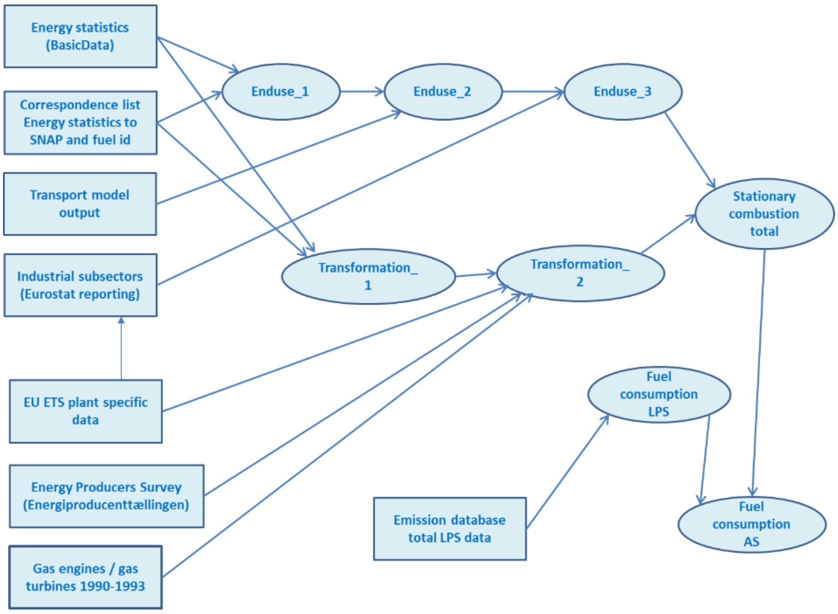


Figure 3.2.34 Fuel consumption data flow.

Both traded and non-traded fuels are included in the Danish energy statistics. Thus, for example, estimation of the annual consumption of non-traded wood is included.

Petroleum coke purchased abroad and combusted in Danish residential plants (border trade of 100-628 TJ in 1992-2018[10]) is not included in the Danish inventory. This is in agreement with the IPCC Guidelines (IPCC, 2006).

The fuel consumption data for large point sources refer to the EU Emission Trading Scheme (EU ETS) data for plants for which the CO_2 emission also refer to EU ETS, see page 123.

For all other large point sources, the fuel consumption refers to an annually updated DEA database; the Energy Producers Survey (DEA, 2022b). The Energy Producers Survey includes the fuel consumption of each district heating and power-producing plant, based on data reported by plant operators. The consistency between EU ETS reporting and the Energy Producers Survey database (DEA, 2022b) is checked by the DEA and discrepancies are corrected prior to the use in the emission inventory.

The fuel consumption of area sources is calculated as total fuel consumption in the energy statistics minus fuel consumption included in the emission inventory database in large point sources.

In Denmark, all waste incineration is utilised for heat and power production. Thus, incineration of waste is included as stationary combustion in the source category Fuel combustion (subcategories 1A1, 1A2 and 1A4).

Fuel consumption data are presented in Chapter 3.2.2.

Fuel consumption for 1A1c Oil and gas extraction

The fuel consumption data for natural gas applied in 1A1c Oil and gas extraction reported in the EU ETS are not in agreement with the energy statistics for

[10] No border trade of petroleum coke in 2019-2021.

1990-2020. This is because data in the energy statistics were based on the default net calorific value (NCV) for natural gas applied in Denmark, whereas the EU ETS data were based on fuel analysis of the natural gas applied offshore at each individual platform. DEA has improved the data collection for natural gas, and for 2021 the two data sets are in agreement. The fuel consumption data applied in the inventory for 1990-2020 for natural gas refer to the EU ETS data.

The gas oil consumption offshore included in EU ETS data have been implemented in the emission inventory. In the energy statistics this consumption is included in domestic sea transport (Rusbjerg, 2021).

Fuel consumption for 1A1b Petroleum refining

The EU ETS data for fuel consumption reported by the two Danish refineries are not always in agreement with the energy statistics due to the use of default values for net calorific value (NCV) in the energy statistics. The EU ETS data are based on fuel analysis. Refinery gas is only applied in the two refineries. The total consumption of refinery gas applied in the emission inventories is based on the EU ETS data.

Biomethane

Biomethane is biogas upgraded for distribution in the natural gas grid. Biomethane has been included as a separate fuel in the energy statistics and in the emission inventory. In this report the fuel is referred to as biomethane, but others might refer to this fuel as bio natural gas or upgraded biogas.

Gas distributed in the Danish gas distribution system consists of (fossil) natural gas and biomethane. The gas composition has been assumed equal for all appliances in Denmark except for offshore consumption and the gas treatment plant. This assumption is in agreement with the Danish energy statistics (DEA, 2021a).

In the EU ETS data system, however, trading of biomethane certificates has been included in the fuel consumption data from the reporting year 2021. This agrees with the EU Guidance document for biomass issues in the EU ETS (EU 2017). In the chapter *5.2 Biogas in natural gas grids* it is specified that *Where an appropriate accounting system for biomass fractions is in place, it may be used under certain conditions. In particular a guarantee of origin system (in accordance with Articles 2(j) and 15 of the RES Directive) might be considered appropriate.* According to IPCC Guidelines (2006) the GHG emission inventories should be based on physical data and thus the trading of certificates will not be included in the inventories. Plant specific fuel consumption data for (fossil) natural gas and biomethane from EU ETS are implemented in the emission inventory by adding natural gas and biomethane and afterwards dividing into the two fuels according to the national split for pipeline gas.

The gas consumption offshore and in the Danish gas treatment plant have been assumed to be 100 % fossil natural gas. This is also in accordance with the Danish energy statistics.

Biogas and biomethane distributed in the town gas grid

The energy statistics includes a consumption of biogas for town gas production. In 2021, 119 TJ biogas and 114 TJ biomethane was distributed in the town gas grid.

In the energy statistics, biogas and biomethane distributed in the town gas grid is included in the fuel category town gas. In the emission inventory, biogas and biomethane distributed in the town gas grid have been included in the fuel categories biogas and biomethane.

Town gas

Town gas (the fossil part) has been included in the fuel category natural gas. The consumption of town gas in Denmark is very low, e.g. 0.6 PJ in 2021. In 1990, the town gas consumption was 1.6 PJ and the consumption has been steadily decreasing throughout the time series.

In Denmark, town gas is produced based on natural gas[11]. The use of coal for town gas production ceased in the early 1980s.

An indicative composition of town gas in 2015 according to the largest supplier of town gas in Denmark is shown in Table 3.2.10 (KE, 2015).

Table 3.2.10 Composition of town gas currently used (KE, 2015).

Component	Town gas, % (mol.)
Methane	43.9
Ethane	2.9
Propane	1.1
Butane	0.5
Carbon dioxide	0.4
Nitrogen	40.5
Oxygen	10.7

The lower heating value of the town gas is 20.31 MJ per Nm^3 and the CO_2 emission factor 56.1 kg per GJ. This is very close to the emission factor used for natural gas in 2015 (57.06 kg per GJ). According to the supplier, both the composition and heating value will change during the year. It has not been possible to obtain a yearly average.

In earlier years, the composition of town gas was somewhat different. Table 3.2.11 shows data for town gas composition in 2000-2005. These data are constructed with the input from Københavns Energi (KE) (Copenhagen Energy) and Danish Gas Technology Centre (DGC), (Jeppesen, 2007; Kristensen, 2007). The data refer to three measurements performed several years apart, the first in 2000 and the latest in 2005.

Table 3.2.11 Composition of town gas, data from 2000-2005.

Component	Town gas, % (mol.)
Methane	22.3-27.8
Ethane	1.2-1.8
Propane	0.5-0.9
Butane	0.13-0.2
Higher hydrocarbons	0-0.6
Carbon dioxide	8-11.6
Nitrogen	15.6-20.9
Oxygen	2.3-3.2
Hydrogen	35.4-40.5
Carbon monoxide	2.6-2.8

[11] Biomethane and biogas is part of the input fuels for town gas production, but in the emission inventory these fuels are treated as part of the fuel categories biomethane and biogas, see above.

The lower calorific value was been between 15.6 and 17.8 MJ per Nm^3. The CO_2 emission factors - derived from the few available measurements - are in the range of 52-57 kg per GJ.

The Danish sectoral approach includes town gas as part of the fuel category natural gas and thus indirectly assumes the same CO_2 emission factor. This is a conservative approach ensuring that the CO_2 emissions are not underestimated.

Due to the scarce data available and the very low consumption of town gas compared to consumption of natural gas (< 0.5 %), the methodology will be applied unchanged in future inventories.

Biogas and biomethane are applied for production of town gas, but in the emission inventory these fuels are included in the fuel categories biogas and biomethane, see Biogas and biomethane distributed in the town gas grid on page 120.

Waste

All waste incineration in Denmark is utilised for heat and/or power production and thus included in the energy sector. The waste incinerated in Denmark for energy production consists of the waste fractions shown in Figure 3.2.35. In 2019, 3 % of the incinerated waste was hazardous waste.

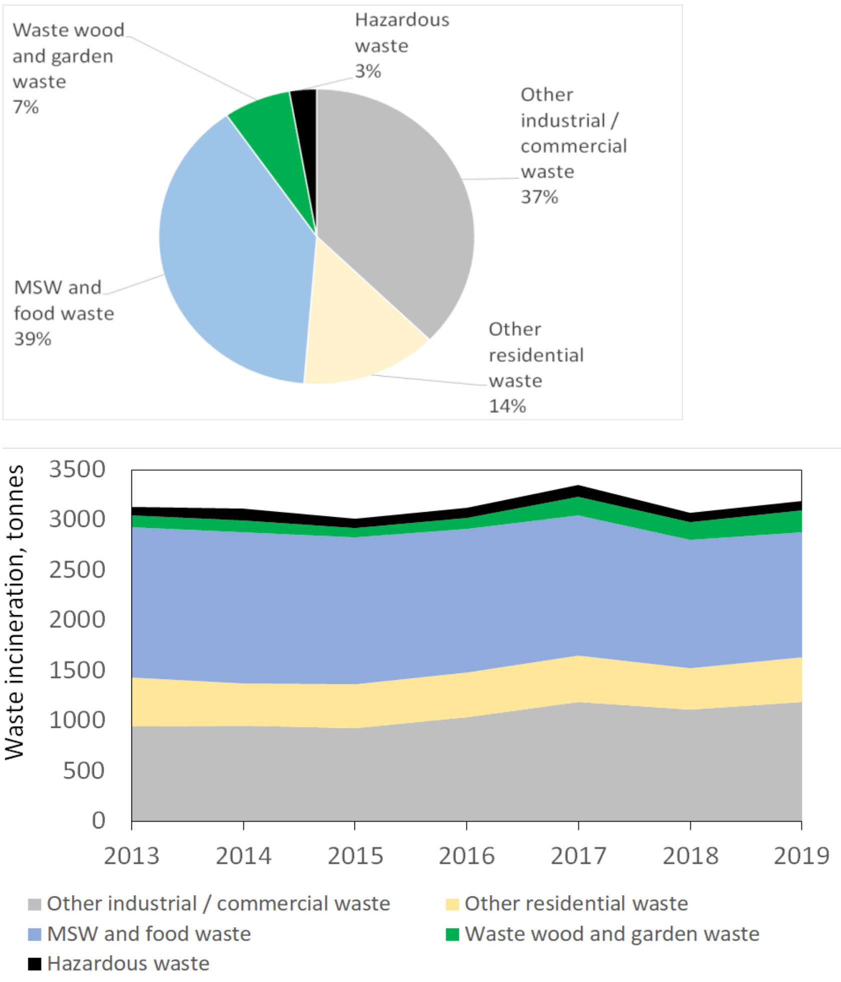


Figure 3.2.35 Waste fractions (weight) for incinerated waste in 2019 and the corresponding time series 2013-2019 (DEPA Waste statistics for 2019, 2021).

In connection to the project estimating an improved CO_2 emission factor for waste (Astrup et al., 2012), the fossil energy fraction was calculated. The fossil fraction was not measured or estimated as part of the project, but the flue gas measurements combined with data from Fellner & Rechberger (2010) indicated a fossil energy part of 45 %. The energy statistics also applies this fraction in the national statistics.

Biogas

Biogas includes landfill gas, sludge gas and manure/organic waste gas[12]. In 2021, 75 % of the produced biogas was upgraded to biomethane. An increasing part of the biogas is upgraded to biomethane.

Biogas upgraded for distribution in the natural gas grid reported as biomethane and is not included in the fuel category "biogas" in the rest of this report. This is also the case for bio gasification gas.

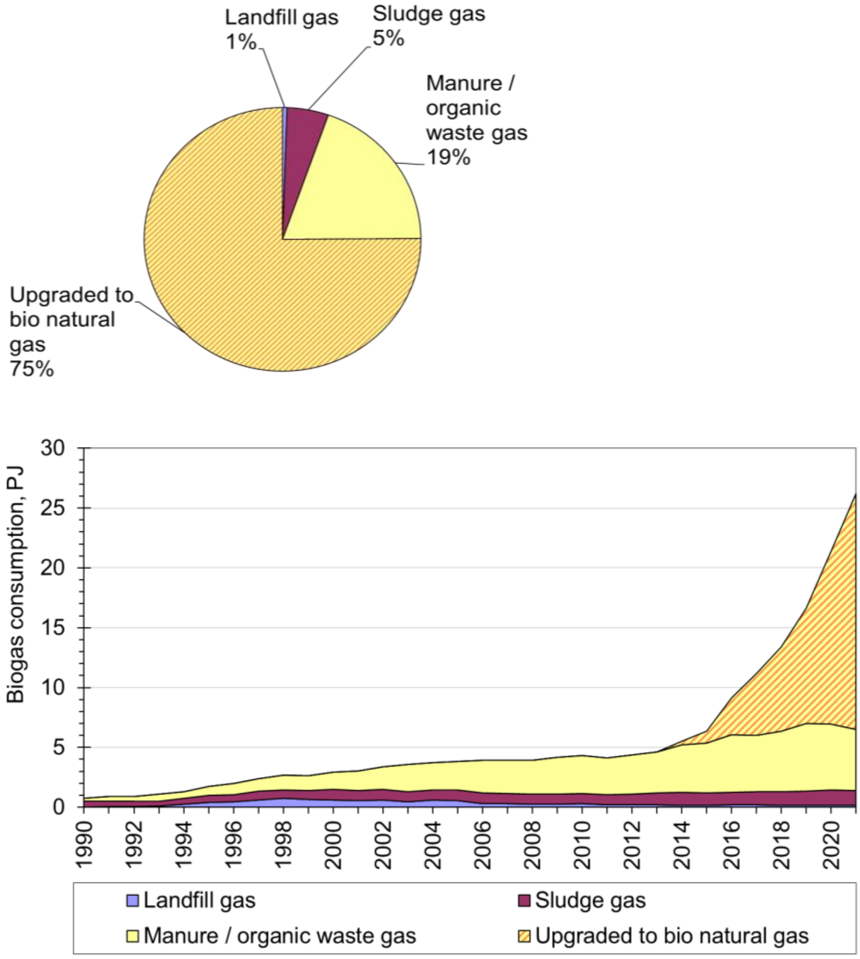


Figure 3.2.36 Biogas types (including biomethane) 2021 and the corresponding time series 1990-2021 (DEA, 2022e; DEA 2022a).

3.2.6 Emission factors

For each fuel and SNAP category (sector and e.g. type of plant), a set of general area source emission factors has been determined. The GHG emission factors are either nationally referenced or based on the IPCC Guidelines

[12] Based on manure with addition of other organic waste.

(2006). The emission factors for other pollutants are either nationally referenced or based on the EMEP/EEA Guidebook (EEA, 2019).

An overview of the type of CO_2 emission factor is shown in Table 3.2.20. A complete list, of emission factors including time series and references, is provided in Annex 3A-4.

EU ETS data for CO_2

The CO_2 emission factors for some large power plants and for combustion in the cement industry and refineries are plant specific and based on the reporting to the EU Emission Trading Scheme (EU ETS). In addition, emission factors for offshore gas turbines and refinery gas are based on EU ETS data. The EU ETS data have been applied for the years 2006 - 2021. For 2021, the EU ETS data set include data for CO_2 emission from biomass.

The EU ETS data are also applied for other source categories and are further discussed in Chapter 1.4.10.

The Danish emission inventory for stationary combustion only includes CO_2 emission data from plants using higher tier methods as defined in the EU decision (EU Commission, 2018), where the specific methods for determining carbon contents, oxidation factor and calorific value are specified. The EU decision includes rules for measuring, reporting and verification.

Fuel consumption data from EU ETS are included for some additional plants and fuels, e.g. biomass fuels.

For each of the plants included with plant and fuel specific CO_2 emission factors in the Danish inventory all applied methodologies are specified in individual monitoring plans that are approved by Danish authorities (DEA) prior to the reporting of the emissions. The plant and fuel specific CO_2 emission factors included in the Danish inventory are all based on fuel quality measurements[13], not default values from the Danish UNFCCC reporting. All fuel analyses are performed according to ISO 17025.

DCE performs QC checks on the reported emission data, see Chapter 1.4.10.

EU ETS data presentation

The EU ETS data include plant specific emission factors for the fossil fuels coal, residual oil, gas oil, natural gas, refinery gas, petroleum coke, coke oven coke and fossil waste. The EU ETS data accounted for 59 % of the fossil CO_2 emission from stationary combustion in 2021.

EU ETS data for coal

EU ETS data for 2021 were available from 14 coal fired plant (or units). The plant specific information accounts for 97 % of the Danish coal consumption and 30 % of the total fossil CO_2 emission from stationary combustion plants.

Data from 13 of the 14 plants have been applied for estimating an average CO_2 emission factor for coal[14]. The average CO_2 emission factor for coal for these

[13] Applying specific methods defined in the EU decision.
[14] Fuel consumption of the 13 plants adds up to more than 99.9% of the fuel consumption of the 14 plants. One plant is not considered representative for the coal consumption in Denmark.

13 units was 93.94 kg per GJ (Table 3.2.12). The plants all apply bituminous coal.

Table 3.2.12 EU ETS data for 13 coal fired plants, 2021.

	Average	Min	Max
Heating value, GJ per tonne	24.1	21.5	29.7
CO_2 implied emission factor, kg per GJ[1)]	93.94	92.54	97.87
Oxidation factor	0.996	0.985	1.000

1) Including oxidation factor.

Table 3.2.13 CO_2 implied emission factor time series for coal fired plants based on EU ETS data.

Year	CO_2 implied emission factor, kg per GJ[1)]
2006	94.4
2007	94.3
2008	94.0
2009	93.6
2010	93.6
2011	94.7
2012	94.25
2013	93.95
2014	94.17
2015	94.46
2016	94.95
2017	94.37
2018	94.04
2019	94.13
2020	94.20
2021	93.94

1) Including oxidation factor.

EU ETS data for residual oil

EU ETS data for 2021 based on higher tier methodologies were available from 8 plants (or units) combusting residual oil. The EU ETS data accounts for 90 % of the residual oil consumption in stationary combustion.

Data from 7 of the 8 plants have been applied for estimating an average CO_2 emission factor for residual oil[15]. Aggregated data and time series are shown in Table 3.2.14 and Table 3.2.15.

Table 3.2.14 EU ETS data for 7 plants combusting residual oil.

	Average	Min	Max
Heating value, GJ per tonne	40.7	40.5	40.9
CO_2 implied emission factor, kg per GJ	79.15	75.79	79.75
Oxidation factor	1.000	1.000	1.000

15 Fuel consumption of the 7 plants adds up to 72% of the fuel consumption of the 8 plants. The remaining plant is not considered representative for the residual oil consumption in Denmark.

Table 3.2.15 CO_2 implied emission factor time series for residual oil fired power plant units based on EU ETS data.

Year	CO_2 implied emission factor, kg per GJ[1)]
2006	78.2
2007	78.1
2008	78.5
2009	78.9
2010	79.2
2011	79.25
2012	79.21
2013	79.28
2014	79.49
2015	79.17
2016	79.29
2017	79.19
2018	79.42
2019	79.32
2020	79.03
2021	79.15

1) Including oxidation factor.

EU ETS data for gas oil

EU ETS data for 2021 based on higher tier methodologies were included from only one plant combusting gas oil. Emission factor average values are shown in Table 3.2.16. The 2019-2021 emission factors are not included because data are only available from one plant.

Table 3.2.16 CO_2 implied emission factor time series for gas oil based on EU ETS data.

Year	CO_2 implied emission factor, kg per GJ[1)]
2006	75.1
2007	74.9
2008	73.7
2009	75.1
2010	74.8
2011	74.7
2012	73.9
2013	72.7
2014	74.2
2015	73.8
2016	74.4
2017	74.7
2018	74.2
2019	-
2020	-
2021	-

1) Including oxidation factor. The 2019-2021 value are not shown because data were only available from one plant.

EU ETS data for waste

EU ETS data for 2021 based on higher tier methodologies were included from 20 waste incineration plants (or units). The EU ETS data for waste incineration are based on emission measurements. The EU ETS data for 2021 included CO_2-emission data for the biomass part of the waste. These data represent new knowledge. The average emission factor values are shown below.

The average emission factor for <u>fossil CO_2</u> emission is based on 19 units[16]. The average fossil waste emission factor is 41.2 kg fossil CO_2 per kg total waste. The interval is 30.6 kg per GJ to 60.3 kg per GJ. The time series for the fossil CO_2-emission factor is shown in Table 3.2.18.

[16] The waste applied in one unit is not considered representative.

Table 3.2.17 EU ETS data for waste incineration, 19 units with data for fossil CO_2.

	Average	Min	Max
Heating value, GJ per tonne	10.62	10.60	10.80
Fossil CO_2 implied emission factor, kg fossil CO_2 per GJ total waste	41.20	30.6	60.3
Oxidation factor	1.000	1.000	1.000

Table 3.2.18 Fossil CO_2 implied emission factor time series for waste incineration.

Year	CO_2 implied emission factor, kg per GJ
2013	43.0
2014	40.8
2015	43.3
2016	43.0
2017	41.4
2018	43.5
2019	42.5
2020	42.6
2021	41.2

The average emission factor for biogenic CO_2 emission is based on 15 units[17]. The average emission factors for fossil CO_2, biogenic CO_2 and total CO_2 are shown in Table 3.2.19. The average fossil CO_2 emission factor is 41.5 kg per GJ, the average biogenic CO_2 emission factor is 59.2 kg per GJ and thus the total CO_2 emission factor is 100.7 kg per GJ. The revised CO_2 emission factor for biomass waste is based on the EU ETS data for 2021, see also page 135.

Table 3.2.19 EU ETS data for waste incineration, 15 units with data for fossil and biogenic CO_2.

	Avg	Min	Max
Heating value, GJ per tonne	10.60	10.60	10.60
Oxidation factor	1.000	1.000	1.000
Fossil CO_2 implied emission factor, kg fossil CO_2 per GJ total waste	41.54	30.6	60.3
Biogenic CO_2 implied emission factor, kg biogenic CO_2 per GJ total waste	59.16	45.22	93.62
Total CO_2 implied emission factor, kg CO_2 per GJ waste	100.70	82.39	124.26

The EU ETS data includes a fuel category for mixed fossil and biomass. This fuel category is included in the fuel categories waste or industrial waste in the emission inventory. Data are not presented here, because data are confidential.

The EU ETS data accounts for 79 % of the energy content of incinerated waste (including industrial waste).

EU ETS data for petroleum coke, coke oven coke, industrial waste and natural gas

The implemented EU ETS data set also includes CO_2 emission factors for industrial waste, petroleum coke and coke oven coke. The industrial plants with additional EU ETS data include cement industry, sugar production, glass wool production, lime production, and vegetable oil production.

[17] A few units did not include data for biogenic CO_2.

EU ETS data for natural gas applied in offshore gas turbines

EU ETS data have been applied to estimate an average CO_2 emission factor for natural gas combusted in offshore gas turbines, see page 134.

EU ETS data for refinery gas

EU ETS data are also applied for the two refineries in Denmark. The emission factor for refinery gas is based on EU ETS data, see page 133.

CO_2 emission factors

The CO_2 emission factors that are not included in EU ETS data or that are included but based on lower tier methodologies are not plant specific in the Danish inventory. The emission factors that are not plant specific accounts for 39 % of the fossil CO_2 emission.

The CO_2 emission factors applied for 2021 are presented in Table 3.2.20. Time series have been estimated for:

- Coal
- Residual oil
- Refinery gas
- Natural gas applied in offshore gas turbines
- Natural gas, other
- Waste, fossil part
- Wood

For all other fuels, the same emission factor has been applied for 1990-2021.

In the reporting to the UNFCCC, the CO_2 emission is aggregated to six fuel types: solid fuels, liquid fuels, gaseous fuels, other fossil fuels, peat, and biomass. Peat is not combusted in Denmark. The correspondence list between the DCE fuel categories and the IPCC fuel categories is also provided in Table 3.2.20.

Only emissions from fossil fuels are included in the total national CO_2 emission. The biomass emission factors are also included in the table, because emissions from biomass are reported to the UNFCCC as a memo item.

The CO_2 emission from incineration of waste is divided into two parts: The emission from combustion of the fossil content of the waste, which is included in the national total, and the emission from combustion of the biomass part, which is reported as a memo item. In the CRF, the fuel consumption and emissions from the fossil content of the waste is reported in the fuel category Other fossil fuels whereas the biomass part is reported in fuel category Biomass.

Table 3.2.20 CO_2 emission factors, 2021.

Fuel	Emission factor, kg per GJ Biomass	Fossil fuel	Reference type	IPCC fuel category
Coal	-	93.94 [1)]	Country specific	Solid
Brown coal briquettes	-	97.5	IPCC (2006)	Solid
Coke oven coke	-	107 [3)]	IPCC (2006)	Solid
Other solid fossil fuels [6)]	-	118 [1)]	Country specific	Solid
Fly ash fossil (from coal)	-	93.94	Country specific	Solid
Petroleum coke	-	93 [3)]	Country-specific	Liquid
Residual oil	-	79.15 [1)]	Country-specific	Liquid
Gas oil	-	74.1 [1)]	Country-specific	Liquid
Kerosene	-	71.9	IPCC (2006)	Liquid
Orimulsion	-	80 [2)]	Country-specific	Liquid
LPG	-	64.8	Country-specific	Liquid
Refinery gas	-	56.486	Country-specific	Liquid
Natural gas, offshore gas turbines	-	57.356	Country-specific	Gas
Natural gas, other [7)]	-	55.47	Country-specific	Gas
Waste	59.2 [3)4)]	+ 42.5[1)3)4)]	Country-specific	Biomass and Other fuels
Industrial waste	59.2 [3)4)]	+ 42.5[1)3)4)]	Country-specific	Biomass and Other fuels
Straw	100	-	Country-specific	Biomass
Wood (national average 2021 for fire-wood, wood chips and wood waste)	103.4	-	Country-specific	Biomass
Wood pellets	97.4	-	Country-specific	Biomass
Bio oil	70.8	-	IPCC (2006)	Biomass
Biogas	81.9	-	Country-specific	Biomass
Biomass gasification gas	142.9[5)]	-	Country-specific	Biomass
Biomethane [7)]	54.9	-	Country-specific	Biomass

1) Plant specific data from EU ETS incorporated for individual plants.
2) Not applied in 2021. Orimulsion was applied in Denmark in 1995 – 2004.
3) Plant specific data from EU ETS incorporated for cement industry and sugar, lime and mineral wool production.
4) The emission factor for waste is (42.5+59.2) kg CO_2 per GJ waste. The fuel consumption and the CO_2 emission have been disaggregated to the two IPCC fuel categories Biomass and Other fossil fuels in CRF. The corresponding fossil CO_2 emission factor for Other fuels is 94.4 kg CO_2 per GJ fossil waste and 107.6 kg biomass CO_2 per GJ biomass waste.
5) Includes a high content of CO_2 in the gas.
6) Anodic carbon. Not applied in Denmark in 2014-2021.
7) Gas distributed in the gas grid consist of a mixture of two fuels: Biomethane and (fossil) natural gas. The two fuels are treated as separate fuels in the emission inventories, see also Chapter 3.2.3

Coal

As mentioned above, EU ETS data have been utilised for the years 2006 - 2021 in the emission inventory. The emission factor for coal is the implied emission factor for plants that report EU ETS data that are based on fuel analysis. Data for industrial plants have been included. In 2021, the implied emission factor (including oxidation factor) was 93.94 kg per GJ. The implied emission factor values were between 92.54 and 97.87 kg per GJ.

The emission factors for coal in the years 2006-2021 refer to the implied emission factors of the EU ETS data estimated for each year. For the years 1990-2005, the emission factor for coal (94 kg/GJ) refers to the average IEF for 2006-2010.

Time series for net calorific value (NCV) of coal are available in the Danish energy statistics. NCV for Electricity plant coal and Other hard coal fluctuates in the interval 23.89-26.88 GJ per tonne. The correlation between NCV and CO_2 IEF (including the oxidation factor) in the EU ETS data (2006-2009) have been analysed and the results are shown in Annex 3A-9. However, a significant correlation between NCV and IEF have not been found in the dataset and thus an emission factor time series based on the NCV time series was not relevant. In addition, the correlation of NCV and CO_2 emission factors has been analysed. This analysis is also shown in Annex 3A-9. As expected, the correlation was better in this dataset, but still insufficient for estimating a time series for the CO_2 emission factor based on the NCV time series. All coal applied in Denmark is bituminous coal (DEA, 2022c) and within the range of coal qualities applied in the plants reporting data to EU ETS a correlation could not be documented.

In 2021, the CO_2 emission from coal consumption was based on the emission factor (93.94 kg per GJ) for 2.5 % of the coal consumption. The remaining 97.5 % was covered by EU ETS data.

Time series for the CO_2 emission factor are shown in Table 3.2.21.

Table 3.2.21 CO_2 emission factor time series for coal.

Year	CO_2 emission factor kg per GJ
1990-2005	94.0
2006	94.4
2007	94.3
2008	94.0
2009	93.6
2010	93.6
2011	93.73
2012	94.25
2013	93.95
2014	94.17
2015	94.46
2016	94.95
2017	94.37
2018	94.04
2019	94.13
2020	94.20
2020	93.94

Brown coal briquettes

The emission factor for brown coal briquettes, 97.5 kg per GJ refers to the IPCC Guidelines, 2006 (IPCC, 2006). The oxidation factor has been assumed equal to 1. The same emission factor has been applied for 1990-2021.

Coke oven coke

The emission factor for coke oven coke, 107 kg per GJ, refers to the IPCC Guidelines 2006 (IPCC, 2006). The oxidation factor has been assumed equal to 1. The same emission factor has been applied for 1990-2021.

Other solid fossil fuels (Anodic carbon)

Anodic carbon was not applied in 2021. Anodic carbon has been applied in Denmark in 2009-2013 in two mineral wool production units. The emission factor 118 kg per GJ refer to EU ETS data from one of the plants in 2012.

The emission factor is not applied because plant specific data are available from the EU ETS dataset.

Fly ash fossil (from coal)

Fly ash from coal combustion is applied in some power plants. The emission factor has been assumed equal to the emission factor for coal.

Petroleum coke

The emission factor 93 kg per GJ is based on EU ETS data for 2006-2010. The data includes one power plant and the cement production plant.

Plant specific EU ETS data have been utilised for the cement production for the years 2006 - 2021.

Residual oil

The emission factor for residual oil is based on EU ETS data.

EU ETS data have been utilised for the 2006 - 2021 emission inventories. In 2021, the implied emission factor (including oxidation factor) for the plants combusting residual oil was 79.15 kg per GJ. The implied emission factor values were between 75.79 and 79.75 kg per GJ.

The emission factors for residual oil in the years 2006-2021 refer to the implied emission factors of the EU ETS data estimated for each year. For the years 1990-2005, the emission factor for residual oil refers to the average IEF for 2006-2010.

In 2021, the CO_2-emission estimate was based on the emission factor for 10 % of the residual oil consumption, whereas plant specific EU ETS data were available for 90 % of the residual oil consumption.

Time series for the CO_2 emission factor are shown in Table 3.2.22.

Table 3.2.22 CO_2 emission factor time series for residual oil.

Year	CO_2 emission factor kg per GJ
1990-2005	78.7
2006	78.6
2007	78.5
2008	78.5
2009	78.9
2010	79.2
2011	79.25
2012	79.21
2013	79.28
2014	79.49
2015	79.17
2016	79.29
2017	79.19
2018	79.42
2019	79.32
2020	79.03
2021	79.15

Gas oil

The emission factor for gas oil, 74.1 kg per GJ, is based on EU ETS data for the years 2008-2016. The emission factor is consistent with the IPCC default emission factor for gas oil (74.1 kg per GJ). The same emission factor has been applied for 1990-2021.

Plant specific EU ETS data have been utilised for a few plants each year in the 2006 - 2021 emission inventories. In 2021, EU ETS data were only available from one plant representing less than 1 % of the consumption of gas oil.

Kerosene

The emission factor for kerosene, 71.9 kg per GJ, refers to IPCC Guidelines (IPCC, 2006). The same emission factor has been applied for 1990-2021.

Orimulsion

The emission factor for orimulsion, 80 kg per GJ, refers to the Danish Energy Agency (DEA, 2022a). The IPCC default emission factor is almost the same: 80.7 kg per GJ assuming full oxidation. The CO_2 emission factor has been confirmed by the only major power plant operator using orimulsion (Andersen, 1996). The same emission factor has been applied for all years. Orimulsion was used in Denmark in 1995-2004.

LPG

Emission factor 2019 onwards

According to Danish legislation the butane content of LPG is below 7.5 % and the content of higher hydrocarbons (C5+) below 0.2 % (Danish Safety Technology Authority, 2018; Danish Safety Authority, 2012). Thus, since 2012 the minimum content of propane is 92.3 %.

According to Drivkraft Danmark, the LPG delivered to Denmark has a propane content of minimum 93 % in recent years (Rosvall, 2021). Bio LPG sold in Denmark is based on certificates from other countries (Rosvall, 2021) and thus all LPG applied in Denmark is considered fossil.

The CO_2 emission factor 64.8 kg/GJ (based on Rosvall, 2021) will be applied for 2019 onwards. This emission factor is based on the gas composition from Drivkraft Danmark, 93 % propane and 7 % butane (Rosvall, 2021). The 93 % propane on which the estimate is based is a minimum, but the emission factor for 100 % propane is 64.6 kg/GJ and thus the emission factor is in the interval 64.6-64.8 kg/GJ.

Different mixtures of propane and butane have been considered and the estimated CO_2 emission factors and calorific values for each of them are shown in Table 3.2.23. For all the considered compositions, the CO_2 emission factors are higher than the emission factor from IPCC Guidelines (2006). The emission factor in IPCC Guidelines (2006), 63.1 kg/GJ, is lower than the emission factors for both propane and butane (see Table 3.2.23 and Juhrich, 2016). The butane content has been considered 1/3 i-Butane and 2/3 n-butane referring to Kjellander (2021).

In Germany, Sweden, Norway and the Netherlands the applied emission factor for 2019 were 66.33 kg/GJ (NIR Germany, 2021)[18], 65.1 kg/GJ (NIR Sweden, 2021), 65.08 kg/GJ (NIR Norway, 2021), and 66.7 kg/GJ (NIR Netherlands, 2021) respectively.

Time series

In 1990-2005, mixed gases with higher butane content was also sold in Denmark (Rosvall, 2021; Kjellander, 2021; Tønder, 2021). The applied mixed gases were primarily applied for vehicles (Kjellander, 2021; Tønder, 2021) and the mixture proportions were 30%/70% in the summer and 50%/50% in the winter (Rosvall, 2021). The use of mixed gases is included in the fuel category LPG in the energy statistics. However, the use of mixed gases was low. The average

[18] 64.0-66.6 kg/GJ (Juhrich, 2016).

LPG composition including mixed gases have been estimated to be 90 % propane and 10 % butane in 1990 (Rosvell, 2021; Kjellander, 2021). In 2005-2017, the minimum propane content was 95 % (Tønder, 2021).

The estimated CO_2 emission factors for different butane shares of LPG is shown in Table 3.2.23. The emission factors for both the 1990 and the 2019 composition is 64.8 kg/GJ. The CO_2 emission factor for 2005-2017 is 64.7 kg/GJ. Due to the marginal difference and the uncertainty, DCE has decided to use the CO_2 emission factor 64.8 kg/GJ for all years.

Table 3.2.23 Estimated LCV and CO_2 emission factors for different LPG compositions.

	Propane	Butane[19]	LCV, MJ/kg	CO_2 emission factor, kg/GJ
LPG according to legislation for LPG gas quality[20] (Danish Safety Technology Authority, 2018)	92.5 %	<7.5 %	46.3	64.8
LPG according to Drivkraft Danmark (Rosvall, 2021)	93 %	7 %	46.3	64.8
LPG according to specification 2005-2017 (Tønder, 2021)	95 %	5 %	46.3	64.7
LPG applied in 1990, (Rosvall, 2021; Kjellander, 2021)	90 %	10 %	46.2	64.8
100 % propane	100 %	0%	46.3	64.6
100 % butane (1/3 i-Butane)	0 %	100 %	45.7	66.3
100 % i-Butane	0 %	100 %	45.6	66.5
100 % n-Butane	0 %	100 %	45.7	66.2

Refinery gas

The emission factor applied for refinery gas refers to EU ETS data for the two refineries in operation in Denmark. Since 2006, implied emission factors for Denmark have been estimated annually based on the EU ETS data. The average implied emission factor for 2006-2009 (57.6 kg per GJ) have been applied for the years 1990-2005. This emission factor is consistent with the emission factor stated in the IPCC Guidelines (IPCC, 2006). The time series is shown in Table 3.2.24.

Table 3.2.24 CO_2 emission factors for refinery gas, time series.

Year	CO_2 emission factor, kg per GJ
1990-2005	57.6
2006	57.812
2007	57.848
2008	57.948
2009	56.817
2010	57.134
2011	57.861
2012	58.108
2013	58.274
2014	57.620
2015	57.508
2016	57.335
2017	57.109
2018	56.144
2019	56.452
2020	56.813
2021	56.486

19 Assumed 2/3 n-Butane and 1/3 i-butane (Kjellander, 2021).
20 <0.2 % higher hydrocarbons (C5+) have not been taken into account.

Natural gas, offshore gas turbines

EU ETS data for the fuel consumption and CO_2 emission for offshore gas turbines are available for the years 2006-2021. Based on data for each oilfield, implied emission factors have been estimated for 2006-2021. The average value for 2006-2009 has been applied for the years 1990-2005. The time series is shown in Table 3.2.25.

Table 3.2.25 CO_2 emission factors for offshore gas turbines, time series.

Year	CO_2 emission factor, kg per GJ
1990-2005	57.469
2006	57.879
2007	57.784
2008	56.959
2009	57.254
2010	57.314
2011	57.379
2012	57.423
2013	57.295
2014	57.381
2015	57.615
2016	57.704
2017	57.628
2018	57.639
2019	57.588
2020	57.456
2021	57.356

Natural gas, other source categories

The fuel category Natural gas refer to fossil natural gas. In recent years, biomethane[21] has also been distributed in the gas grid in Denmark. Natural gas (fossil) and biomethane is considered two separate fuels in the emission inventory.

The emission factor for natural gas is estimated by the Danish gas transmission company, Energinet.dk[22]. The calculation is based on gas analysis carried out daily by Energinet.dk at Egtved.

The offshore gas platform Tyra in the North Sea has for decades been the major gas supplier for Denmark. The platform is shut down for redevelopment from September 2019 to winter 2023/2024 (Energinet.dk, 2023). Thus in 2021, the import of natural gas is high, and the production low compared to the years before 2019. This cause a change of gas quality and CO_2 emission factor in 2020 and 2021. In 2021, the natural gas production was 53 PJ, the import was 87 PJ, the export 64 PJ.

Before 2010, only natural gas from the Danish gas fields was utilised in Denmark. Energinet.dk have stated that the difference between the emission factor for 2011 based on measurements at Egtved and the average value at Froeslev very close to the border differed less than 0.3 % for 2011 (Bruun, 2012).

Energinet.dk and the Danish Gas Technology Centre have calculated emission factors for 2000-2021. The emission factor applied for 1990-1999 refers to Fenhann & Kilde (1994). This emission factor was confirmed by the two major

[21] Biomethane.

[22] Former Gastra and before that part of DONG. Historical data refer to these companies.

power plant operators in 1996 (Christiansen, 1996 and Andersen, 1996). The time series for the CO_2 emission factor is provided in Table 3.2.26.

Table 3.2.26 CO_2 emission factor time series for natural gas.

Year	CO_2 emission factor, kg per GJ
1990-1999	56.9
2000	57.1
2001	57.25
2002	57.28
2003	57.19
2004	57.12
2005	56.96
2006	56.78
2007	56.78
2008	56.77
2009	56.69
2010	56.74
2011	56.97
2012	57.03
2013	56.79
2014	56.95
2015	57.06
2016	57.01
2017	57.00
2018	56.89
2019	56.54
2020	55.52[1)]
2021	55.47[1)]

1) The low CO_2 emission factor in 2020 and 2021 is caused by shut down of the offshore gas platform Tyra in the North Sea. The platform is shut down for redevelopment from September 2019 to winter 2023/2024 (Energinet.dk, 2023). The gas quality of import gas differs from the gas quality from Tyra.

Waste – fossil CO_2 and biomass CO_2

The CO_2 emission from incineration of waste is divided into two parts: The emission from combustion of the fossil content of the waste, which is included in the national total, and the emission from combustion of the rest of the waste – the biomass part, which is reported as a memo item.

EU ETS data included only data for fossil CO_2 for the years 2013-2020. For 2021, EU ETS data included data for both fossil CO_2 and biomass CO_2.

Fossil CO_2

The fossil CO_2 emission factor 42.5 kg fossil CO_2 per GJ total waste is based on EU ETS data for 2013-2016. The annual average emission factors for the plants that applied plant specific data are shown in Table 3.2.27 below. The emission factor applied for 2013-2021 is the average value for 2013-2016, 42.5 kg fossil CO_2 per GJ total waste. The emission factor for the fossil fraction corresponds to 94.44 kg fossil CO_2 per GJ fossil waste.

The increasing waste separation and recycling might influence the composition of incinerated waste. However, so far the annual average values of EU ETS emission data have not indicated a need for revision of the emission factor.

As mentioned, plant specific EU ETS data for fossil CO_2 emission have been reported by CHP plants incinerating waste for 2013-2021. In the emission inventory for 2021, plant specific emission factors have been implemented for

20 plants or units using municipal waste. In 2021, the average fossil CO_2 emission factor for 19 plants (one plant not included, se also EU ETS data presentation above) was 41.2 kg fossil CO_2 per GJ total waste. The emission factors vary between plants – 30.6 kg per GJ to 60.3 kg per GJ.

The CO_2 emission data included from EU ETS are based on flue gas emission measurements. The content of biogenic and fossil carbon is based on measurements. Two different methods are applied: a radiocarbon dating (14C analysis) of CO_2 sampled from the flue gas, and an approved mass and energy balance calculation.

The EU ETS data accounts for 79 % of the energy content of incinerated waste (including industrial waste).

The emission factor for 1990-2010 is based on the project, *Biogenic carbon in Danish combustible waste* that included emission measurements from five Danish waste incineration plants (Astrup et al., 2012). The average of the fossil emission factors for waste was estimated to be 37 kg per GJ waste and the interval for the five plants was 25 – 51 kg per GJ. The five plants represented 44 % of the incinerated waste in 2010. The emission factor 37 kg per GJ waste corresponds to 82.22 kg per GJ fossil waste.

The time series for the fossil CO_2 emission factor is shown in Table 3.2.28.

Table 3.2.27 Average fossil CO_2 emission factors based on EU ETS data for waste.

Year	Fossil CO_2 emission factor, kg fossil CO_2 per GJ waste (total)
2013	43.0
2014	40.8
2015	43.3
2016	43.0
2017	41.4
2018	43.5
2019	42.5
2020	42.6
2021	41.2
Average 2013-2016	42.5

Table 3.2.28 Time series for the fossil CO_2 emission factor for waste.

Year	CO_2 emission factor, kg per GJ
1990-2010	37.0
2011	37.5
2012	40.0
2013-2021	42.5

Data from the waste statistics have been analysed with the purpose to improve the time series for 1990-2012 of the fossil waste emission factor. However, the data analysis has shown that is difficult to relate the available waste fraction data and the measured fossil CO_2 emission. Thus, currently it is not possible to estimate an improved time series for the emission factor for the years 1990-2012.

Biomass CO_2

The CO_2 emission factor for the biomass part of waste is based on plant specific emission data reported to the EU ETS for 2021. The estimated emission factor is 59.2 kg biogenic CO_2 per GJ total waste. Assumed that 55 % of the energy content of waste is biogenic, this corresponds to 107.6 kg biogenic CO_2 per GJ biogenic waste.

The emission factor is based on 15 data sets including both total CO_2 emission and fossil CO_2 emission. The plants represent 86 % of the municipal waste consumption in EU ETS (industrial waste excluded) or 62 % of the total waste consumption (including industrial waste) in Denmark in 2021.

For the years before 2021, the total CO_2 emission and the biomass CO_2 emission was not reported in the EU ETS data. The CO_2 emission factor for the biomass part of waste applied for 1990-2020 has been assumed equal to the CO_2 emission factor for 2021.

Industrial waste – fossil CO_2 and biomass CO_2

The fuel category industrial waste is only applied for one plant; the cement production plant Aalborg Portland. The waste applied in this plant differ considerably from waste applied in waste incineration plants.

Plant specific data are considered confidential, and thus the *default* CO_2 emission factors for both Other fuels (fossil) (42.5 kg fossil CO_2 per GJ total waste) and biomass (59.2 kg biogenic CO_2 per GJ total waste) are equal to the CO_2 emission factors for waste. However, only the plant specific emission factors are actually applied.

Plant specific data for fossil CO_2 emission are available from EU ETS since 2006, and thus the emission inventories are based on these data.

The CO_2 emission data for the biomass part of waste is based on plant specific emission data reported to the EU ETS for 2021. Data are confidential, but plant specific data have been implemented in the emission inventory.

The waste applied by Aalborg Portland includes several industrial waste products but no municipal waste. The fossil content of each of the applied waste fuels is defined in the EU ETS data.

Wood

The CO_2 emission factor for wood has been revised this year.

The fuel category Wood includes three fuel categories from the Danish energy statistics:

- Firewood
- Wood chips
- Wood waste

Wood pellets is included as a separate fuel in the emission inventory and thus not included in the fuel category Wood.

The carbon content of dry wood is considered the same for all three wood types, but the water content and thus the LCV is different for the three wood types.

Lower heating value (LCV)

The lower heating value (LCV) of firewood applied in the Danish energy statistics is 10.40 GJ/m^3 for hardwood[23] and 7.60 GJ/m^3 for conifer[23]. These values are based on 15 % water content and refers to a note from the Danish Energy Agency that was updated by EA Energy Analysis in 2018 (EA & DEA, 2018b). The LCVs are 18.7 GJ/tonne dry matter for hardwood and 19.4 GJ/tonne dry matter for conifer (EA & DEA, 2018b). The estimated LCVs in GJ/tonne with a water content of 15 % are:

Deciduous:	18.7 GJ/tonne • 0.85 – 2.45 GJ/tonne • 0.15 = 15.5 GJ/tonne
Conifers:	9.4 GJ/tonne • 0.85 – 2.45 GJ/tonne • 0.15 = 16.1 GJ/tonne

The lower heating value (LCV) of wood chips applied in the Danish energy statistics is 9.30 GJ/tonne. This value is based on 45 % water content and refers to a note from the Danish Energy Agency that was updated by EA Energy Analysis in 2018 (EA & DEA, 2018c).

According to EA & DEA (2018c), the dry matter calorific value is 19.0 GJ/tonne and with a 45 % water content the LCV 9.30 GJ/tonne is estimated.

19.0 GJ/tonne • 0.55 – 2.45 GJ/tonne • 0.45 = 9.3 GJ/tonne

However, plant specific data from EU ETS are available for a larger number of plants using wood chips. The plant specific LCVs reported to EU ETS for 2014-2021 have been collected. The average LCV for plants with plant specific with plant specific data is 10.42 GJ/tonne for 2014-2021. The plants with plant specific LCVs represent 44 – 59 % of the annual total wood chip consumption in Denmark.

Based on the LCV for dry wood 19 GJ/tonne and the LCV for wet wood 10.42 GJ/tonne, the water content is estimated to be 40 % and thus lower than the water content applied in the Danish energy statistics.

19.0 GJ/tonne • 0.60 – 2.45 GJ/tonne • 0.40 = 10.4 GJ/tonne

The values based on EU ETS is applied for estimating the CO_2 emission factor for wood chips. DEA has indicated that the LCV in the energy statistics will be revised next year (DEA, 2023).

The lower heating value (LCV) of wood waste applied in the Danish energy statistics is 14.7 GJ/tonne. This value is based on 20 % water content and refers to a note from the Danish Energy Agency that was updated by EA Energy Analysis in 2018 (EA & DEA, 2018d).

According to EA & DEA (2018d), the dry matter calorific value is 19.0 GJ/tonne and with a 20 % water content the LCV 14.7 GJ/tonne is estimated.

19.0 GJ/tonne • 0.80 – 2.45 GJ/tonne • 0.20 = 14.7 GJ/tonne

A large part of the consumption of wood waste is included in EU ETS, but in general for waste wood the default LCV has been applied rather than plant specific data.

[23] m^3 of solid wood volume.

CO_2 emission factor

The carbon content of wood is available from several studies, see Table 3.2.29. The carbon content 50 %-weight (dry matter) is applied for all three wood types. The LCV (dry) 19.0 GJ/tonne is applied for all three wood types (EA & DEA, 2018b; EA & DEA, 2018c; EA & DEA, 2018d).

Table 3.2.29 Carbon content in wood.

Reference	Wood type	Carbon content, %-w dry basis
Bech & Dahlin (1989)	Wood	(37.5 wet) 50.0
Frey (2019)	Wood	50
Bäfver et al. (2011)	Wood logs	50.6
Gustavsson et al. (2004)	Wood logs	50.6
Johansson et al. (2004)	Wood logs	50.6
Lamlom & Savidge (2003)	Hardwood (22 types)	46.27-49.97
Lamlom & Savidge (2003)	Softwood (19 types)	47.21-55.2
Schmidl et al. (2011)	Beech logs	50
Schmidl et al. (2011)	Briquettes	51
Schmidl et al. (2011)	Oak logs	48
Schmidl et al. (2011)	Spruce logs	51
Schmidl et al. (2011)	Wood chips	47

The estimated CO_2 emission factors for wood are:

Firewood: (1000• 0.50•(1-0.15)•44/12)/(19*(1-0.15)-2.45•0.15) = 98.7 kg/GJ

Wood chips: (1000•0.50•(1-0.40)•44/12)/(19*(1-0.40)-2.45•0.40) = 105.6 kg/GJ

Wood waste: (1000• 0.50•(1-0.20)•44/12)/(19*(1-0.20)-2.45•0.20) = 99.7 kg/GJ

The revised emission factors are all below the IPCC (2006) default emission factor for wood, 112 kg/GJ.

In the emission inventories firewood, wood chips and wood waste are added and thus an implied emission factor for CO_2 based on the Danish energy statistics is applied. The implied emission factor is estimated each year. The same emission factor is applied for all subsectors.

The time series for the CO_2 emission factor is shown in Table 3.2.30.

Table 3.2.30 Time series for the implied emission factor for CO_2 from wood.

Year	Implied emission factor for CO_2 from wood
1990	99.785
1991	99.661
1992	99.718
1993	99.691
1994	99.802
1995	99.819
1996	99.897
1997	99.894
1998	100.081
1999	100.057
2000	99.948
2001	100.009
2002	100.161
2003	100.583
2004	100.615
2005	100.448
2006	100.490
2007	100.293
2008	100.658
2009	100.955
2010	101.041
2011	101.299
2012	101.512
2013	101.275
2014	101.481
2015	101.277
2016	101.537
2017	102.088
2018	102.492
2019	102.793
2020	103.116
2021	103.388

Wood pellets

The CO_2 emission factor for wood pellets has been revised this year.

The lower heating value (LCV) of wood pellets applied in the Danish energy statistics is 17.5 GJ/tonne. This value refers to a note from the Danish Energy Agency that was updated by EA Energy Analysis in 2018 (EA & DEA, 2018e). According to EA & DEA (2018e), the dry matter calorific value is 17.5 GJ/tonne based on numerous laboratory analyses. The water content of wood pellets is 7 % and thus the estimated LCV is

$$19 \text{ GJ/tonne} \bullet 0.07 - 2.45 \text{ GJ/tonne} \bullet 0.07 = 17.5 \text{ GJ/tonne}$$

Based on 50 %-weight (dry) C, the estimated CO_2 emission factor for wood pellets is:

$$\text{Wood pellets} \quad (1000 \bullet 0.50 \bullet (1-0.07) \bullet 44/12)/(19 * (1-0.07)-2.45 \bullet 0.07) = 97.4 \text{ kg/GJ}$$

The CO_2-emission factor 97.4 kg/GJ is applied for all years.

Straw

The CO_2 emission factor for straw has been revised this year.

The lower heating value (LCV) of straw applied in the Danish energy statistics is 14.5 GJ/tonne. This value refers to a note from the Danish Energy Agency that was updated by EA Energy Analysis in 2018 (EA & DEA, 2018a).

According to EA & DEA (2018), the dry matter calorific value is 17.5 GJ/tonne based on numerous laboratory analyses. The water content of straw is 15 % and thus the estimated LCV is

17.5 GJ/tonne • 0.85 – 2.45 GJ/tonne • 0.15 = 14.5 GJ/tonne

The water content and LCV of straw was confirmed by Kristensen (2022a).

The carbon content of straw is available from several studies, see Table 3.2.31. The table also includes data for LCV and water content. Some original data are based on dry straw (d) and some on dry ash free straw (daf).

The emission factor is based on the average value from Videncenter (1995). This reference includes data from Denmark, and the CO_2 emission factor levels agree with other references considered. The estimated emission factor is 100 kg/GJ. This emission factor is be applied for all years.

Table 3.2.31 Data for LCV and carbon content for straw.

Reference	Comments	Water content (weight %)	LCV (GJ/tonne) dry basis[4]	LCV (GJ/tonne) at 15 % water	Carbon content (weight %, dry basis)	Carbon content (weight %, 15 % water)	CO_2 emission factor, kg/GJ
Bech & Dahlin (1989)		10	-	(14.5)[1]	(43 wet) 47.8	40.6	103
Videncenter (1993)	Yellow straw	15		14.4	-		-
Videncenter (1993)	Grey straw	15		15.0	-		-
Videncenter (1995)	Barley 1	-	(18.65 daf) 18.0	14.9	48.13	40.9	101
Videncenter (1995)	Barley 2	-	(18.55 daf) 17.8	14.8	47.44	40.3	100
Videncenter (1995)	Wheat	-	(18.71 daf) 17.8	14.8	47.38	40.3	100
Videncenter (1995)	Rye	-	(18.80 daf) 18.2	15.1	47.38	40.3	98
Videncenter (1995)	Rapeseed	-	(18.63 daf) 17.7	14.7	47.95	40.8	102
Frey et al. (2017)	Yellow straw	10-20[2]	(18.2 daf) 17.5	14.4	(42 wet)[2] 49.4	42[2]	107[2]
Frey et al. (2017)	Grey straw	10-20[2]	(18.7 daf) 18.1	15	(43 wet) [2] 50.6	43[2]	105[2]
Jensen et al. (2017)	Yellow straw	8.8	17.20	14.3	-	-	-
Jensen et al. (2017)	Grey straw	9.4	16.98	14.1	-	-	-
Jensen et al. (2017)	Grey straw	9.2	17.40	14.4	-	-	-
Bakker et al. (2013)	Wheat straw	10.4	(18.181 daf) 16.9	14.0	(49 daf) 45.5	38.7	101
Zeng et al. (2017)	Test fuel A1, wheat straw 2	10.9	16.9	(14.0)	45.3	38.5	101
Zeng et al. (2017)	Test fuel A2, wheat straw 2	9.4	16.5	(13.7)	44.9	38.2	102
Zeng et al. (2017)	Reference fuel A, wheat straw	11.6	16.7	(13.8)	45.8	38.9	103
Skøtt (2011)	Yellow straw	10-20		(14.4[3])	42		-
Skøtt (2011)	Grey straw	10-20		(15.0[3])	43		-

1) Assumed equal to the value applied in the energy statistics.
2) Assumed 15 % water.
3) The water content corresponding to this LCV is unknown.
4) daf: Dry ash-free, d: dry.

Bio oil

The emission factor, 70.8 kg per GJ refers to the IPCC (2006). The consumption of bio oil in stationary combustion plants is below 2 PJ all years.

Biogas

The CO_2 emission factor for biogas has been revised this year.

In Denmark, three different types of biogases are applied: Manure/organic waste-based biogas, landfill-based biogas, and wastewater treatment biogas (sludge gas). Manure / organic waste-based biogas represented 94 % of the biogas production in 2021. Most of the biogas based on manure / organic waste is however upgraded to biomethane, that is included as a separate fuel in the emission inventories. The CO_2 emission factor for biomethane differs from the emission factor for biogas.

The fuel category *Biogas* includes the not-upgraded biogas from manure (79% in 2020), landfill gas (2% in 2020) and sludge gas (19% in 2020). Seven fuel analysis were measured by Kristensen (2003). The fuel analyses, that include manure gas, sludge gas and landfill gas, are shown in Table 3.2.32. The average CO_2 emission factor for five of the fuel analysis have been estimated to 81.9 kg/GJ. Two analyses were not included in the average: #24 is an outlier, and #5 does not sum up to 100 %. The emission factor 81.9 kg/GJ is close to the factor for manure gas.

The emission factor 81.9 kg/GJ is applied for all biogas types and all years in the emission inventory.

Table 3.2.32 Biogas analysis from Kristensen (2003). The CO_2 emission factors have been added by DCE.

Biogas type	CH_4 mol %	CO_2 mol %	N_2 mol %	O_2 mol %	LCV MJ/m^3_n	CO_2 emission factor kg/GJ
Manure gas #4	61.00	33.76	4.48	0.76	21.92	84.9
Manure gas #5 2)	63.06	29.03	6.39	1.17	22.73	79.5
Manure gas #18	69.10	30.00	0.81	0.18	24.82	78.4
Sludge gas #21	64.91	34.10	0.64	0.35	23.33 1)	83.3
Sludge gas #25	67.88	31.30	0.56	0.26	24.39	79.8
Landfill gas #22	62.61	32.29	5.10	0.00	22.5	82.9
Landfill gas #24	47.63	32.63	19.14	0.6	17.11	92.1

1. A typing error in the report has been corrected.
2. The sum is not 100 % for this biogas.

Biomass gasification gas

Biomass gasification gas applied in Denmark is based on wood. The gas composition is known for three different plants and the applied emission factor 142.9 kg/GJ have been estimated by Danish Gas Technology Centre (Kristensen, 2010) based on the gas composition measured on the plant with the highest consumption. The emission factor includes the CO_2-content of the gasification gas.

The consumption of biomass gasification gas is below 2 PJ for all years.

Biomethane

The CO_2 emission factor for biomethane have been revised this year.

Biogas upgraded for distribution in the natural gas grid is referred to as biomethane in this report. Other references might refer to this fuel as bio natural gas or upgraded biogas. Biomethane has been applied in Denmark since 2014.

A typical biomethane composition have been stated by Energinet (Energinet, 2022). The gas composition is 99.15 mole-% CH_4, 0.37 mole-% N_2, 0.12 mole-

% O_2 and 0.36 mole-% CO_2 (Energinet, 2022). This corresponds to the CO_2 emission factor 54.9 kg/GJ. This emission factor is applied all years.

CH_4 emission factors

The CH_4 emission factors applied for 2021 are presented in Table 3.2.33. In general, the same emission factors have been applied for 1990-2021. However, time series have been estimated for both natural gas fuelled engines and biogas fuelled engines, residential wood combustion, natural gas fuelled gas turbines[24] and waste incineration plants.

Emission factors for CHP plants < 25 MW_e refer to emission measurements carried out on Danish plants (Nielsen et al., 2010a; Nielsen & Illerup, 2003; Nielsen et al., 2008). The emission factors for residential wood combustion are based on technology dependent data.

Emission factors that are not nationally referenced all refer to the IPCC Guidelines (IPCC, 2006).

Gas engines combusting natural gas or biogas accounted for 52 % of the CH_4 emission from stationary combustion plants in 2021. The relatively high emission factor for gas engines is well documented and further discussed below.

[24] A minor emission source.

Table 3.2.33 CH_4 emission factors, 2021.

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
SOLID	Coal	1A1a	Public electricity and heat production	0101 0102	0.9	IPCC (2006), Tier 3, Table 2-6, Utility Boiler, Pulverised bituminous coal combustion, Wet bottom.
		1A2 a-g	Industry	03	10	IPCC (2006), Tier 1, Table 2-3, Manufacturing industries.
		1A4b i	Residential	0202	300	IPCC (2006), Tier 1, Table 2.5, Residential, Bituminous coal.
		1A4c i	Agriculture/ Forestry	0203	10	IPCC (2006), Tier 1, Table 2-4, Commercial, coal.[1)]
	BKB	1A4b i	Residential	0202	300	IPCC (2006), Tier 1, Table 2-5, Residential, brown coal briquettes
	Coke oven coke	1A2 a-g	Industry	03	10	IPCC (2006), Tier 1, Table 2-4, Commercial, coke oven coke.
		1A4b i	Residential	0202	300	IPCC (2006), Tier 1, Table 2-5, Residential, coke oven coke.
	Anodic carbon	1A2 a-g	Industry	03	10	IPCC (2006), Tier 1, Table 2-3, Manufacturing industries.
	Fossil fly ash	1A1a	Public electricity and heat production	0101	0.9	IPCC (2006), Tier 3, Table 2-6, Utility Boiler, Pulverised bituminous coal combustion, Wet bottom.
LIQUID	Petroleum coke	1A2 a-g	Industry	03	3	IPCC (2006), Tier 1, Table 2-3, Industry, petroleum coke.
		1A4a	Commercial/ Institutional	0201	10	IPCC (2006), Tier 1, Table 2-4, Commercial, Petroleum coke.
		1A4b	Residential	0202	10	IPCC (2006), Tier 1, Table 2-5, Residential / agricultural, Petroleum coke.
		1A4c	Agriculture/ Forestry	0203	10	IPCC (2006), Tier 1, Table 2-5, Residential / agricultural, Petroleum coke.
	Residual oil	1A1a	Public electricity and heat production	010101	0.8	IPCC (2006), Tier 3, Table 2-6, Utility Boiler, Residual fuel oil.
				010102 010103	1.3	Nielsen et al. (2010a)
				010104	3	IPCC (2006), Tier 1, Table 2-2, Energy industries, residual oil.
				010105	4	IPCC (2006), Tier 3, Table 2-6, Utility, Large diesel engines
				010203	0.8	IPCC (2006), Tier 3, Table 2-6, Utility Boiler, Residual fuel oil.
		1A1b	Petroleum refining	010306	3	IPCC (2006), Tier 1, Table 2-2, Energy industries, residual fuel oil.
		1A2 a-g	Industry	03	1.3	Nielsen et al. (2010a)
				Engines	4	IPCC (2006), Tier 3, Table 2-6, Utility, Large diesel engines
		1A4a	Commercial/ Institutional	0201	1.4	IPCC (2006), Tier 3, Table 2-10, Commercial, residual fuel oil boilers.
		1A4b	Residential	0202	1.4	IPCC (2006), Tier 3, Table 2-9, Residential, residual fuel oil.
		1A4c	Agriculture/ Forestry	0203	1.4	IPCC (2006), Tier 3, Table 2-10, Commercial, residual fuel oil boilers.[1)].
	Gas oil	1A1a	Public electricity and heat production	010101 010102 010103	0.9	IPCC (2006), Tier 3, Table 2-6, Utility, gas oil, boilers.
				010104	3	IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil.
				010105	24	Nielsen et al. (2010a)
				010202 010203	0.9	IPCC (2006), Tier 3, Table 2-6, Utility, gas oil, boilers.
		1A1b	Petroleum refining	010306	3	IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil.
		1A1c	Oil and gas extraction	010500	0.9	IPCC (2006), Tier 3, Table 2-6, Utility, gas oil, boilers.
		1A2 a-g	Industry	03	0.2	IPCC (2006), Tier 3, Table 2-7, Industry, gas oil, boilers.
				Turbines	3	IPCC (2006), Tier 1, Table 2-3, Industry, gas oil.
				Engines	24	Nielsen et al. (2010a)

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
		1A4a	Commercial/ Institutional	0201	0.7	IPCC (2006), Tier 3, Table 2-10, Commercial, gas oil.
				020105	24	Nielsen et al. (2010a)
		1A4b i	Residential	0202	0.7	IPCC (2006), Tier 3, Table 2.9, Residential, gas oil.
				020204	24	Nielsen et al. (2010a)
		1A4c	Agriculture/ Forestry	0203	0.7	IPCC (2006), Tier 3, Table 2-10, Commercial, gas oil[1)].
				020304	24	Nielsen et al. (2010a)
	Kerosene	1A2 a-g	Industry	03	3	IPCC (2006), Tier 1, Table 2-3, Industry, other kerosene.
		1A4a	Commercial/ Institutional	0201	10	IPCC (2006), Tier 1, Table 2-4, Commercial, other kerosene.
		1A4b i	Residential	0202	10	IPCC (2006), Tier 1, Table 2-5, Residential/agricultural, other kerosene.
		1A4c i	Agriculture/ Forestry	0203	10	IPCC (2006), Tier 1, Table 2-5, Residential/agricultural, other kerosene.
	LPG	1A1a	Public electricity and heat production	0101 0102	1	IPCC (2006), Tier 1, Table 2-2, Energy Industries, LPG.
		1A1b	Petroleum refining	0103	1	IPCC (2006), Tier 1, Table 2-2, Energy Industries, LPG.
		1A2 a-g	Industry	03	1	IPCC (2006), Tier 1, Table 2-3, Industry, LPG
		1A4a	Commercial/ Institutional	0201	5	IPCC (2006), Tier 1, Table 2-4, Commercial, LPG.
		1A4b i	Residential	0202	5	IPCC (2006), Tier 1, Table 2-5, Residential / agricultural, LPG.
		1A4c i	Agriculture/ Forestry	0203	5	IPCC (2006), Tier 1, Table 2-5, Residential / agricultural, LPG.
	Refinery gas	1A1b	Petroleum refining	010304	1.7	Assumed equal to natural gas fuelled gas turbines. Nielsen et al. (2010a)
				010306	1	IPCC (2006), Tier 1, Table 2-2, refinery gas.
GAS	Natural gas	1A1a	Public electricity and heat production	010101 010102 010103	1	IPCC (2006), Tier 3, Table 2-6, Utility, natural gas, boilers.
				010104	1.7	Nielsen et al. (2010a)
				010105	481	Nielsen et al. (2010a)
				010202 010203	1	IPCC (2006), Tier 3, Table 2-6, Utility, natural gas, boilers.
		1A1b	Petroleum refining	010306	1	Assumed equal to industrial boilers.
		1A1c	Oil and gas extraction	010503	1	Assumed equal to industrial boilers.
				010504	1.7	Nielsen et al. (2010a)
		1A2 a-g	Industry	Other	1	IPCC (2006), Tier 3, Table 2-7, Industry, natural gas boilers.
				Gas turbines	1.7	Nielsen et al. (2010a)
				Engines	481	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201 020105	1 481	IPCC (2006), Tier 3, Table 2-10, Commercial, natural gas boilers. Nielsen et al. (2010a)
		1A4b i	Residential	0202	37.5	Schweitzer, 2020
				020204	481	Nielsen et al. (2010a)
		1A4c i	Agriculture/ Forestry	0203	1	IPCC (2006), Tier 3, Table 2-10, Commercial, natural gas boilers[1)].
				020304	481	Nielsen et al. (2010a)
WASTE	Waste	1A1a	Public electricity and heat production	0101 0102	0.34	Nielsen et al. (2010a)
		1A2 a-g	Industry	03	30	IPCC (2006), Tier 1, Table 2-3, Industry, municipal wastes.
		1A4a	Commercial/ Institutional	0201	30	IPCC (2006), Tier 1, Table 2-3, Industry, municipal wastes [2)].
	Industrial waste	1A2f	Industry	0316	30	IPCC (2006), Tier 1, Table 2-3, Industry, industrial wastes.
BIO-MASS	Wood	1A1a	Public electricity and heat production	0101	3.1	Nielsen et al. (2010a)

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
				0102	11	IPCC (2006), Tier 3, Table 2-6, Utility boilers, wood
		1A2 a-g	Industry	03	11	IPCC (2006), Tier 3, Table 2-7, Industry, wood, boilers.
		1A4a	Commercial/ Institutional	0201	11	IPCC (2006), Tier 3, Table 2-10, Commercial, wood.
		1A4b i	Residential	0202	93.6	DCE estimate based on technology distribution, Nielsen et al. (2021) [3)]
		1A4c i	Agriculture/ Forestry	0203	11	IPCC (2006), Tier 3, Table 2-10, Commercial, wood.[1)].
	Straw	1A1a	Public electricity and heat production	0101	0.47	Nielsen et al. (2010a)
				0102	30	IPCC (2006), Tier 1, Table 2-2, Energy industries, other primary solid biomass
		1A4b i	Residential	0202	300	IPCC (2006), Tier 1, Table 2-5, Residential, other primary solid biomass.
		1A4c i	Agriculture/ Forestry	020300	300	IPCC (2006), Tier 1, Table 2-5, Agriculture, other primary solid biomass.
				020302	30	IPCC (2006), Tier 1, Table 2-2, Energy industries, other primary solid biomass (large agricultural plants considered equal to this plant category)
	Wood pellets	1A1a	Public electricity and heat production	0101	3.1	Nielsen et al. (2010a)
				0102	3	Paulrud et al. (2005)
		1A2 a-g	Industry	03	3	Paulrud et al. (2005)
		1A4a	Commercial/ Institutional	0201	3	Paulrud et al. (2005)
		1A4b i	Residential	0202	3	Paulrud et al. (2005)
		1A4c i	Agriculture/ Forestry	0203	3	Paulrud et al. (2005)
	Bio oil	1A1a	Public electricity and heat production	010102	3	IPCC (2006), Tier 1, Table 2-2, Energy industries, biodiesels.
				010105	24	Nielsen et al. (2010a) assumed same emission factor as for gas oil fuelled engines.
				0102	3	IPCC (2006), Tier 1, Table 2-2, Energy industries, biodiesels.
		1A2 a-g	Industry	03	3	IPCC (2006), Tier 1, Table 2-3, Industry, biodiesels.
				030902	0.2	-
		1A4b i	Residential	0202	10	IPCC (2006), Tier 1, Table 2-5, Residential, biodiesels.
	Biogas	1A1a	Public electricity and heat production	0101	1	IPCC (2006), Tier 1, Table 2-2, Energy industries, other biogas.
				010105	434	Nielsen et al. (2010a)
				0102	1	IPCC (2006), Tier 1, Table 2-2, Energy industries, other biogas.
		1A2 a-g	Industry	03	1	IPCC (2006), Tier 1, Table 2-3, Industry, other biogas.
				Engines	434	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201	5	IPCC (2006), Tier 1, Table 2-4, Commercial, other biogas.
				020105	434	Nielsen et al. (2010a)
		1A4b	Residential	0202	1	Assumed equal to natural gas.
		1A4c i	Agriculture/ Forestry	0203	5	IPCC (2006), Tier 1, Table 2-5, Agriculture, other biogas.
				020304	434	Nielsen et al. (2010a)
	Bio gasification gas	1A1a	Public electricity and heat production	010101	1	Assumed equal to biogas.
				010105	13	Nielsen et al. (2010a)
		1A4a	Commercial/Institutional	020105	13	Nielsen et al. (2010a)
	Biomethane	1A1a	Public electricity and heat production	0101 0102	1	Assumed equal to natural gas.
				Turbines	1.7	Assumed equal to natural gas.
				Engines	481	Assumed equal to natural gas.

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
		1A1b	Petroleum refining	0103	1	Assumed equal to natural gas.
		1A2 a-g	Industry	03	1	Assumed equal to natural gas.
				Tur-bines	1.7	Assumed equal to natural gas.
				Engines	481	Assumed equal to natural gas.
		1A4a	Commercial/ Institu-tional	0201	1	Assumed equal to natural gas.
				Engines	481	Assumed equal to natural gas.
		1A4b	Residential	0202	37.5	Assumed equal to natural gas.
				Engines	481	Assumed equal to natural gas.
		1A4c	Agriculture/ Forestry	0203	1	Assumed equal to natural gas.
				Engines	481	Assumed equal to natural gas.

1) Assumed same emission factors as for commercial plants. Plant capacity and technology are similar for Danish plants.

2) Assumed same emission factor as for industrial plants. Plant capacity and technology is similar to industrial plants rather than to residential plants.

3) Aggregated emission factor based on the technology distribution in the sector (Nielsen et al., 2021) and technology specific emission factors that refer to Paulrud et al. (2005), Johansson et al. (2004) and Olsson & Kjällstrand (2005). The emission factor is within the IPCC (2006) interval for residential wood combustion (100-900 g per GJ).

CHP plants

A considerable part of the electricity production in Denmark is based on decentralised CHP plants, and well-documented emission factors for these plants are, therefore, of importance. In a project carried out for the electricity transmission company, Energinet.dk, emission factors for CHP plants <25MW$_e$ have been estimated. The work was reported in 2010 (Nielsen et al., 2010a).

The work included waste incineration plants, CHP plants combusting wood and straw, natural gas and biogas-fuelled (reciprocating) engines, natural gas fuelled gas turbines, gas oil fuelled engines, gas oil fuelled gas turbines, steam turbines fuelled by residual oil and engines fuelled by biomass gasification gas. CH_4 emission factors for these plants all refer to Nielsen et al. (2010a). The estimated emission factors were based on existing emission measurements as well as on emission measurements carried out within the project. The number of emission data sets was comprehensive. Emission factors for subgroups of each plant type were estimated, e.g. the CH_4 emission factors for different gas engine types were determined.

Time series for the CH_4 emission factors are based on a similar project estimating emission factors for year 2000 (Nielsen & Illerup, 2003).

Natural gas, gas engines

The emission factor for natural gas engines refers to the Nielsen et al. (2010a). The emission factor includes the increased emission during start/stop of the engines estimated by Nielsen et al. (2008). Emission factor time series for the years 1990-2007 have been estimated based on Nielsen & Illerup (2003). These three references are discussed below.

Nielsen et al. (2010a):

> *CH_4 emission factors for gas engines were estimated for 2003-2006 and for 2007-2010. The dataset was split in two, due to new emission limits for engines from October 2006. The emission factors were based on emission measurements from 366 (2003-2006) and 157 (2007-2010) engines respectively. The engines from which emission measurements were available for 2007-2010 represented 38 % of the gas consumption. The emission factors*

were estimated based on fuel consumption for each gas engine type and the emission factor for each engine type. The majority of emission measurements that were not performed within the project related solely to the emission of total unburned hydrocarbon (CH_4 + NMVOC). A constant disaggregation factor was estimated based on 9 emission measurements including both CH_4 and NMVOC.

Nielsen & Illerup (2003):

The emission factor for natural gas engines was based on 291 emission measurements in 114 different plants. The plants from which emission measurements were available represented 44 % of the total gas consumption in gas engines in year 2000.

Nielsen et al. (2008):

This study calculated a start/stop correction factor. This factor was applied to the time series estimated in Nielsen & Illerup (2003). Further, the correction factors were applied in Nielsen et al. (2010a).

The emission factor for lean-burn gas engines is relatively high, especially for pre-chamber engines, which account for more than half the gas consumption in Danish gas engines. However, the emission factors for different pre-chamber engine types differ considerably.

The installation of natural gas engines in decentralised CHP plants in Denmark has taken place since 1990. The first engines installed were relatively small open-chamber engines but later mainly pre-chamber engines were installed. As mentioned above, pre-chamber engines have a higher emission factor than open-chamber engines; therefore, the emission factor has increased during the period 1990-1995. After that, technical improvements of the engines have been implemented as a result of upcoming emission limits that most installed gas engines had to meet in late 2006 (DEPA, 2005).

The time series were based on:

- Full load emission factors for different engine types in year 2000 (Nielsen & Illerup, 2003), 2003-2006 and 2007-2010 (Nielsen et al., 2010a).
- Data for year of installation for each engine and fuel consumption of each engine 1994-2002 from the Danish Energy Agency (DEA, 2003).
- Research concerning the CH_4 emission from gas engines carried out in 1997 (Nielsen & Wit, 1997).
- Correction factors including increased emission during start/stop of the engines (Nielsen et al., 2008).

Table 3.2.34 Time series for the CH_4 emission factor for natural gas fuelled engines.

Year	Emission factor, g per GJ
1990	266
1991	309
1992	359
1993	562
1994	623
1995	632
1996	616
1997	551
1998	542
1999	541
2000	537
2001	522
2002	508
2003	494
2004	479
2005	465
2006	473
2007-2021	481

Gas engines, biogas

The emission factor for biogas engines was estimated to 434 g per GJ in 2007-2021. The emission factor is lower than the factor for natural gas mainly because most biogas-fuelled engines are lean-burn open-chamber engines - not prechamber engines.

Time series for the emission factor have been estimated. The emission factors for biogas engines were based on Nielsen et al. (2010a) and Nielsen & Illerup (2003). The two references are discussed below. The time series are shown in Table 3.2.35.

Nielsen et al. (2010a):

> *CH_4 emission factors for gas engines were estimated for 2006 based on emission measurements performed in 2003-2010. The emission factor was based on emission measurements from 10 engines. The engines from which emission measurements were available represented 8 % of the gas consumption. The emission factor was estimated based on fuel consumption for each gas engine type and the emission factor for each engine type. The majority of emission measurements that were not performed within the project related solely to the emission of total unburned hydrocarbon (CH_4 + NMVOC). A constant disaggregation factor was estimated based on 3 emission measurements including both CH_4 and NMVOC.*

Nielsen & Illerup (2003):

> *The emission factor for natural gas engines was based on 18 emission measurements from 13 different engines. The engines from which emission measurements were available represented 18 % of the total biogas consumption in gas engines in year 2000.*

Table 3.2.35 Time series for the CH_4 emission factor for biogas-fuelled engines.

Year	Emission factor, g per GJ
1990	239
1991	251
1992	264
1993	276
1994	289
1995	301
1996	305
1997	310
1998	314
1999	318
2000	323
2001	342
2002	360
2003	379
2004	397
2005	416
2006	434
2007-2021	434

Gas turbines, natural gas

The emission factor for gas turbines was estimated to be below 1.7 g per GJ in 2005 (Nielsen et al., 2010a). The emission factor was based on emission measurements on five plants. The emission factor in year 2000 was 1.5 g per GJ (Nielsen & Illerup, 2003). A time series has been estimated.

CHP, wood

The emission factor for CHP plants combusting wood was estimated to be below 3.1 g per GJ (Nielsen et al., 2010a) and the emission factor 3.1 g per GJ has been applied for all years. The emission factor was based on emission measurements on two plants.

CHP, straw

The emission factor for CHP plants combusting straw was estimated to be below 0.47 g per GJ (Nielsen et al., 2010a) and the emission factor 0.47 g per GJ has been applied for all years. The emission factor was based on emission measurements on four plants.

CHP, waste

The emission factor for CHP plants combusting waste was estimated to be below 0.34 g per GJ in 2006 (Nielsen et al., 2010a) and 0.59 g per GJ in year 2000 (Nielsen & Illerup, 2003). A time series has been estimated. The emission factor was based on emission measurements on nine plants.

The emission factor has also been applied for district heating plants.

Residential boilers, natural gas and biomethane

The CH_4 emission factors for residential boilers using natural gas or biomethane have been revised this year.

The emission factors have been revised based on a new reference, Schweitzer (2020). The emission factor is 37.5 g/GJ. The reference include emissions during start and stop of gas boilers.

Residential wood combustion

The emission factor for residential wood combustion (not including wood pellets) is based on technology specific data. The emission factor time series is shown in Table 3.2.36.

Table 3.2.36 CH_4 emission factor time series for residential wood combustion[1)].

Year	Emission factor, g per GJ
1990	327
1991	321
1992	314
1993	308
1994	302
1995	296
1996	289
1997	283
1998	276
1999	270
2000	263
2001	256
2002	248
2003	240
2004	227
2005	215
2006	206
2007	197
2008	188
2009	178
2010	167
2011	160
2012	152
2013	145
2014	138
2015	131
2016	124
2017	117
2018	111
2019	105
2020	99
2021	94

1) Wood pellets not included.

The emission factors for each technology and the corresponding reference are shown in Table 3.2.37. The emission factor time series is estimated based on time series (1990-2021) for wood consumption in each technology (Nielsen et al., 2021).

Table 3.2.37 Technology specific CH_4 emission factors for residential wood combustion.

Technology	Emission factor, g per GJ	Reference
Stoves (-1989)	430	Methane emissions from residential biomass combustion, Paulrud et al. (2005) (SMED report, Sweden)
Stoves (1990-2007)	215	Assumed ½ the emission factor for stoves (-1989).
Stoves (2008-2014)	125	Estimated based on the emission factor for stoves (1990-2007) and the emission factors for NMVOC.
Stoves (2015-2016)	125	Same as stoves (2008-2014)
Stoves (2017-)	125	Same as stoves (2008-2014)
Eco labelled stoves / new advanced stoves (-2014)	2	Low emissions from wood burning in an ecolabelled residential boiler. Olsson & Kjällstrand (2005).
Eco labelled stoves / new advanced stoves (2015-2016)	2	Same as advanced/ecolabelled stoves
Eco labelled stoves / new advanced stoves (2017-)	2	Same as advanced/ecolabelled stoves
Open fireplaces and similar	430	Assumed equal to stoves (-1989).
Masonry heat accumulating stoves and similar	215	Assumed equal to stoves (-1989).
Boilers with accumulation tank (-1979)	211	Methane emissions from residential biomass combustion, Paulrud et al 2005 (SMED report, Sweden)
Boilers without accumulation tank (-1979)	256	Methane emissions from residential biomass combustion, Paulrud et al 2005 (SMED report, Sweden)
Boilers with accumulation tank (1980-)	50	Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Johansson et al. (2004)
Boilers without accumulation tank (1980-)	50	Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Johansson et al. (2004)

The time series for wood consumption in the 14 different technologies are illustrated in Figure 3.2.37. The consumption in new/ecolabelled stoves has increased. Details about disaggregation of the wood consumption between technologies are given in Nielsen et al. (2021).

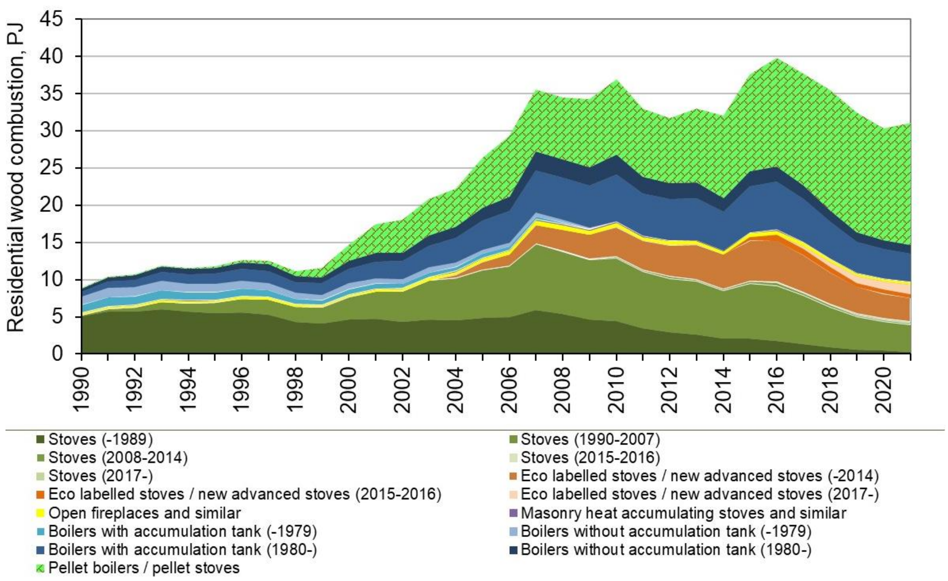


Figure 3.2.37 Technology specific wood consumption in residential plants. The consumption of wood pellets is included in the figure.

Wood pellets

The emission factor for wood pellets refer to Paulrud et al. (2005). For further details, see Nielsen et al. (2021).

Other stationary combustion plants

Emission factors for other plants refer to the IPCC Guidelines (IPCC, 2006).

N_2O emission factors

The N_2O emission factors applied for the 2021 inventory are listed in Table 3.2.38. Time series have been estimated for natural gas fuelled gas turbines and refinery gas fuelled turbines. All other emission factors have been applied unchanged for 1990-2021.

Emission factors for natural gas fuelled reciprocating engines, natural gas fuelled gas turbines, CHP plants < 300 MW combusting wood, straw or residual oil, waste incineration plants, engines fuelled by gas oil and gas engines fuelled by biomass gasification gas all refer to emission measurements carried out on Danish plants, Nielsen et al. (2010a).

The emission factor for coal-powered plants in public power plants refers to research conducted by Elsam (now part of Ørsted).

Plant specific emission factors have been included for two industrial plants.

The emission factor for offshore gas turbines has been assumed to follow the time series for natural gas fuelled gas turbines in Danish CHP plants. There is no evidence to suggest that offshore gas turbines have different emission characteristics for N_2O compared to onshore natural gas turbines and the emission factor is considered applicable.

The emission factor for natural gas fuelled gas turbines has been applied for refinery gas fuelled gas turbines. Refinery gas has similar properties as natural gas, i.e. similar nitrogen content in the fuel, which means that N_2O formation will be similar under similar combustion conditions.

All emission factors that are not nationally referenced refer to the IPCC Guidelines (IPCC, 2006).

Table 3.2.38 N_2O emission factors 2021.

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
SOLID	Coal	1A1a	Public electricity and heat production	0101	0.8	Henriksen (2005)
				0102	1.4	IPCC (2006), Tier 3, Table 2.6, Utility source, pulverised bituminous coal, wet bottom boiler.
		1A2 a-g	Industry	03	1.5	IPCC (2006), Tier 1, Table 2-3, Manufacturing industries, coal
		1A4b i	Residential	0202	1.5	IPCC (2006), Tier 1, Table 2-5, Residential, coal
		1A4c i	Agriculture/ Forestry	0203	1.5	IPCC (2006), Tier 1, Table 2-4, Commercial, coal[1)]
	BKB	1A4b i	Residential	0202	1.5	IPCC (2006), Tier 1, Table 2-5, Residential, brown coal briquettes
	Coke oven coke	1A2 a-g	Industry	03	1.5	IPCC (2006), Tier 1, Table 2-3, Industry, coke oven coke
			Industry – mineral wool	030701	71	Emission factor based on plant specific data for the mineral wool industry, 2021
		1A4b i	Residential	020200	1.5	IPCC (2006), Tier 1, Table 2-5, Residential, coke oven coke
	Anodic carbon	1A2 a-g	Industry	03	1.5	IPCC (2006), Tier 1, Table 2-3, manufacturing industries, other bituminous coal
	Fossil fly ash	1A1a	Public electricity and heat production	0101	0.8	Assumed equal to coal.
LIQUID	Petroleum coke	1A2 a-g	Industry – other	03	0.6	IPCC (2006), Tier 1, Table 2-3, Industry, petroleum coke
				031600	1.5	-
		1A4a	Commercial/ Institutional	0201	0.6	IPCC (2006), Tier 1, Table 2-4, Commercial, petroleum coke
		1A4b i	Residential	0202	0.6	IPCC (2006), Tier 1, Table 2-5, Residential, petroleum coke
		1A4c i	Agriculture/ Forestry	0203	0.6	IPCC (2006), Tier 1, Table 2-5, Residential/Agricultural, petroleum coke
	Residual oil	1A1a	Public electricity and heat production	010101	0.3	IPCC (2006), Tier 3, Table 2-6, Utility, residual fuel oil
				010102 010103	5	Nielsen et al. (2010a)
				010104 010105	0.6	IPCC (2006), Tier 1, Table 2-2, Energy industries, residual fuel oil
				010203	0.3	IPCC (2006), Tier 3, Table 2-6, Utility, residual fuel oil
		1A1b	Petroleum refining	010306	0.6	IPCC (2006), Tier 1, Table 2-2, Energy industries, residual fuel oil
		1A2 a-g	Industry	03	5	Nielsen et al. (2010a)
				Engines	0.6	IPCC (2006), Tier 1, Table 2-3, manufacturing industries and construction, residual fuel oil.
		1A4a	Commercial/ Institutional	0201	0.3	IPCC (2006), Tier 3, Table 2-10, Commercial, fuel oil boilers
		1A4b i	Residential	0202	0.6	IPCC (2006), Tier 1, Table 2-5, Residential, residual fuel oil
		1A4c i	Agriculture/ Forestry	0203	0.3	IPCC (2006), Tier 3, Table 2-10, Commercial, fuel oil boilers[1)]
	Gas oil	1A1a	Public electricity and heat production	010101 010102 010103	0.4	IPCC (2006), Tier 3, Table 2-6, Utility, gas oil boilers
				010104	0.6	IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil
				010105	2.1	Nielsen et al. (2010a)

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
				0102	0.4	IPCC (2006), Tier 3, Table 2-6, Utility, gas oil boilers
		1A1b	Petroleum refining	010306	0.6	IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil
		1A1c	Oil and gas extraction	010500	0.4	IPCC (2006), Tier 3, Table 2-6, Utility, gas oil boilers
		1A2 a-g	Industry	03	0.4	IPCC (2006), Tier 3, Table 2-7, Industry, gas oil boilers
				Tur-bines	0.6	IPCC (2006), Tier 1, Table 2-3, Industry, gas oil
				Engines	2.1	Nielsen et al. (2010a)
			Industry – mineral wool	030701	71	Emission factor based on plant specific data for the mineral wool industry, 2021
		1A4a	Commercial/ Institutional	0201	0.4	IPCC (2006), Tier 3, Table 2-10, Commercial, gas oil boilers
				Engines	2.1	Nielsen et al. (2010a)
		1A4b i	Residential	0202	0.6	IPCC (2006), Tier 1, Table 2-5, Residential, gas oil
				Engines	2.1	Nielsen et al. (2010a)
		1A4c	Agriculture/ Forestry	0203	0.4	IPCC (2006), Tier 3, Table 2-10, Commercial, gas oil boilers 1)
				Engines	2.1	Nielsen et al. (2010a)
	Kerosene	1A2 a-g	Industry	03	0.6	IPCC (2006), Tier 1, Table 2-3, Industry, other kerosene
		1A4a	Commercial/ Institutional	0201	0.6	IPCC (2006), Tier 1, Table 2-4, Commercial, other kerosene
		1A4b i	Residential	0202	0.6	IPCC (2006), Tier 1, Table 2-5, Residential, other kerosene
		1A4c i	Agriculture/ Forestry	0203	0.6	IPCC (2006), Tier 1, Table 2-4, Commercial, other kerosene 1)
	LPG	1A1a	Public electricity and heat production	0101 0102	0.1	IPCC (2006), Tier 1, Table 2-2, Energy industries, LPG
		1A1b	Petroleum refining	010306	0.1	IPCC (2006), Tier 1, Table 2-2, Energy industries, LPG
		1A2 a-g	Industry	03	0.1	IPCC (2006), Tier 1, Table 2-3, Industry, LPG
		1A4a	Commercial/ Institutional	0201	0.1	IPCC (2006), Tier 1, Table 2-4, Commercial, LPG
		1A4b i	Residential	0202	0.1	IPCC (2006), Tier 1, Table 2-5, Residential, LPG
		1A4c i	Agriculture/ Forestry	0203	0.1	IPCC (2006), Tier 1, Table 2-5, Residential/Agricultural, LPG
	Refinery gas	1A1b	Petroleum refining	010304	1	Assumed equal to natural gas fuelled turbines. Based on Nielsen et al. (2010a).
				010306	0.1	IPCC (2006), Tier 1, Table 2-2, Energy industries, refinery gas
GAS	Natural gas	1A1a	Public electricity and heat production	010101 010102 010103	1	IPCC (2006), Tier 3, Table 2-6, Natural gas, Utility, boiler
				010104	1	Nielsen et al. (2010a)
				010105	0.58	Nielsen et al. (2010a)
				0102	1	IPCC (2006), Tier 3, Table 2-6, Natural gas, Utility, boiler
		1A1b	Petroleum refining	010306	1	IPCC (2006), Tier 3, Table 2-6, Natural gas, Utility, boiler
		1A1c	Oil and gas extraction	010504	1	Nielsen et al. (2010a)
		1A2 a-g	Industry	03	1	IPCC (2006), Tier 3, Table 2-7, Industry, natural gas boilers

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
				Gas turbines	1	Nielsen et al. (2010a)
				Engines	0.58	Nielsen et al. (2010a)
			Industry – mineral wool	030701	71	Emission factor based on plant specific data for the mineral wool industry, 2021
		1A4a	Commercial/ Institutional	020100 020103	1	IPCC (2006), Tier 3, Table 2-10, Commercial, natural gas boilers
				Engines	0.58	Nielsen et al. (2010a)
		1A4b i	Residential	0202	1	IPCC (2006), Tier 3, Table 2-9, Residential, natural gas boilers
				Engines	0.58	Nielsen et al. (2010a)
		1A4c i	Agriculture/ Forestry	0203	1	IPCC (2006), Tier 3, Table 2-10, Commercial, natural gas boilers 1)
				Engines	0.58	Nielsen et al. (2010a)
WASTE	Waste	1A1a	Public electricity and heat production	0101 0102	1.2	Nielsen et al. (2010a)
		1A2 a-g	Industry	03	4	IPCC (2006), Tier 1, Table 2-3, Industry, wastes
		1A4a	Commercial/ Institutional	0201	4	IPCC (2006), Tier 1, Table 2-4, Commercial, municipal wastes
	Industrial waste	1A2 a-g	Industry	03	4	IPCC (2006), Tier 1, Table 2-3, Industry, industrial wastes
BIO-MASS	Wood	1A1a	Public electricity and heat production	0101	0.8	Nielsen et al. (2010a)
				0102	4	IPCC (2006), Tier 1, Table 2-2, Energy industries, wood
		1A2 a-g	Industry	03	7	IPCC (2006), Table 2-7 Industrial source emission factors, wood / wood waste boilers
		1A4a	Commercial/ Institutional	0201	4	IPCC (2006), Tier 1, Table 2-4, Commercial, wood
		1A4b i	Residential	0202	4	IPCC (2006), Tier 1, Table 2-5, Residential, wood
		1A4c i	Agriculture/ Forestry	0203	4	IPCC (2006), Tier 1, Table 2-5, Agriculture, wood
	Straw	1A1a	Public electricity and heat production	0101	1.1	Nielsen et al. (2010a)
				0102	4	IPCC (2006), Tier 1, Table 2-2, Energy industries, other primary solid biomass
		1A4b i	Residential	0202	4	IPCC (2006), Tier 1, Table 2-5, Residential, other primary solid biomass
		1A4c i	Agriculture/ Forestry	0203	4	IPCC (2006), Tier 1, Table 2-5, Agriculture, other primary solid biomass
	Wood pellets	1A1a	Public electricity and heat production	0101	0.8	Nielsen et al. (2010a)
				0102	4	IPCC (2006), Tier 1, Table 2-2, Energy industries, wood
		1A2 a-g	Industry	03	4	IPCC (2006), Tier 1, Table 2-3, Industry, wood
		1A4a	Commercial/ Institutional	0201	4	IPCC (2006), Tier 1, Table 2-4, Commercial, wood
		1A4b i	Residential	0202	4	IPCC (2006), Tier 1, Table 2-5, Residential, wood
	Bio oil	1A1a	Public electricity and heat production	0101 0102	0.6	IPCC (2006), Tier 3, Table 2-2, Utility, biodiesels
				Engines	2.1	Assumed equal to gas oil. Based on Nielsen et al. (2010a)
		1A2 a-g	Industry	03	0.4	Assumed equal to gas oil.

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
		1A4b i	Residential	0202	0.6	IPCC (2006), Tier 1, Table 2-5, Residential, biodiesels
	Biogas	1A1a	Public electricity and heat production	0101 0102	0.1	IPCC (2006), Tier 1, Table 2-2, Energy industries, other biogas
				Engines	1.6	Nielsen et al. (2010a)
		1A2 a-g	Industry	03	0.1	IPCC (2006), Tier 1, Table 2-3, Industry, other biogas
				Engines	1.6	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201	0.1	IPCC (2006), Tier 1, Table 2,4, Commercial, other biogas
				Engines	1.6	Nielsen et al. (2010a)
		1A4b	Residential	0202	1	Assumed equal to natural gas.
		1A4c i	Agriculture/ Forestry	0203	0.1	IPCC (2006), Tier 1, Table 2-5, Agriculture, other biogas
				Engines	1.6	Nielsen et al. (2010a)
	Bio gasification gas	1A1a	Public electricity and heat production	010101	0.1	Assumed equal to biogas.
				010105	2.7	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	020105	2.7	Nielsen et al. (2010a)
	Biomethane	1A1a	Public electricity and heat production	0101 or 0102	1	Assumed equal to natural gas.
				Engines	0.58	Assumed equal to natural gas.
		1A1b	Petroleum refining	0103	1	Assumed equal to natural gas.
		1A2 a-g	Industry	03	1	Assumed equal to natural gas.
				Engines	0.58	Assumed equal to natural gas.
		1A4a	Commercial/ Institutional	0201	1	Assumed equal to natural gas.
				Engines	0.58	Assumed equal to natural gas.
		1A4b	Residential	0202	1	Assumed equal to natural gas.
				Engines	0.58	Assumed equal to natural gas.
		1A4c	Agriculture/ Forestry	0203	1	Assumed equal to natural gas.
				Engines	0.58	Assumed equal to natural gas.

1) In Denmark, plants in Agriculture/Forestry are similar to Commercial plants.

3.2.7 Uncertainty

Uncertainty estimates include uncertainty regarding the total emission inventory as well as uncertainty regarding trends.

Methodology

The uncertainty for greenhouse gas emissions have been estimated according to the IPCC Guidelines (IPCC, 2006). This year the uncertainty has been estimated only by approach 1. Approach 1 is further described in Chapter 1.7.

Approach 1 is based on a normal distribution and a confidence interval of 95 %.

The input data for the approach 1 are:

- Emission data for the base year and the latest year.
- Uncertainties for emission factors
- Uncertainty for fuel consumption rates.

The emission source categories applied are listed in Table 3.2.39.

Source categories

Due to large differences in data uncertainty, some emission source categories have been further disaggregated than suggested in the IPCC Guidelines (2006):

- For five different fuels, CO_2 emissions based on ETS data and on non-ETS data have been considered two different emission sources.
- CH_4 emission from natural gas fuelled engines
- CH_4 emission from biogas fuelled engines
- CH_4 emission from residential wood combustion
- CH_4 emission from residential and agricultural combustion of straw
- N_2O emission from residential wood combustion
- N_2O emission from residential and agricultural combustion of straw

The separate uncertainty estimation for gas engine CH_4 emission and CH_4 emission from other plants is applied, because in Denmark, the CH_4 emission from gas engines is much larger than the emission from other stationary combustion plants, and the CH_4 emission factor for gas engines is estimated with a much smaller uncertainty level than for other stationary combustion plants.

The 2021 uncertainty levels have been applied in uncertainty calculation.

Fuel

The applied uncertainty rates for fuel consumption are shown below.

Table 3.2.39 Uncertainties for fuel consumption 2021.

IPCC Source category	2021	Reference
1A1, 1A2, 1A4 St. comb. Coal, ETS data, CO_2	0.5%	ETS data
1A1, 1A2, 1A4 St. comb. Coal, no ETS data, CO_2	1.6%	Estimated based on IPCC (2006) values.
1A1, 1A2, 1A4 St. comb., BKB, CO_2	2.9%	Estimated based on IPCC (2006) values.
1A1, 1A2, 1A4 St. comb., Coke oven coke, CO_2	1.8%	Estimated based on IPCC (2006) values.
1A1, 1A2, 1A4 St. comb., Fossil waste, ETS data, CO_2	2%	DCE assumption
1A1, 1A2, 1A4 St. comb., Fossil waste, no ETS data, CO_2	5%	DCE assumption
1A1, 1A2, 1A4 St. comb., Petroleum coke, ETS data, CO_2	0.5%	ETS data
1A1, 1A2, 1A4 St. comb., Petroleum coke, no ETS data, CO_2	2.0%	Estimated based on IPCC (2006) values.
1A1, 1A2, 1A4 St. comb., Residual oil, ETS data, CO_2	0.5%	ETS data
1A1, 1A2, 1A4 St. comb., Residual oil, no ETS data, CO_2	1.0%	Estimated based on IPCC (2006) values.
1A1, 1A2, 1A4 St. comb., Gas oil, CO_2	2.4%	Estimated based on IPCC (2006) values.
1A1, 1A2, 1A4 St. comb., Kerosene, CO_2	2.8%	Estimated based on IPCC (2006) values.
1A1, 1A2, 1A4 St. comb., LPG, CO_2	1.9%	Estimated based on IPCC (2006) values.
1A1b,St. comb., Refinery gas, CO_2	1.0%	Estimated based on IPCC (2006) values.
1A1, 1A2, 1A4, Stationary combustion, Natural gas, onshore, CO_2	1.5%	Estimated based on IPCC (2006) values. Offshore gas turbines not included in this category.
1A1c Off shore gas turbines, Natural gas, CO_2	0.5%	ETS data for 2021, IPCC (2006) for 1990.
1A1, Stationary Combustion, SOLID, CH_4	1.0%	IPCC (2006), less than 1%
1A1, Stationary Combustion, LIQUID, CH_4	1.0%	IPCC (2006), less than 1%
1A1, Stationary Combustion, not engines, GAS, CH_4	1.0%	IPCC (2006), less than 1%
1A1, Stationary Combustion, WASTE, CH_4	3.0%	DCE assumption. The uncertainty for the total consumption of waste is lower than the uncertainty for the fossil part.
1A1, Stationary Combustion, not engines, BIOMASS, CH_4	3.0%	DCE assumption
1A2, Stationary Combustion, SOLID, CH_4	2.0%	IPCC (2006)
1A2, Stationary Combustion, LIQUID, CH_4	2.0%	IPCC (2006)
1A2, Stationary Combustion, not engines, GAS, CH_4	2.0%	IPCC (2006)
1A2, Stationary Combustion, WASTE, CH_4	3.0%	DCE assumption. The uncertainty for the total consumption of waste is lower than the uncertainty for the fossil part.
1A2, Stationary Combustion, not engines, BIOMASS, CH_4	3.0%	IPCC (2006)
1A4, Stationary Combustion, SOLID, CH_4	3.0%	IPCC (2006)
1A4, Stationary Combustion, LIQUID, CH_4	3.0%	IPCC (2006)
1A4, Stationary Combustion, not engines, GAS, CH_4	3.0%	IPCC (2006)
1A4, Stationary Combustion, WASTE, CH_4	3.0%	DCE assumption. The uncertainty for the total consumption of waste is lower than the uncertainty for the fossil part.
1A4, Stationary Combustion, not engines, not residential wood and not residential/agricultural straw, BIOMASS, CH_4	3.0%	IPCC (2006)
1A4, Stationary Combustion, Residential wood combustion, CH_4	10.0%	DCE assumption
1A4, Stationary Combustion, Residential and agricultural straw combustion, CH_4	10.0%	DCE assumption
1A1, 1A2, 1A4 Natural gas fuelled engines, GAS, CH_4	1.0%	Lindgren (2010)
1A1, 1A2, 1A4 Biogas fuelled engines, GAS, CH_4	3.0%	DCE assumption
1A1, Stationary Combustion, SOLID, N_2O	1.0%	IPCC (2006), less than 1%
1A1, Stationary Combustion, LIQUID, N_2O	1.0%	IPCC (2006), less than 1%
1A1, Stationary Combustion, GAS, N_2O	1.0%	IPCC (2006), less than 1%
1A1, Stationary Combustion, WASTE, N_2O	3.0%	DCE assumption
1A1, Stationary Combustion, BIOMASS, N_2O	3.0%	DCE assumption
1A2, Stationary Combustion, SOLID, N_2O	2.0%	IPCC (2006)
1A2, Stationary Combustion, LIQUID, N_2O	2.0%	IPCC (2006)
1A2, Stationary Combustion, GAS, N_2O	2.0%	IPCC (2006)
1A2, Stationary Combustion, WASTE, N_2O	3.0%	DCE assumption
1A2, Stationary Combustion, BIOMASS, N_2O	3.0%	DCE assumption
Continued		
1A4, Stationary Combustion, SOLID, N_2O	3.0%	IPCC (2006)
1A4, Stationary Combustion, LIQUID, N_2O	3.0%	IPCC (2006)
1A4, Stationary Combustion, GAS, N_2O	3.0%	IPCC (2006)
1A4, Stationary Combustion, WASTE, N_2O	3.0%	DCE assumption
1A4, Stationary Combustion, not residential wood and not residential/agricultural straw, BIOMASS, N_2O	3.0%	DCE assumption

IPCC Source category	2021	Reference
1A4b, Stationary Combustion, Residential wood combustion, N_2O	10.0%	DCE assumption
1A4b/c, Stationary Combustion, Residential and agricultural straw combustion, N_2O	10.0%	DCE assumption

Emission factors

Uncertainties for emission factors are shown in Table 3.2.40.

Table 3.2.40 Uncertainties for emission factors, 2021.

IPCC Source category	2021	Reference
1A1, 1A2, 1A4 St. comb. Coal, ETS data, CO_2	0.3%	ETS data, 2020 estimate
1A1, 1A2, 1A4 St. comb. Coal, no ETS data, CO_2	1.0%	DCE assumption
1A1, 1A2, 1A4 St. comb., BKB, CO_2	5.0%	IPCC (2000), chapter 2.1.1.6.
1A1, 1A2, 1A4 St. comb., Coke oven coke, CO_2	5.0%	IPCC (2000), chapter 2.1.1.6.
1A1, 1A2, 1A4 St. comb., Fossil waste, ETS data, CO_2	3.0%	ETS data, DCE estimate based on Astrup et al. (2012).
1A1, 1A2, 1A4 St. comb., Fossil waste, no ETS data, CO_2	10.0%	Non-ETS data, DCE estimate based on Astrup et al. (2012).
1A1, 1A2, 1A4 St. comb., Petroleum coke, ETS data, CO_2	0.5%	ETS data, 2020 estimate
1A1, 1A2, 1A4 St. comb., Petroleum coke, no ETS data, CO_2	5.0%	IPCC (2000), chapter 2.1.1.6.
1A1, 1A2, 1A4 St. comb., Residual oil, ETS data, CO_2	0.5%	ETS data, 2015 estimate
1A1, 1A2, 1A4 St. comb., Residual oil, no ETS data, CO_2	2.0%	Jensen & Lindroth (2002).
1A1, 1A2, 1A4 St. comb., Gas oil, CO_2	1.3%	DCE estimate.
1A1, 1A2, 1A4 St. comb., Kerosene, CO_2	3.0%	Based on interval in IPCC (2006).
1A1, 1A2, 1A4 St. comb., LPG, CO_2	4.0%	Based on interval in IPCC (2006).
1A1b,St. comb., Refinery gas, CO_2	0.5%	1990: IPCC (2000), chapter 2.1.1.6. 2020: DCE assumption, EU ETS data.
1A1, 1A2, 1A4, Stationary combustion, Natural gas, onshore, CO_2	0.4%	Lindgren (2010). Personal communication.
1A1c Offshore gas turbines, Natural gas, CO_2	0.5%	ETS data for 2020, but not for 1990
1A1, Stationary Combustion, SOLID, CH_4	100%	Based on interval in IPCC (2006), table 2.12
1A1, Stationary Combustion, LIQUID, CH_4	100%	Based on interval in IPCC (2006), table 2.12
1A1, Stationary Combustion, not engines, GAS, CH_4	100%	Based on interval in IPCC (2006), table 2.12
1A1, Stationary Combustion, WASTE, CH_4	100%	Based on interval in IPCC (2006), table 2.12
1A1, Stationary Combustion, not engines, BIOMASS, CH_4	100%	Based on interval in IPCC (2006), table 2.12
1A2, Stationary Combustion, SOLID, CH_4	100%	Based on interval in IPCC (2006), table 2.12
1A2, Stationary Combustion, LIQUID, CH_4	100%	Based on interval in IPCC (2006), table 2.12
1A2, Stationary Combustion, not engines, GAS, CH_4	100%	Based on interval in IPCC (2006), table 2.12
1A2, Stationary Combustion, WASTE, CH_4	100%	Based on interval in IPCC (2006), table 2.12
1A2, Stationary Combustion, not engines, BIOMASS, CH_4	100%	Based on interval in IPCC (2006), table 2.12
1A4, Stationary Combustion, SOLID, CH_4	100%	Based on interval in IPCC (2006), table 2.12
1A4, Stationary Combustion, LIQUID, CH_4	100%	Based on interval in IPCC (2006), table 2.12
1A4, Stationary Combustion, not engines, GAS, CH_4	100%	Based on interval in IPCC (2006), table 2.12
1A4, Stationary Combustion, WASTE, CH_4	100%	Based on interval in IPCC (2006), table 2.12
1A4, Stationary Combustion, not engines, not residential wood and not residential/agricultural straw, BIOMASS, CH_4	100%	Based on interval in IPCC (2006), table 2.12
1A4, Stationary Combustion, Residential wood combustion, CH_4	150%	Upper value in IPCC (2006), table 2.12.
1A4, Stationary Combustion, Residential and agricultural straw combustion, CH_4	150%	Upper value in IPCC (2006), table 2.12.
1A1, 1A2, 1A4 Natural gas fuelled engines, GAS, CH_4	2%	1990: DCE estimate based on Nielsen et al. (2010a). 2018: Jørgensen et al. (2010). Uncertainty data for NMVOC + CH_4.
1A1, 1A2, 1A4 Biogas fuelled engines, GAS, CH_4	10%	DCE estimate based on Nielsen et al. (2010a).

IPCC Source category	2021	Reference
1A1, Stationary Combustion, SOLID, N_2O	400%	DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark.
1A1, Stationary Combustion, LIQUID, N_2O	1000%	IPCC (2000)
1A1, Stationary Combustion, GAS, N_2O	750%	DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark and 1000 % if not.
1A1, Stationary Combustion, WASTE, N_2O	400%	DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark.
1A1, Stationary Combustion, BIOMASS, N_2O	400%	DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark.
1A2, Stationary Combustion, SOLID, N_2O	400%	DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark.
1A2, Stationary Combustion, LIQUID, N_2O	1000%	IPCC (2000)
1A2, Stationary Combustion, GAS, N_2O	750%	DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark and 1000 % if not.
1A2, Stationary Combustion, WASTE, N_2O	400%	DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark.
1A2, Stationary Combustion, BIOMASS, N_2O	400%	DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark.
1A4, Stationary Combustion, SOLID, N_2O	400%	DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark.
1A4, Stationary Combustion, LIQUID, N_2O	1000%	IPCC (2000)
1A4, Stationary Combustion, GAS, N_2O	750%	DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark and 1000 % if not.
1A4, Stationary Combustion, WASTE, N_2O	400%	DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark.
1A4, Stationary Combustion, not residential wood and not residential/agricultural straw, BIOMASS, N_2O	400%	DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark.
1A4b, Stationary Combustion, Residential wood combustion, N_2O	500%	DCE estimate.
1A4b/c, Stationary Combustion, Residential and agricultural straw combustion, N_2O	500%	DCE estimate.

Results

Approach 1 uncertainty estimates for stationary combustion emission inventories are shown in Table 3.2.41. Detailed calculation sheets are provided in Annex 3A-7.

The uncertainty interval for the total greenhouse gas emission is estimated to be ±2.5 % and the trend in greenhouse gas emissions is -64.3 % ± 0.8 %-age points. The main sources of uncertainty for greenhouse gas emissions in 2021 are N_2O emission from residential wood combustion, N_2O emission from biomass combusted in Energy industries (1A1) and N_2O emission from gaseous fuels combusted in industrial plants (1A2). The main sources of uncertainty in the trend in greenhouse gas emission are the N_2O emission from residential wood combustion, N_2O emissions from biomass combusted in Energy industries (1A1), and N_2O emission from gaseous fuels in industrial plants (1A2).

Table 3.2.41 Danish uncertainty estimates, Approach 1, 2021.

Pollutant	Uncertainty Total emission, %	Trend 1990-2021, %	Uncertainty trend, %-age points
GHG	±2.5	-64.3	±0.8
CO_2	±0.7	-65.1	±0.4
CH_4	±33	35	±63
N_2O	±180	6.8	±230

3.2.8 Source specific QA/QC and verification

The quality work for the Danish GHG emission inventories are accounted for in *Quality manual for the Danish emission greenhouse gas inventory, Version 3* (Nielsen et al., 2020a). The quality manual outlines the quality work undertaken by the emission inventory group at the Department of Environmental Science, Aarhus University in connection with the preparation and reporting of the Danish greenhouse gas inventory.

Information on the Danish quality work is also included in NIR Chapter 1.6. Sector specific QA/QC for stationary combustion is accounted for in this chapter.

The QA/QC defined in the Quality manual defines Critical control points and a Points of measurement. Some points of measurement are sector specific whereas others are general.

Sector specific points of measurement

Table 3.2.42 lists the sector specific points of measurement and specification about the points of measurement for stationary combustion.

Table 3.2.42 List of sectoral points of measurement, and QC for stationary combustion.

Level	CCP	Id	Description		Stationary combustion QC
Data Storage level 1	1. Accuracy	DS.1.1.1	General level of uncertainty for every dataset including the reasoning for the specific values.	Sectoral	Uncertainties are estimated and references given in NIR chapter 3.2.6.
	2. Comparability	DS1.2.1	Comparability of the emission factors/calculation parameters with data from international guidelines, and evaluation of major discrepancies.	Sectoral	In general, if national referenced emission factors differ considerably from IPCC Guideline values this is discussed in NIR chapter 3.2.5. This documentation is improved annually based on reviews. At CRF level, a project has been carried out comparing the Danish inventories with those of other countries (Fauser et al., 2013).
	3.Completeness	DS.1.3.1	Ensuring that the best possible national data for all sources are included, by setting down the reasoning behind the selection of datasets.	Sectoral	A list of external data is shown and discussed below (Table 3.2.43).
	4.Consistency	DS.1.4.1	The original external data has to be archived with proper reference.	Sectoral	It is ensured that all original external data are archived. Subsequent data processing takes place in other spreadsheets or databases. The datasets are archived annually in order to ensure that the basic data for a given report are always available in their original form. All original data for stationary combustion are archived in the emission inventory archive: ST_ENVS-Luft-Emi/Inventory/(year)/1A1 1A2 and 1A4 Stationary combustion All original data for 1) the reference approach, 2) the comparison of EU ETS sum and CRF and 3) the comparison of Eurostat data and CRF are archived in the emission inventory archive: ST_ENVS-Luft-Emi/Inventory/(year)/1A Other Energy
	6.Robustness	DS.1.6.1	Explicit agreements between the external institution holding the data and AU, DCE about the conditions of delivery.	Sectoral	For stationary combustion, a data delivery agreement is made with the DEA. DCE and DEA have renewed the data delivery agreement in 2014. Most of the other external data sources are available due to legislation. See Table 3.2.43.
	7.Transparency	DS.1.7.1	Listing of all archived datasets and external contacts.	Sectoral	A list of external datasets and external contacts is shown in Table 3.2.43 below.
Data Processing level 1	1. Accuracy	DP.1.1.1	Uncertainty assessment for every data source not part of DS.1.1.1 as input to Data Storage level 2 in relation to type and scale of variability.	Sectoral	Uncertainties are estimated and references given in NIR chapter 3.2.6.

Level	CCP	Id	Description		Stationary combustion QC
	2.Comparability	DP.1.2.1	The methodologies have to follow the international guidelines suggested by UNFCCC and IPCC.	Sectoral	The methodological approach is consistent with international guidelines. An overview of tiers is given in NIR Chapter 3.2.5.
	3.Completeness	DP.1.3.1	Identification of data gaps with regard to data sources that could improve quantitative knowledge.	Sectoral	The energy statistics (the basic data sheet) is considered complete. Total fuel consumption is based on the energy statistics whereas other data sources are used for specification of technology, subsectors, plant specific data etc.
	4.Consistency	DP.1.4.1	Documentation and reasoning of methodological changes during the time series and the qualitative assessment of the impact on time series consistency.	Sectoral	The two main methodological changes in the time series; implementation of Energy Producers Survey (plant specific fuel consumption data) from 1994 onwards and implementation of EU ETS data from 2006 onwards is discussed in NIR chapter 3.2.5.
	5.Correctness	DP.1.5.2	Verification of calculation results using time series.	Sectoral	Time series for activity data on SNAP and CRF source category level are used to identify possible errors. Time series for emission factors and the emission from CRF subcategories are also examined.
		DP.1.5.3	Verification of calculation results using other measures.	Sectoral	The IPCC reference approach validates the fuel consumption rates and CO_2 emission. Except for 2016 and 2021, both differ less than 2.0 % in 1990-2021. The reference approach is included in NIR Chapter 3.4. The chapter gives an account of the differences between the national approach and the reference approach.
	7.Transparency	DP.1.7.1	The calculation principle, the equations used and the assumptions made must be described.	Sectoral	This is included in NIR chapter 3.2.5.
		DP.1.7.2	Clear reference to dataset at Data Storage level 1.	Sectoral	This is included in NIR chapter 3.2.5.
		DP.1.7.3	A manual log to collect information about recalculations.	Sectoral	A manual log is implemented in the emission database.
Data Storage level 2	5.Correctness	DS.2.5.1	Check if a correct data import to level 2 has been made.	Sectoral	To ensure a correct connection between data on level 2 and level 1, different controls are in place, e.g. control of sums and random tests.
Data Storage level 4	4.Consistency	DS.4.4.3	The IEFs from the CRF are checked both regarding level and trend. The level is compared to relevant emission factors to ensure correctness. Large dips/jumps in the time series are explained.	Sectoral	Large dips/jumps in time series are discussed and explained in NIR chapter 3.2.3 and 3.2.4.
	5. Correctness	DS.4.5.2	Check that additional information and information related to land-use changes has been correctly aggregated compared to the	Sectoral	(Not relevant for stationary combustion)

Level	CCP	Id	Description	Stationary combustion QC
			individual submissions of Denmark and Greenland.	

Table 3.2.43 List of external data sources for stationary combustion.

Dataset	Data reference	Contact(s)	Description	Years included	Data agreement/ Comment
Energy Producers Survey	The Danish Energy Agency (DEA)	Kaj Stærkind	Dataset for all plants producing electricity and district heating for the public grids. For each production unit, the dataset includes the consumption of each fuel, production of heat and electricity, technology and year of installation. The dataset is regarded as complete for fuel consumption since the plants are obliged to report the data to DEA.	1994 onwards	Data agreement 2014.
Gas consumption for gas engines and gas turbines 1990-1993	The Danish Energy Agency (DEA)	Kaj Stærkind	Historical dataset for gas engines and gas turbines. For the years 1990-1994, DEA has estimated consumption of natural gas and biogas in gas engines and gas turbines (DEA, 2003). Estimated fuel consumption data for 1990-1993 was based on engine specific data for year of installation and for fuel consumption in 1994. The 1994 data were based on the Energy Producers Survey. DCE assesses that the DEA estimate is the best available data for 1990-1993.	1990-1993	No data agreement. Historical data
Basic data	The Danish Energy Agency (DEA)	Jane Rusbjerg	The Danish energy statistics. The dataset is applied for both the reference approach and the national approach. The spreadsheet from the Danish energy statistics (DEA) is used for the CO_2 emission calculation in accordance with the IPCC reference approach and is also the first dataset applied in the national approach.	1972 and 1975 onwards	Data agreement 2014. However, the dataset is also published as part of national energy statistics.
Energy statistics for industrial subsectors	The Danish Energy Agency (DEA)	Jane Rusbjerg and Ali Zarnaghi	Disaggregation of the industrial fuel consumption. The data includes disaggregation of the fuel consumption for industrial plants. The dataset is estimated for the reporting to Eurostat. The data are included in the 2014 update of the agreement with DEA.		Included in data delivery agreement 2014.

Dataset	Data reference	Contact(s)	Description	Years included	Data agreement/ Comment
Emission factors	See chapter regarding emission factors		Emission factors refer to a large number of sources. For specific references, see the Chapter 3.2.6 regarding emission factors. Some of the annually updated CO_2 emission factors are based on EU ETS data, see below.		Some of the annually updated CO_2 emission factors are based on EU ETS data, and thus included in the data delivery agreement with DEA. For other emission factors there is no formal data delivery agreement.
Annual environmental reports / environmental data / PRTR	Various plants		Emissions from plants defined as large point sources Some large plants are obligated to report annual environmental data including emission data to PRTR. In addition, some plants publish annual environmental reports. And finally, some plant owners non-compulsory report annual emission data to DCE.		No data agreement. Some plants are obligated to report data (DEPA, 2010b; DEPA, 2015) and data are published on the Danish EPA homepage.
EU ETS data	The Danish Energy Agency (DEA)	Rikke Brynaa Lintrup	Plant specific CO_2 emission factors and fuel consumption data. EU ETS data includes information on fuel consumption, heating values, carbon content of fuel, oxidation factor and CO_2 emissions. DCE receives the verified reports for all plants, which utilises a detailed estimation methodology. DCE's QC of the received data consists of comparing to calculation using standard emission factors as well as comparing reported values with those for previous years.		Plants are obligated by law. The availability of detailed information is part of the data agreement with DEA (2014 update).

Additional sector specific QC procedures

Some additional sector specific QC procedures are performed.

- Check of units for fuel rate, emission factors and plant-specific emissions.
- Check of emission factors for large point sources. Emission factors for pollutants that are not plant-specific should be the same as those defined for area sources.
- Additional checks on database consistency.
- Emission factor references are included in NIR Chapter 3.2.6.
- Most country-specific emission factors are based on input from companies that have implemented some QA/QC work. The major power plant owner/operator in Denmark, Ørsted (former DONG Energy) has obtained the ISO 14001 certification for an environmental management system. The Danish Gas Technology Centre and Force Technology both run accredited laboratories for emission measurements.

Sector specific verification

The IPCC reference approach for CO_2 emission is the primary verification of the CO_2 emission from the energy sector. The reference approach for the energy sector is shown in NIR Chapter 3.4.

In addition, as part of the EU review of the reported GHG emission data, EU performs for each member state a comparison of Eurostat energy data in terms of TJ with energy data provided in the CRF. The comparison has been performed in accordance with the Commission implementing regulation (EU) No 749/2014 of 30 June 2014 and with the IPCC Guidelines (2006). The latest comparison included comparisons of the reference approach (RA) and the sectoral approach (SA) for the years 2005 and 2008-2021. The comparison of fuel consumption data in CRF and energy statistics from Eurostat is shown in NIR Annex 9 including explanation of the differences.

Finally, a verification of the Danish GHG emission inventories has been published by Fauser et al. (2013).

National external review for stationary combustion

The 2004, 2006, 2009, 2014, 2018 and 2021 updates of the sector report for stationary combustion has been reviewed by external experts (Nielsen & Illerup, 2004; Nielsen & Illerup, 2006; Nielsen et al., 2009, Nielsen et al., 2014; Nielsen et al., 2018; Nielsen, 2021). The national external review forms a vital part of the QA activities for stationary combustion.

The 2004, 2006, 2009, 2014, 2018 and 2021 updates of this report were reviewed by Jan Erik Johnsson from the Technical University of Denmark, Bo Sander from Elsam Engineering, Annemette Geertinger from FORCE Technology, Vibeke Vestergaard Nielsen, AU DCE, energy statistics experts from the Danish Energy Agency and Jytte Boll Illerup, The Danish Environmental Protection Agency.

3.2.9 Source specific recalculations and improvements

Emission data for CO_2, CH_4 and N_2O reported this year have been compared to emissions reported last year. Table 3.2.44 shows recalculations for CO_2, CH_4 and N_2O[25].

Sector specific recalculations for 2020 are shown in Table 3.2.45.

The main recalculations are discussed below.

Table 3.2.44 Recalculations. GHG emissions reported this year compared to emissions reported last year.

GHG	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	%	%	%	%	%	%	%	%	%	%
CO_2	100.72	100.59	100.66	100.64	100.57	100.62	100.47	100.57	100.61	100.66
CH_4	109.26	109.59	109.12	108.37	106.64	105.05	104.69	104.43	104.30	104.32
N_2O	100.24	100.21	100.22	100.22	100.20	100.19	100.16	100.18	100.18	100.19
GHG	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	%	%	%	%	%	%	%	%	%	%
CO_2	100.73	100.71	100.74	100.67	100.76	100.82	100.65	100.74	100.80	100.86
CH_4	104.19	104.30	104.20	104.57	104.60	104.90	105.06	105.07	105.09	105.67
N_2O	100.19	100.19	100.20	100.19	100.20	100.20	100.17	100.58	100.65	100.69
GHG	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	%	%	%	%	%	%	%	%	%	%
CO_2	100.72	100.81	100.90	100.80	100.93	100.99	100.86	100.92	100.87	101.00
CH_4	105.90	105.99	107.68	108.34	108.95	109.97	110.69	111.20	111.83	113.02
N_2O	100.61	100.71	100.76	99.94	100.14	100.13	100.20	100.16	100.36	99.70
GHG	2020									
	%									
CO_2	101.31									
CH_4	114.70									
N_2O	99.80									

Table 3.2.45 Recalculations for stationary combustion, 2020.

	CO_2 , kt	CH_4, t	N_2O t	CO_2 %	CH_4, %	N_2O %
1A1 Energy industries	-10.08	281.59	-6.04	-0.14	8.37	-2.38
1A1a Public electricity and heat production	-4.51	281.59	-6.04	-0.08	8.48	-2.57
1A1b Petroleum refining	-5.57	0.00	0.00	-0.61	0.00	0.00
1A1c Oil and gas extraction	0.00	0.00	0.00	0.00	0.00	0.00
1A2 Industry	84.29	48.00	4.64	2.85	5.37	2.94
1A2a Iron and steel	-3.41	0.26	0.22	-3.64	15.71	13.56
1A2b Non-ferrous metals	0.00	0.00	0.00	-	-	-
1A2c Chemicals	3.82	1.88	0.72	1.87	3.73	18.74
1A2d Pulp, paper and print	0.44	0.18	0.18	0.80	4.12	5.48
1A2e Food processing, beverages and tobacco	31.56	43.68	4.28	3.63	7.39	16.02
1A2f Non-metallic minerals	20.39	1.44	3.22	1.34	0.82	3.33
1A2gviii Other manufacturing industry	31.48	0.56	-3.98	14.54	0.78	-15.63
1A4 Other sectors	87.87	860.01	0.19	4.02	22.44	0.10
1A4ai Commercial/institutional: Stationary	-0.07	4.26	-0.05	-0.01	1.12	-0.27
1A4bi Residential: Stationary	3.36	909.93	0.03	0.22	36.68	0.02
1A4ci Agriculture/Forestry/Fishing: Stationary	84.57	-54.18	0.21	55.20	-5.57	1.82
Stationary combustion	162.08	1189.60	-1.21	1.31	14.70	-0.20

[25] In addition, if comparing the *CO_2 equivalent* emissions, the revised equivalence factors should be taken into account.

The recalculation of CO_2 emission from stationary combustion is +0.7 for 1990 and +1.3 for 2020. The recalculation of CH_4 emission from stationary combustion is +9.3 for 1990 and +14.7 for 2020. The recalculation of N_2O emission from stationary combustion is +0.2 for 1990 and -0.2 for 2020.

Fuel consumption

For stationary combustion plants, the emission estimates for the years 1990-2020 have been updated according to the latest energy statistics published by the Danish Energy Agency. The update included both end use and transformation and also a source category update. The changes in the energy statistics are largest for the years 2018, 2019 and 2020. The revisions are shown in the energy statistics. A large number of fuels have been revised including coal, natural gas, bio methane, wood, wood pellets, biogas, agricultural waste (straw), fossil waste and biomass waste.

A revision of the energy statistics for consumption of coal in industrial plants in 2020 cause an increase of the CO_2 emission reported for the industrial sector. The 242 TJ increase of coal consumption in industry cause a 23 kt increase of the reported CO_2 for 2020.

The consumption of natural gas in the Danish gas treatment plant Nybro was earlier reported as part of the sector 1A1c whereas it is now reported in sector 1A1a. Thus in 1990, there is an increase of the reported emissions in sector 1A1a and a corresponding decrease in sector 1A1c. In later years, there has been no fuel consumption in the gas turbine installed in the gas treatment plant.

Revised estimates for combustion of gas-/diesel oil in mobile sources have resulted in revised split between stationary combustion and mobile sources. Further details about the background for the recalculation is included in the mobile combustion chapter. The gas oil reallocated from mobile sources to stationary combustion is +3752 TJ for 1990 corresponding to +278 kt CO_2. For 2020, the recalculation is + 1926 TJ corresponding to +143 ktonne CO_2. This recalculation is split between industrial plants (1A2, +158 kt in 1990 and + 59 kt in 2020) and agricultural plants (1A4c, + 120 kt in 1990 and + 84 kt in 2020).

An improved disaggregation of biomethane to plant types has been implemented. As a result, a higher consumption of gas applied in reciprocating gas engines has been estimated for 2020, and this cause a higher estimate for CH_4 emission.

Emission factors

The CO_2 emission factors for biomass have been revised, and in general, fuel data from Denmark is now applied rather than the IPCC default values. The references are included in Chapter 3.2.6.

The CH_4 emission factor for residential gas boilers have been revised based on a new reference (Schweitzer, 2020) including emission measurements during start/stop of gas boilers. The emission factor for CH_4 from gas boilers is changed from 1 g/GJ to 37.5 g/GJ. This causes an increase of the reported CH_4 emission for sector 1A4b. The estimated CH_4 emission increase 634 tonnes for 1990 and 902 tonnes for 2020.

3.2.10 Response to the review process

Report on the individual review of the annual submission of Denmark submitted in 2021.
See below the comments and improvements related to the review.

Table 3, E.1: See NIR Chapter 3.4.

Table 5, E.6: NIR chapter 3.2.6 now further clarify the information on EFs for both waste and industrial waste, the fossil and biomass part of the fuels, and the use of confidential EU ETS data for industrial waste in the cement industry.

Report on the individual review of the annual submission of Denmark submitted in 2022 (Draft)
See below the comments and improvements related to the review.

Table 3, E.1: NIR chapter 3.2.6 now further clarify the information on EFs for both waste and industrial waste, the fossil and biomass part of the fuels, and the use of confidential EU ETS data for industrial waste in the cement industry.

Table 3, E.5: See NIR Chapter 3.4.

Table 5, E.6: Information has been added in Chapter 3.2.1 (and in Chapter 3.3 and 3.5)

3.2.11 Planned improvements

If possible, a tier 2 emission factor for N_2O from residential wood combustion will be implemented.

3.2.12 References for Chapter 3.2 and Annex 3A

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3.3 Transport and other mobile sources

The emission inventory basis for mobile sources is fuel consumption information from the Danish energy statistics. In addition, background data for road transport (fleet and mileage), air traffic (aircraft type, flight numbers, origin and destination airports), national sea transport (fuel surveys, ferry technical data, number of return trips, sailing time), fisheries (vessel technical data, hours at sea), railways (e.g. train technical data, number of train km's) and non-road machinery (engine no., engine size, load factor and annual working hours) are used to make the emission estimates sufficiently detailed. Emission data mainly comes from the EMEP/EEA Air Pollutant Emission Inventory Guidebook (EMEP/EEA, 2019). However, for railways, measurements specific to Denmark are used.

In the Danish emissions database, all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution) according to the CORINAIR system. The emission inventories are prepared from a complete emission database based on the SNAP sectors. The aggregation to the sector codes used for both the UNFCCC and UNECE Conventions is based on a correspondence list between SNAP and IPCC classification codes (CRF), shown in Table 3.3.1 (mobile sources only).

Table 3.3.1 SNAP – CRF correspondence table for transport.

SNAP classification	CRF/NFR classification
0701 Road traffic: Passenger cars	1A3bi Road transport: Passenger cars
0702 Road traffic: Light duty vehicles	1A3bii Road transport: Light duty vehicles
0703 Road traffic: Heavy duty vehicles	1A3biii Road transport: Heavy duty vehicles
0704/0705 Road traffic: Mopeds and motor cycles	1A3biv Road transport: Mopeds & motorcycles
0706 Road traffic: Evaporation	1A3bv Road transport: Evaporation
0707 Road traffic: Brake and tire wear	1A3bvi Road transport: Brake and tire wear
0708 Road traffic: Road abrasion	1A3bvii Road transport: Road abrasion
0801 Military	1A5b Other, Mobile
0802 Railways	1A3c Railways
0803 Inland waterways	1A5b Other, Mobile
080402 National sea traffic	1A3dii National navigation (Shipping)
080403 National fishing	1A4ciii Agriculture/Forestry/Fishing: National fishing
080404 International sea traffic	1A3di (i) International navigation (Shipping)
080501 Dom. airport traffic (LTO < 1000 m)	1A3aii (i) Civil aviation (Domestic, LTO
080502 Int. airport traffic (LTO < 1000 m)	1A3ai (i) Civil aviation (International, LTO)
080503 Dom. cruise traffic (> 1000 m)	1A3aii (ii) Civil aviation (Domestic, Cruise)
080504 Int. cruise traffic (> 1000 m)	1A3ai (ii) Civil aviation (International, Cruise)
0806 Agriculture	1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry
0807 Forestry	1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry
0808 Industry	1A2gvii Manufacturing industries/Construction (mobile)
0809 Household and gardening	1A4bii Residential: Household and gardening (mobile)
0811 Commercial and institutional	1A4aii Commercial/Institutional: Mobile

Military transport activities (land and air) refer to the CRF/NFR sector Other (1A5), the latter sector also including recreational craft (SNAP code 0803).

Road traffic evaporation, brake and tire wear, and road abrasion (SNAP codes 0706-0708) is not a part of the CRF list since no greenhouse gases are emitted from these sources.

Emissions from lubricants during use are reported under 2D3 as per the UNFCCC reporting guidelines. Two-stroke engines in road transport are only relevant for mopeds and motorcycles (and the odd veteran vehicle) and even in these categories four-stroke engines have gained popularity in part due to environmental considerations. The Danish energy statistics only include lubricants for non-energy purposes and any consumption in two-stroke mopeds/motorcycles will be negligible and fall far below the threshold of significance.

For aviation, LTO (Landing and Take Off)[1] refers to the part of flying which is below 1000 m. This part of the aviation emissions (SNAP codes 080501 and 080502) are included in the national emissions total as prescribed by the UNECE reporting rules. According to UNFCCC, the national emissions for aviation comprise the emissions from domestic LTO (0805010) and domestic cruise (080503). The fuel consumption and emission development explained in the following are based on these latter results.

Agricultural and forestry non-road machinery (SNAP codes 0806 and 0807) is accounted for in the Agriculture/forestry (1A4cii) sector. Fishing activities (SNAP code 080403) regardless of vessel flag is reported under 1A4ciii.

For mobile sources, the DEMOS (Danish Emission model system for Mobile Sources) model developed at DCE, Aarhus University, is used to calculate the emission inventories. The DEMOS model system comprise database models for road transport (DEMOS-Road), aviation (DEMOS-Aviation), navigation (DEMOS-Navigation), railways (DEMOS-Rail) and non-road mobile machinery (DEMOS-NRMM).

For emission reporting purposes the output results from DEMOS are calculated in a SNAP format, as activity rates (fuel consumption) and emission factors, which are then exported directly to the central Danish CollectER database.

Apart from national inventories, the DEMOS model is used also as a calculation tool in research projects, environmental impact assessment studies, and to produce basic emission information, which requires various aggregation levels.

A Key Category Analysis (KCA) approach 1 and approach 2 for the years 1990 and 2021 and for the trend 1990-2020 for Denmark has been carried out in accordance with the IPCC Guidelines (IPCC, 2006). Table 3.3.2 shows the 12 mobile source categories. The table is based on the analysis including LULUCF. The full key category analysis for Denmark is shown in NIR Chapter 1.5 and Annex 1.

[1]A LTO cycle consists of the flying modes approach/descent, taxiing, take off and climb out. In principle, the actual times-in-modes rely on the actual traffic circumstances, the airport configuration, and the aircraft type in question.

Mobile sources include quite many key categories in the case of CO_2. Most notably, road transport and non-road mobile machinery in industry and agriculture are key sources in 1990 and 2021 and for the emission trend in both the approach 1 and approach 2 analysis.

CH_4 is not a key category in any case for mobile sources. Finally, due to the relatively high uncertainty for N_2O, emission factors the N_2O emission from a few emission sources are also key categories in the approach 2 analysis.

Table 3.3.2 Key category overview[2], mobile sources.

		Approach 1			Approach 2		
		1990	2021	1990-2021	1990	2021	1990-2021
1.A.2.g Industry (mobile)	CO_2	Level	Level	Trend	Level	Level	Trend
1.A.3.a Civil aviation	CO_2	Level					
1.A.3.b Road Transport	CO_2	Level	Level	Trend	Level	Level	Trend
1.A.3.c Railways	CO_2	Level	Level				
1.A.3.d Navigation (large vessels)	CO_2	Level	Level	Trend			
1.A.4.a Commercial/Institutional (mobile)	CO_2		Level				
1.A.4.b Residential (mobile)	CO_2						
1.A.4.c ii Agriculture (mobile)	CO_2	Level	Level	Trend	Level	Level	Trend
1.A.4.c ii Forestry (mobile)	CO_2						
1.A.4.c iii Fisheries	CO_2	Level	Level				
1.A.5.b Other (military)	CO_2						
1.A.5.b Other (small boats)	CO_2		Level				
1.A.2.g Industry (mobile)	CH_4						
1.A.3.a Civil aviation	CH_4						
1.A.3.b Road Transport	CH_4						
1.A.3.c Railways	CH_4						
1.A.3.d Navigation (large vessels)	CH_4						
1.A.4.a Commercial/Institutional (mobile)	CH_4						
1.A.4.b Residential (mobile)	CH_4						
1.A.4.c ii Agriculture (mobile)	CH_4						
1.A.4.c ii Forestry (mobile)	CH_4						
1.A.4.c iii Fisheries	CH_4						
1.A.5.b Other (military)	CH_4						
1.A.5.b Other (small boats)	CH_4						
1.A.2.g Industry (mobile)	N_2O					Level	Trend
1.A.3.a Civil aviation	N_2O						
1.A.3.b Road Transport	N_2O		Level				
1.A.3.c Railways	N_2O						
1.A.3.d Navigation (large vessels)	N_2O						
1.A.4.a Commercial/Institutional (mobile)	N_2O						
1.A.4.b Residential (mobile)	N_2O						
1.A.4.c ii Agriculture (mobile)	N_2O					Level	Trend
1.A.4.c ii Forestry (mobile)	N_2O						
1.A.4.c iii Fisheries	N_2O						
1.A.5.b Other (military)	N_2O						

3.3.1 Source category description

The following description of source categories explains the development in fuel consumption and emissions for road transport and other mobile sources.

[2] For Denmark, not including Greenland & Faroe Island. Based on the KCA including LULUCF.

Total fuel consumption for mobile sources

Table 3.3.3 shows the fuel consumption for mobile sources based on DEA statistics for 2021 in CRF sectors (DEA, 2022a). The fuel consumption figures in time series 1985-2021 are given in Annex 2.B.16 (CRF format) and are shown for 2021 in Annex 2.B.15 (CollectER format). Road transport has a major share of the fuel consumption for mobile sources. In 2021, this sector's fuel consumption share is 80 %, while the fuel consumption shares for Off road agriculture/forestry, Manufacturing industries (mobile) and National navigation are 5 %, 4 % and 5 %, respectively. For the remaining sectors, the total fuel consumption share is 7 %.

Table 3.3.3 Fuel consumption (PJ) for domestic mobile sources in 2021 in CRF sectors.

CRF ID	Fuel consumption (PJ)
Manufacturing industries/Construction (mobile)	8.5
Civil aviation (Domestic)	1.2
Road transport: Passenger cars	87.3
Road transport:Light duty vehicles	21.8
Road transport:Heavy duty vehicles	52.9
Road transport: Mopeds & motorcycles	1.0
Railways	2.5
National navigation (Shipping)	7.2
Commercial/Institutional: Mobile	2.4
Residential: Household and gardening (mobile)	0.4
Agriculture/Forestry/Fishing: Off-road agriculture/forestry	9.2
Agriculture/Forestry/Fishing: National fishing	5.0
Other. Mobile	3.1
Road transport total	163.0
Other mobile total	39.6
Domestic total	202.6
Civil aviation (International)	17.5
Navigation (international)	18.2

From 1990 to 2021, diesel (sum of diesel and biodiesel) and gasoline (sum of neat gasoline and bio ethanol) fuel consumption has changed by 53 % and -20 %, respectively (Figure 3.3.1), and in 2021 the fuel consumption shares for diesel and gasoline were 70 % and 27 %, respectively (not shown). Other fuels only have a 3 % share of the domestic mobile sources total (Figures 3.3.2). Almost all gasoline is used in road transportation vehicles. Gardening machinery and recreational craft are merely small consumers. Regarding diesel, there is considerable fuel consumption in most of the domestic mobile sources categories, whereas a more limited use of residual oil and jet fuel is being used in the navigation sector and by aviation (civil and military flights), respectively[3].

[3] The gasoline and diesel fuel sold at the conventional gas filling stations contain bio ethanol and biodiesel. Small amounts of gasoline and diesel are bought by individuals at the gas stations, filled into fuel cans and subsequently used to propel gasoline working machines (gasoline) and recreational craft (gasoline and diesel).

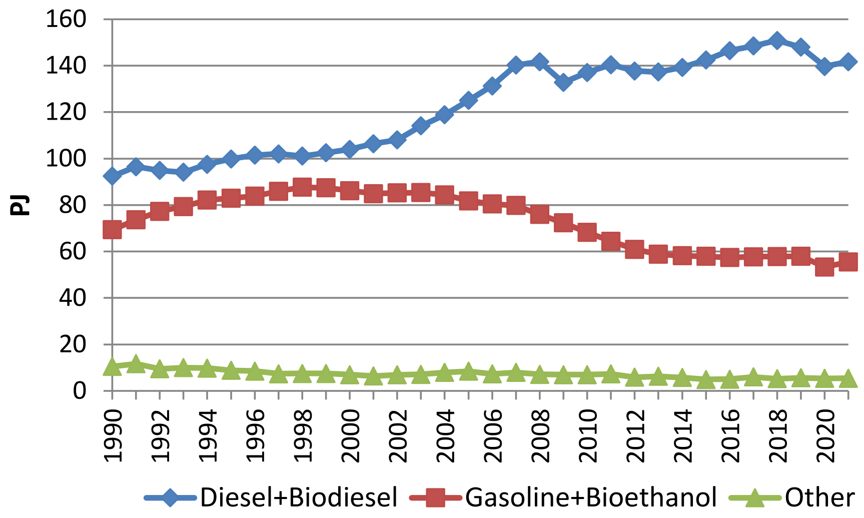


Figure 3.3.1 Fuel consumption per fuel type for domestic mobile sources 1990-2021.

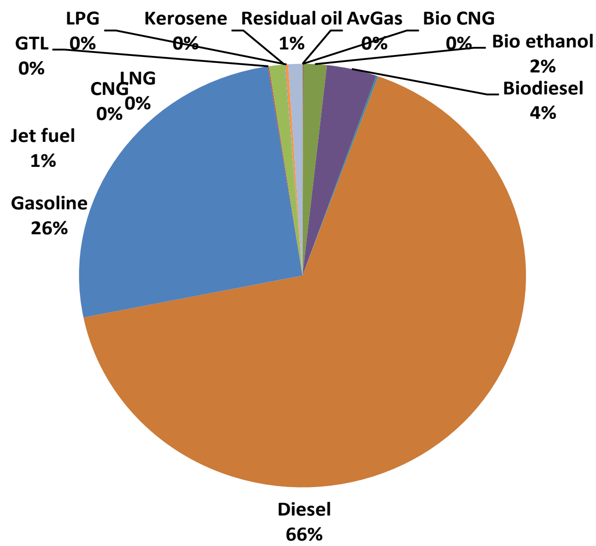


Figure 3.3.2 Fuel consumption share per fuel type for domestic mobile sources in 2021.

Fuel consumption for road transport

As shown in Figure 3.3.3, the fuel consumption for road transport[4] has generally increased until 2007, except from a small fuel consumption decline noted in 2000. Significant fuel consumption declines are noted for 2008- 2009 and in 2020, respectively, due to the global financial crisis and Covid 19 social restrictions. The fuel consumption development is due to a decreasing trend in the use of gasoline fuels from 1999 to 2013 combined with a steady growth in the use of diesel until 2007, and from 2014 to 2018. Within sub-sectors, passenger cars represent the most fuel-consuming vehicle category, followed by heavy-duty vehicles, light duty vehicles and 2-wheelers, in decreasing order (Figure 3.3.4).

[4] The sum share of bioethanol and biodiesel in the gasoline and diesel fuel blends for road transport is 5.4 %, in 2021.

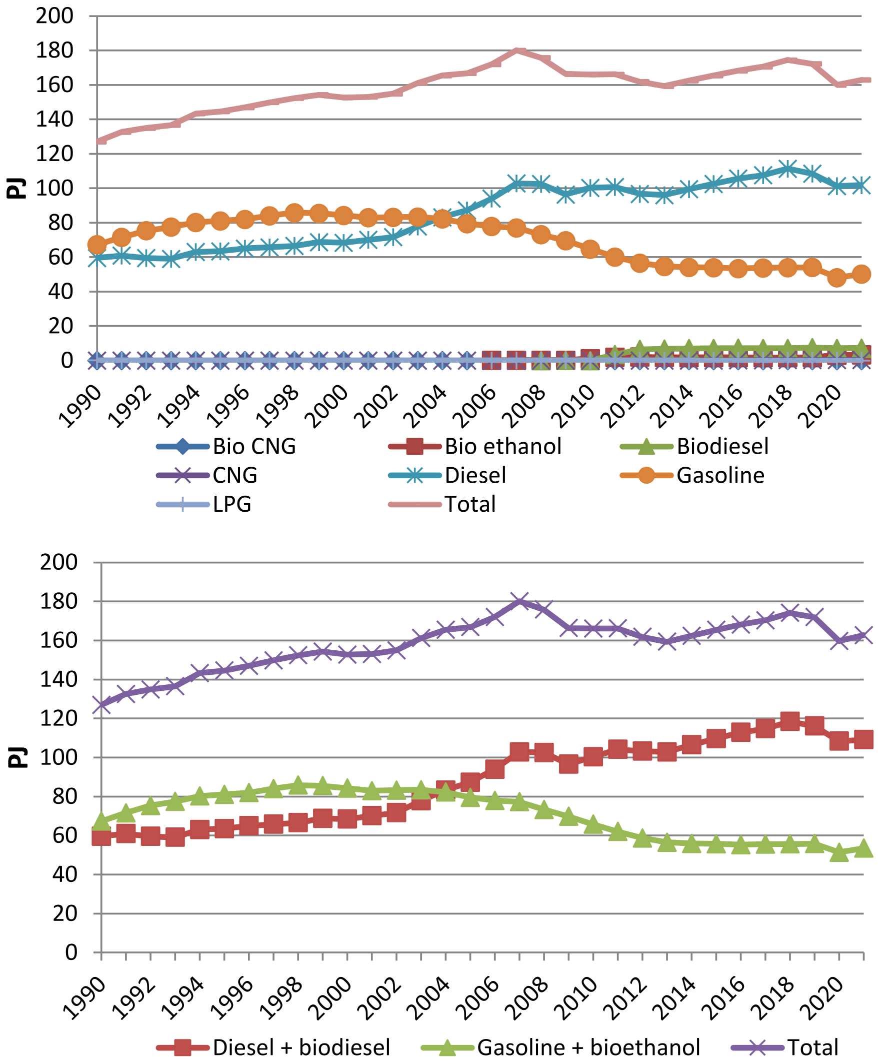


Figure 3.3.3 Fuel consumption per fuel type and as totals for road transport 1990-2021.

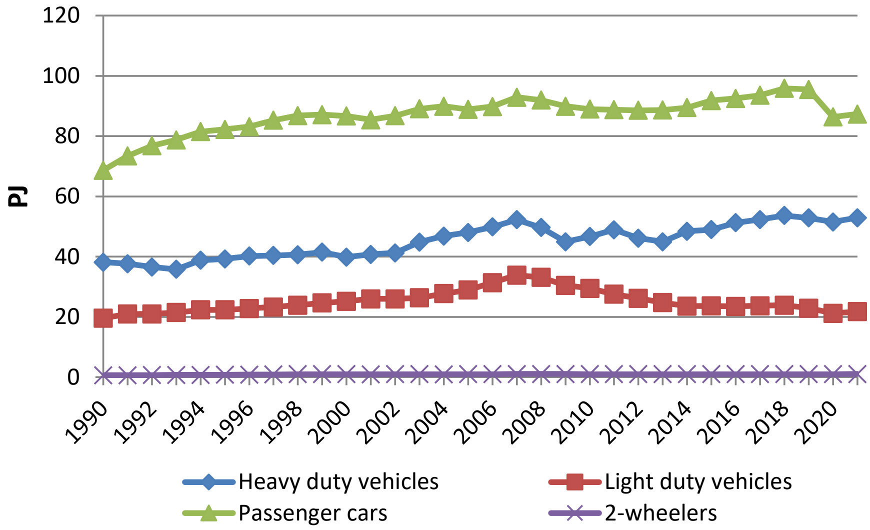


Figure 3.3.4 Total fuel consumption per vehicle type for road transport 1990-2021.

As shown in Figure 3.3.5, fuel consumption for gasoline passenger cars dominates the overall gasoline consumption trend. The development in diesel fuel consumption in recent years (Figure 3.3.6) is characterised by increasing fuel consumption for diesel passenger cars until 2018, while declines in the fuel consumption for trucks and buses (heavy-duty vehicles) are noted for 2008-2009, 2012-2013 and 2019-2020, and fuel consumption reductions for light duty vehicles are noted for 2008-2014 and 2019-2020.

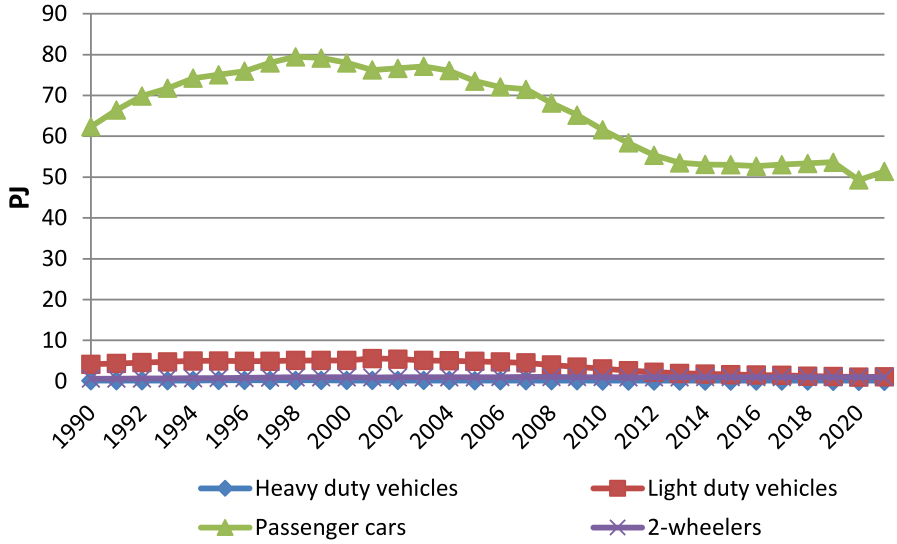


Figure 3.3.5 Gasoline fuel consumption per vehicle type for road transport 1990-2021.

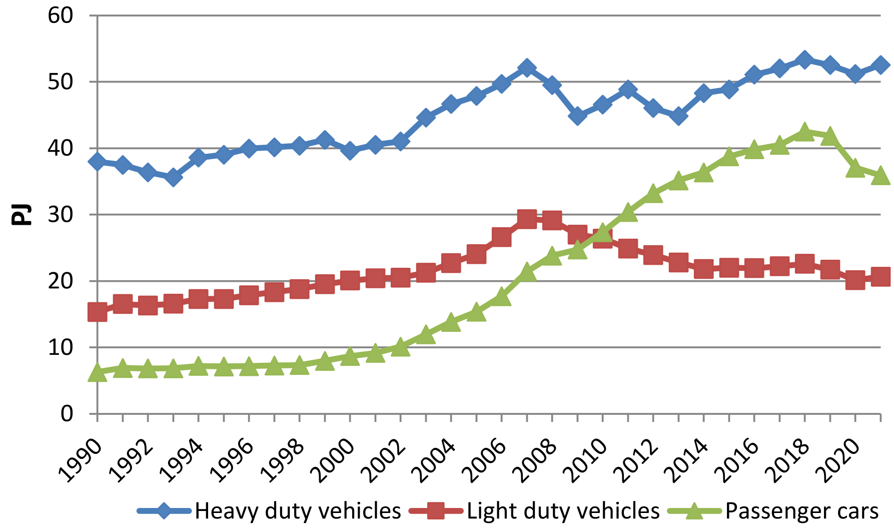


Figure 3.3.6 Diesel fuel consumption per vehicle type for road transport 1990-2021.

In 2021, fuel consumption shares for gasoline passenger cars, diesel heavy-duty vehicles, diesel passenger cars and diesel light duty vehicles were 31, 32, 22 and 13 %, respectively (Figure 3.3.7).

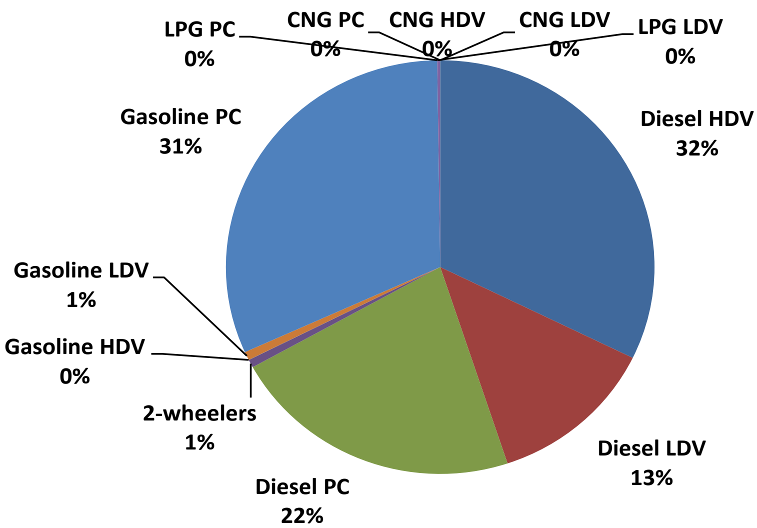


Figure 3.3.7 Fuel consumption shares per vehicle type for road transport in 2021.

Fuel consumption for other mobile sources

It must be noted that the fuel consumption figures behind the Danish inventory for mobile equipment in the agriculture, forestry, industry, household and gardening (residential), and inland waterways (part of navigation) sectors, are less certain than for other mobile sectors. For these types of machinery, the DEA statistical figures do not directly provide fuel consumption information, and fuel consumption totals are subsequently estimated from activity data and fuel consumption factors. For recreational craft the latest historical year is 2004.

As seen in Figure 3.3.8, classified according to CRF the most important sectors are Agriculture/forestry/fisheries (1A4c), Industry-other (mobile machinery part of 1A2g) and Navigation (1A3d). Minor fuel consuming sectors are Civil Aviation (1A3a), Railways (1A3c), Other (military mobile and recreational craft: 1A5b), Commercial/institutional (1A4a) and Residential (1A4b).

The 1990-2021 time series are shown per fuel type in Figures 3.3.9-3.3.12 for diesel, gasoline, residual oil and jet fuel, and liquefied natural gas (LNG) and gas-to-liquid (GTL) manufactured from natural gas, respectively.

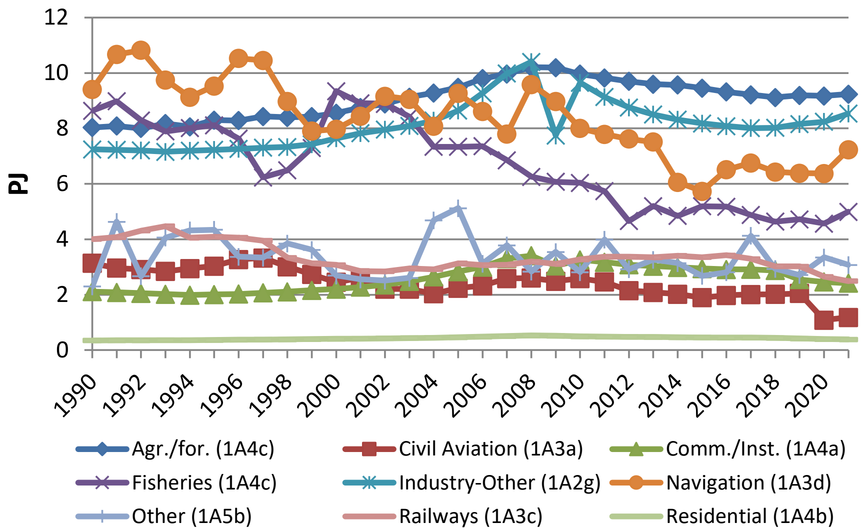


Figure 3.3.8 Total fuel consumption in CRF sectors for other mobile sources 1990-2021.

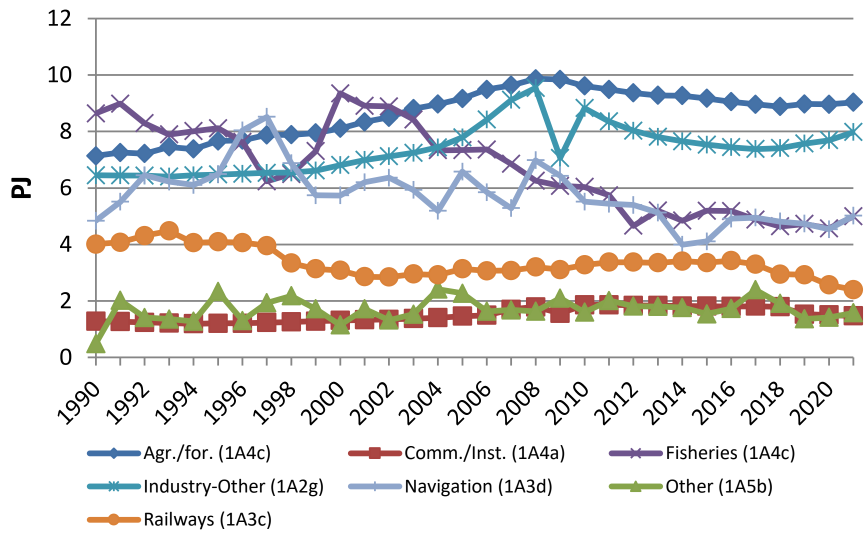


Figure 3.3.9 Diesel fuel consumption in CRF sectors for other mobile sources 1990-2021.

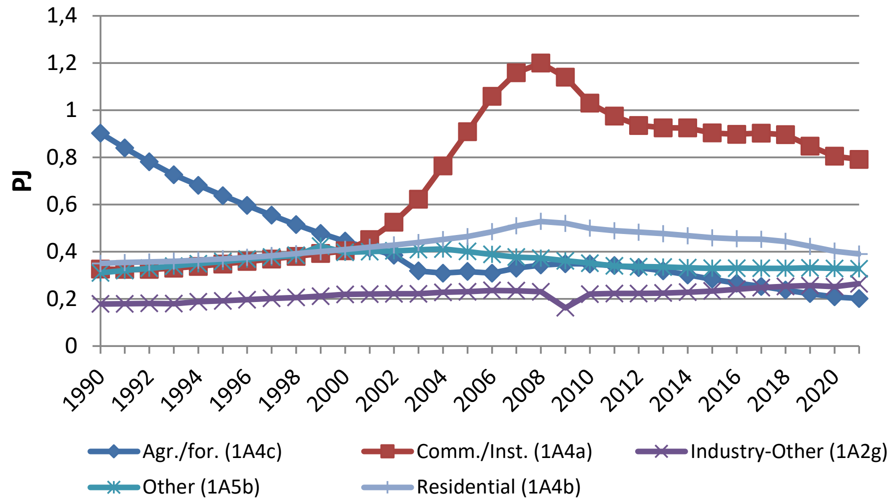


Figure 3.3.10 Gasoline fuel consumption in CRF sectors for other mobile source 1990-2021.

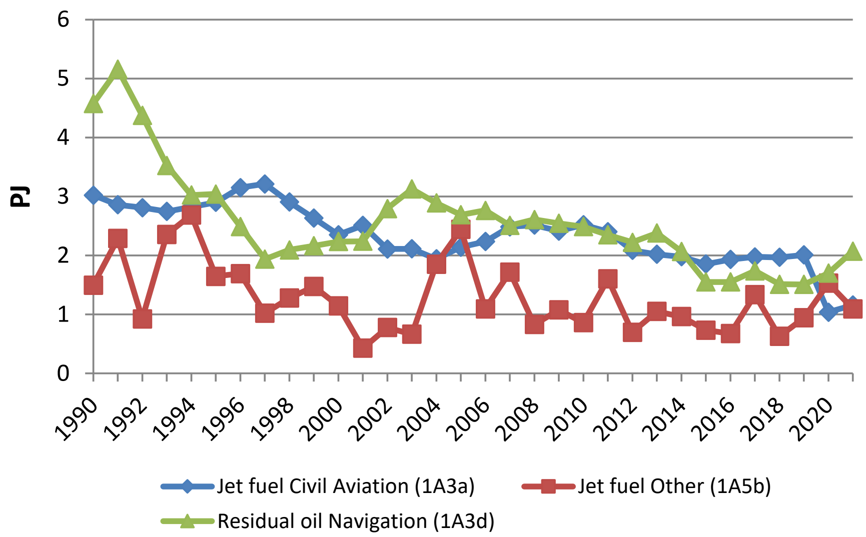


Figure 3.3.11 Residual oil and jet fuel consumption in CRF sectors for other mobile sources 1990-2021.

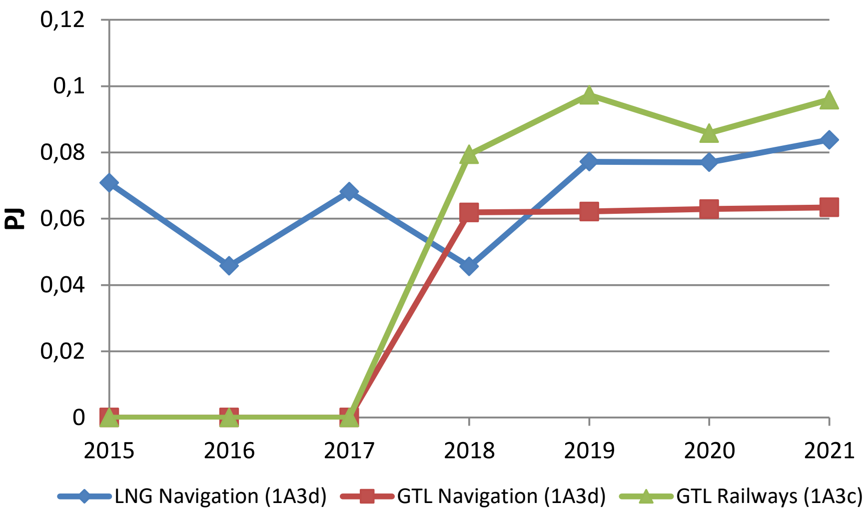


Figure 3.3.12 LNG and GTL fuel consumption in CRF sectors for other mobile sources 1990-2021.

For diesel, although the number of tractors and harvesters decrease in the entire period 1985-2020, the contemporary increase in the engine sizes of new sold machines makes the total fuel consumption grow until 2008. The turnover of old less fuel efficient machinery and the decline in the number of tractors and harvesters explain the total fuel consumption decrease from 2008 to 2018. The fuel consumption for industry has increased from the beginning of the 1990's, due to an increase in the activities for construction machinery. The fuel consumption increase has been very pronounced in 2005-2008, for 2009; however, the global financial crisis has a significant impact on the building and construction activities. The fuel efficiency improvements for new sold vehicles is the main reason for total fuel consumption decline from 2010-2018. For fisheries, the development in fuel consumption reflects the activities in this sector.

The Navigation sector comprises national sea transport (fuel consumption between two Danish ports including sea travel directly between Denmark and Greenland/Faroe Islands). For national sea transport, the diesel fuel consumption curve reflects the combination of traffic and ferries in use for regional ferries. In 1998 and 1999, a significant decline in fuel consumption is apparent. The most important explanation here is the closing of ferry service routes in connection with the opening of the Great Belt Bridge in 1997. For railways, the gradual shift towards electrification explains the lowering trend in diesel fuel consumption and the emissions for this transport sector. The fuel consumed (and associated emissions) to produce electricity is accounted for in the stationary combustion part of the Danish inventories.

The largest gasoline fuel consumption is calculated for the Commercial/Institutional (1A4a) sector related to the use of household and gardening machinery. For these types of machinery, a somewhat smaller gasoline fuel consumption is calculated for the Residential (1A4b) sector. For household and gardening equipment, especially from 2001-2006, a significant fuel consumption increase is apparent due to considerable growth in the machinery stock. The gasoline fuel consumption development for Agriculture/forestry/fisheries (1A4c) is due to the gradual phasing out of gasoline-fuelled agricultural tractors until 2005 and the gradual increase in new sales of ATV's from the mid 2000's until 2011, followed by a decrease in new sales of ATV's from 2011 forward.

In terms of residual oil, there has been a substantial decrease in the fuel consumption for regional ferries. The fuel consumption decline is most significant from 1991-1994 and from 1995-1997.

The considerable variations from one year to another in military jet fuel consumption are due to planning and budgetary reasons, and the passing demand for flying activities. Consequently, for some years, a certain amount of jet fuel stock-building might disturb the real picture of aircraft fuel consumption. Civil aviation has decreased until 2004, since the opening of the Great Belt Bridge in 1997, both in terms of number of flights and total jet fuel consumption. From 2011 to 2012, the total consumption of jet fuel decreased significantly due to a drop in the number of domestic flights, and in 2020 a huge decline in jet fuel consumption is noted due to the impact of Covid 19 on flight travel demand.

From 2015 onwards small amounts of LNG has been used by domestic ferries, and from 2018 onwards GTL has been used by a few domestic ferries and private railway lines.

Fuel consumption for international transport

The residual oil and diesel oil fuel consumption fluctuations reflect the quantity of fuel sold in Denmark to international ferries, international warships, other ships with foreign destinations, transport to Greenland and the Faroe Islands, tank vessels and foreign fishing boats. For jet petrol, the sudden fuel consumption drop in 2002 is explained by the recession in the aviation sector due to the events of September 11, 2001 and structural changes in the aviation business. In 2009, the impact of the global financial crisis on flying activities becomes very visible, and in 2020 a huge decline in jet fuel consumption is noted due to the impact of COVID-19 on flight travel demand.

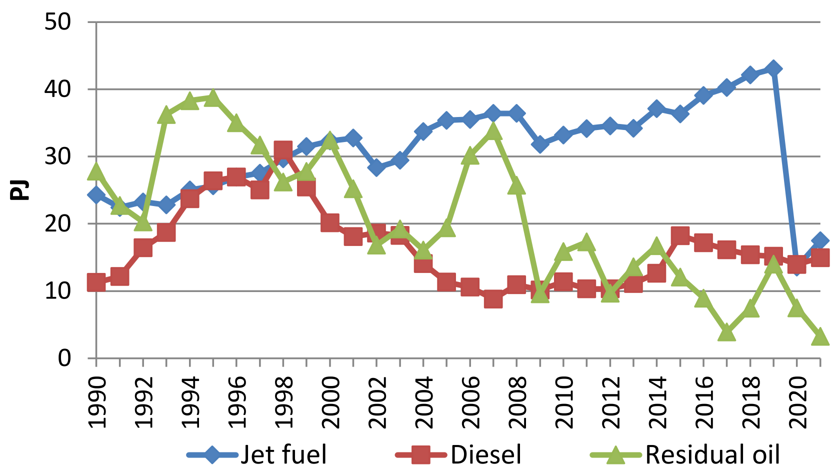


Figure 3.3.13 Bunker fuel consumption 1990-2021.

Total emissions of CO_2, CH_4 and N_2O for mobile sources

In Table 3.3.4 the CO_2, CH_4 and N_2O emissions for road transport and other mobile sources are shown for 2021 in CRF sectors. The emission figures in time series 1990-2021 are given in Annex 3.B.16 (CRF format) and are shown for 1990 and 2021 in Annex 3.B.15 (CollectER format).

From 1990 to 2021, the road transport emissions of CO_2 and N_2O have increased by 21 and 43 %, respectively, whereas the emissions of CH_4 have decreased by 90 % (from Figures 3.3.14 - 3.3.16). From 1990 to 2021 the other mobile CO_2 emissions have decreased by 13 %, (from Figures 3.3.18 - 3.3.20).

Table 3.3.4 Emissions of CO_2, CH_4 and N_2O in 2021 for road transport and other mobile sources.

	CO_2 ktonnes	CH_4 tonnes	N_2O tonnes
Manufacturing industries/Construction (mobile)	628	22	29
Civil aviation (Domestic)	85	1	4
Road transport: Passenger cars	6016	200	128
Road transport:Light duty vehicles	1510	6	43
Road transport:Heavy duty vehicles	3667	41	247
Road transport: Mopeds & motorcycles	70	71	1
Railways	185	2	6
National navigation (Shipping)	543	31	14
Commercial/Institutional: Mobile	173	30	7
Residential: Household and gardening (mobile)	27	20	0
Agriculture/Forestry/Fishing: Off-road agriculture/forestry	683	42	33
Agriculture/Forestry/Fishing: National fishing	370	6	9
Other, Mobile	219	9	8
Road transport exhaust total	11262	318	419
Road transport non exhaust total	0	0	0
Other mobile sources total	2912	163	110
Domestic total	14174	481	529
Civil aviation (International)	1258	4	42
Navigation (International)	1363	23	34

Emissions of CO_2, CH_4 and N_2O for road transport

CO_2 emissions are directly fuel consumption dependent and, in this way, the development in the emission reflects the trend in fuel consumption. As shown in Figure 3.3.14, the most important emission source for road transport is passenger cars, followed by heavy-duty vehicles, light-duty vehicles and 2-wheelers in decreasing order. In 2021, the respective emission shares were 53, 33, 13 and 1 %, respectively (Figure 3.3.17).

The majority of CH_4 emissions from road transport come from gasoline passenger cars (Figure 3.3.15). The emission drop from 1992 onwards is explained by the penetration of catalyst cars into the Danish fleet. The 2021 emission shares for CH_4 were 63, 22, 13 and 2 % for passenger cars, 2-wheelers, heavy-duty vehicles and light-duty vehicles, respectively (Figure 3.3.17).

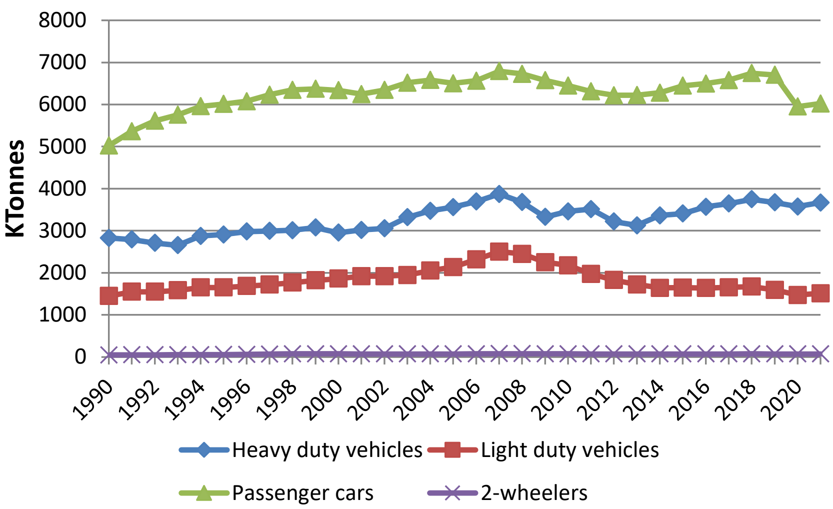


Figure 3.3.14 CO_2 emissions (k-tonnes) per vehicle type for road transport 1990-2021.

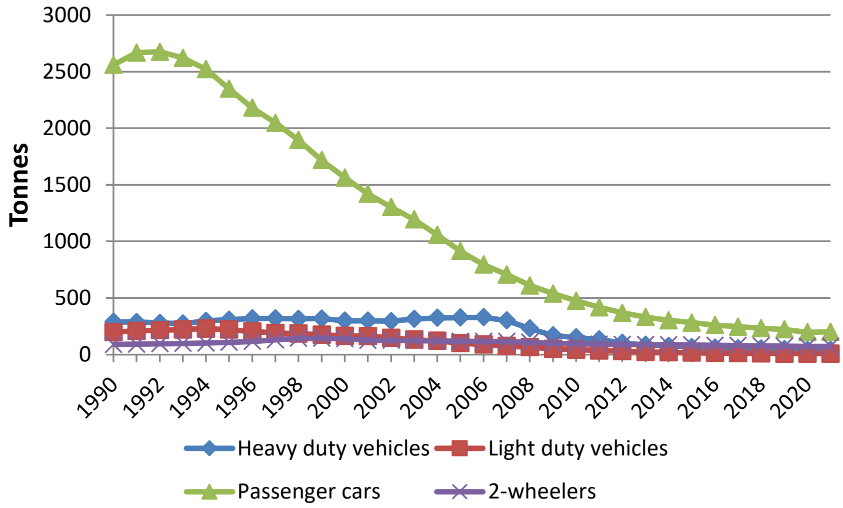


Figure 3.3.15 CH_4 emissions (tonnes) pr. vehicle type for road transport 1990-2021.

An undesirable environmental side effect of the introduction of catalyst cars is the increase in the emissions of N_2O from the first generation of catalyst cars (Euro 1) compared to conventional cars. The emission factors for later catalytic converter technologies are considerably lower than the ones for Euro 1, thus causing the emissions to decrease from 1998 onwards (Figure 3.3.16). In 2021, emission shares for passenger cars, heavy and light-duty vehicles were 59, 31 and 10 %, of the total road transport N_2O, respectively (Figure 3.3.17).

Referring to the fifth IPCC assessment report, 1 g CH_4 and 1 g N_2O has the greenhouse effect of 28 and 265 g CO_2, respectively. In spite of the relatively large CH_4 and N_2O global warming potentials, the largest contribution to the total CO_2 emission equivalents for road transport comes from CO_2, and the CO_2 emission equivalent shares per vehicle category are almost the same as the CO_2 shares.

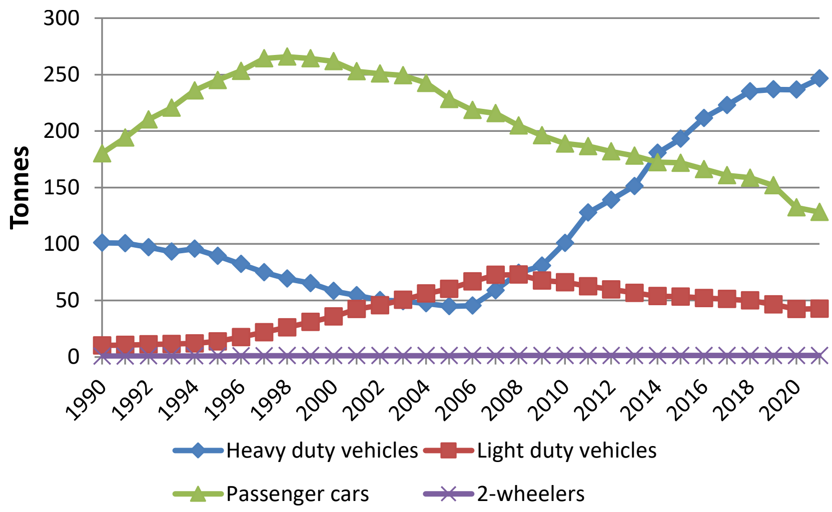


Figure 3.3.16 N_2O emissions (tonnes) per vehicle type for road transport 1990-2021.

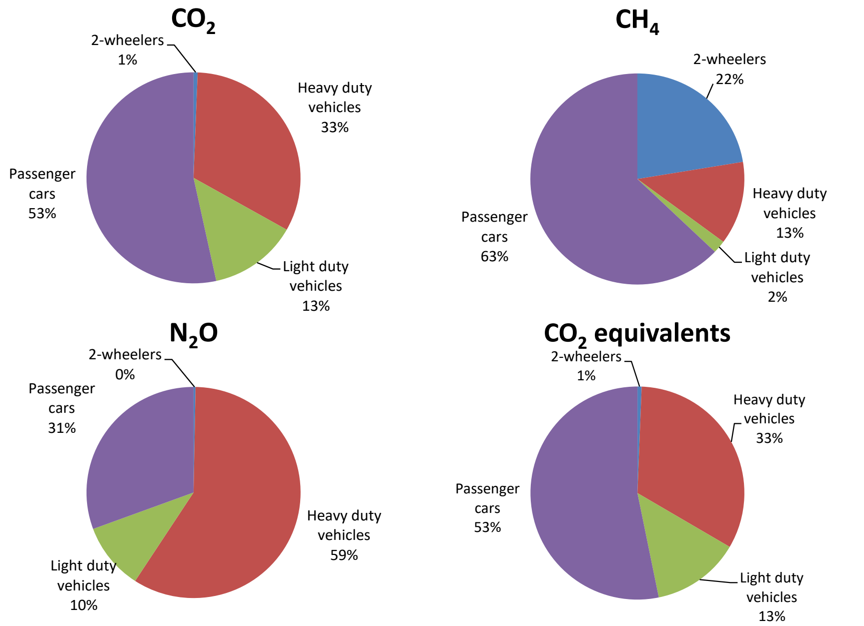


Figure 3.3.17 CO_2, CH_4 and N_2O emission shares and GHG equivalent emission distribution for road transport in 2021.

Emissions of CO_2, CH_4 and N_2O for other mobile sources

For other mobile sources, the highest CO_2 emissions in 2021 come from Agriculture/forestry/fisheries (1A4c), Industry-other (1A2g) and Navigation (1A3d), with shares of 36 %, 22 %, 19, respectively (Figure 3.3.21). The 1990-2021 emission trend is directly related to the fuel consumption development in the same time-period. Minor CO_2 emission contributors are sectors such as Commercial/Institutional (1A4a), Residential (1A4b), Railways (1A3c), Civil Aviation (1A3a) and Other (1A5).

For CH_4, the most important sources are Agriculture/forestry/fisheries (1A4c), Navigation (1A3d), Commercial/Institutional (1A4a), Industry-other (1A2g), and Residential (1A4b), see Figure 3.3.21. The emission shares are 29 %, 19 %, 18 %, 13 % and 13 %, respectively in 2021. For the remaining sectors the emission shares 6 % or less. The CH_4 emission contributions from Commercial/Institutional (1A4a) and Residential (1A4b) are quite high compared to their relative fuel consumption (and CO_2 emissions) contributions, due the high CH_4 emission factors for gasoline fuelled working machinery in general.

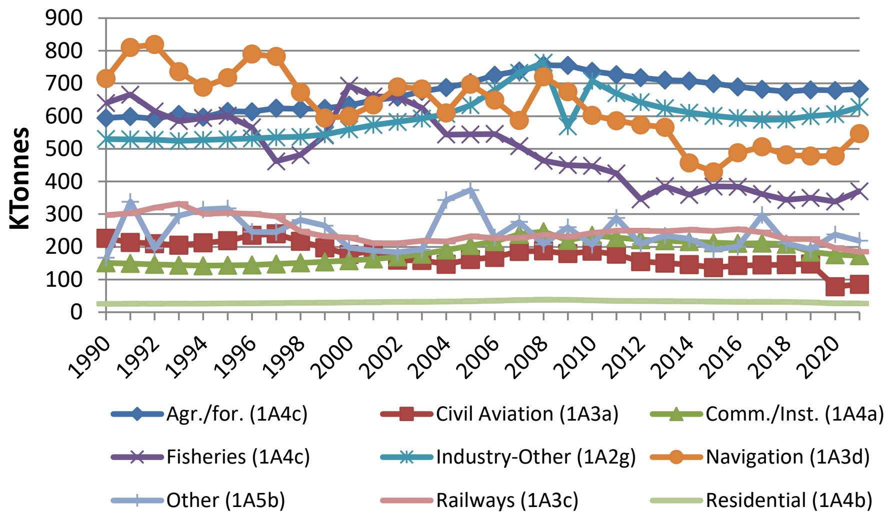


Figure 3.3.18 CO_2 emissions (ktonnes) in CRF sectors for other mobile sources 1990-2021.

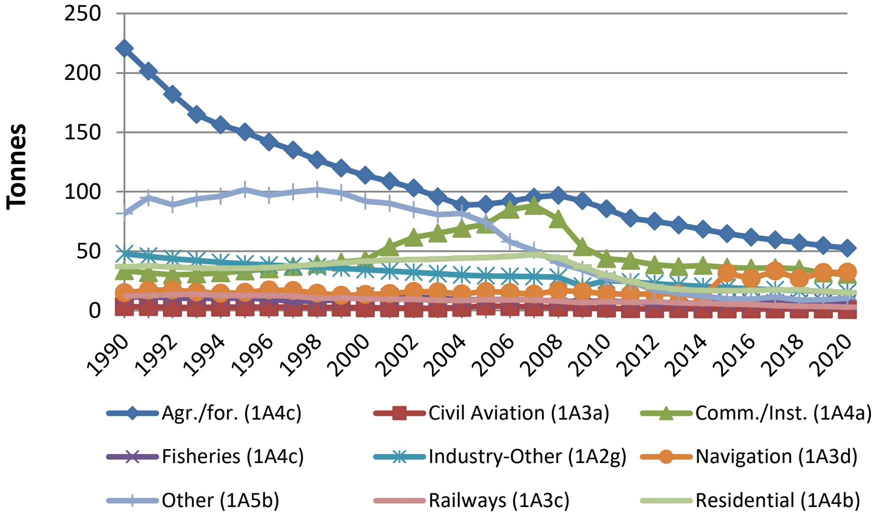


Figure 3.3.19 CH_4 emissions (tonnes) in CRF sectors for other mobile sources 1990-2021.

For N_2O, the emission trend in sub-sectors is the same as for fuel consumption and CO_2 emissions (Figure 3.3.20).

As for road transport, CO_2 alone contributes with by far the most CO_2 emission equivalents in the case of other mobile sources, and per sector the CO_2 emission equivalent shares are almost the same as those for CO_2, itself (Figure 3.3.21).

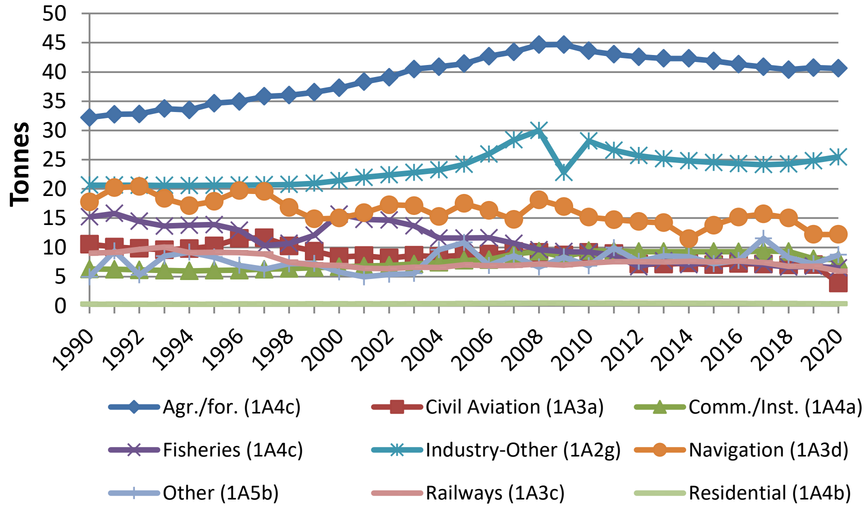


Figure 3.3.20 N_2O emissions (tonnes) in CRF sectors for other mobile sources 1990-2021.

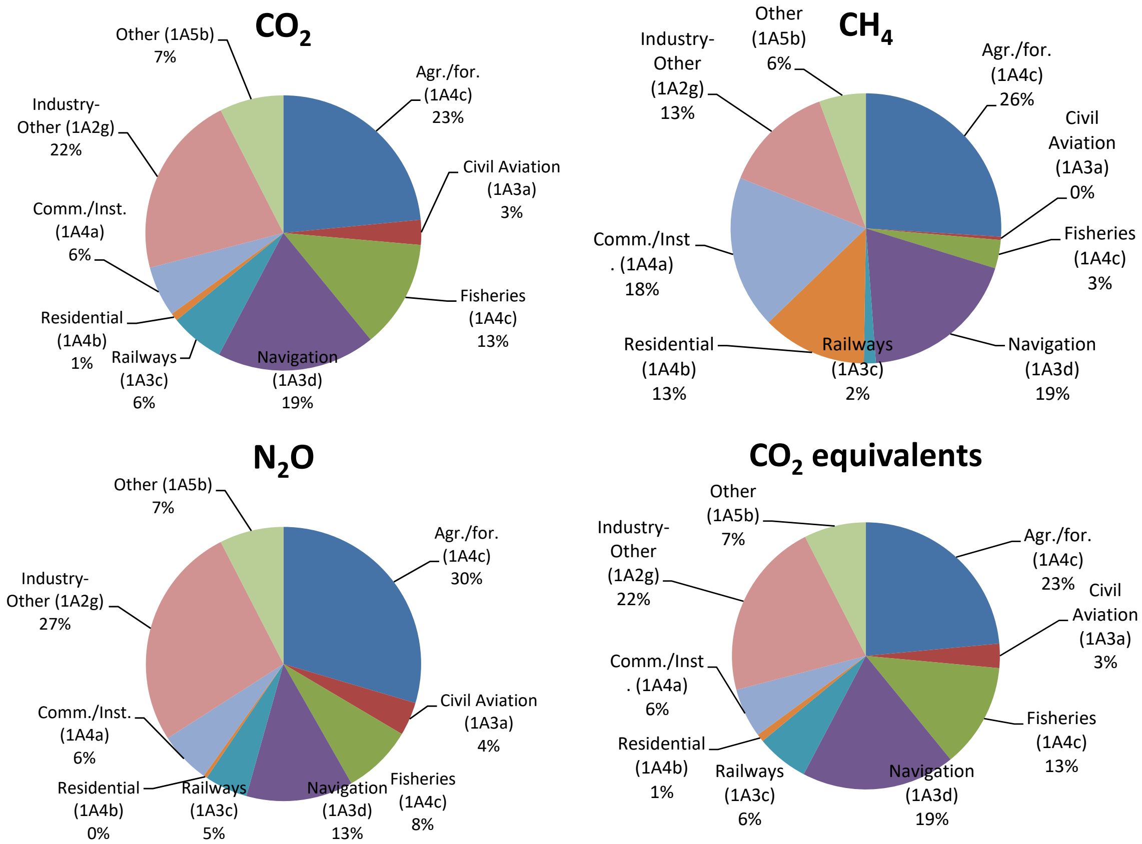


Figure 3.3.21 CO_2, CH_4 and N_2O emission shares and GHG equivalent emission distribution for other mobile sources in 2021.

Emissions of CO_2, CH_4 and N_2O for international transport

The most important emissions from bunker fuel consumption (fuel consumption for international transport) are SO_2 and NO_X. In terms of greenhouse gas emissions, the level of emissions from Danish bunker fuel consumption are 18 %, 6 % and 14 %, respectively, for CO_2, CH_4 and N_2O, compared with the emission total for mobile sources in 2021.

The bunker emission totals of CO_2, CH_4 and N_2O are shown in Table 3.3.4 for 2021, split into sea transport and civil aviation. All emission figures in the 1990-2021 time series are given in Annex 3.B.16 (CRF format). In Annex 3.B.15, the emissions are also given in CollectER format for the years 1990 and 2021.

For further explanations of SO_2 and NO_x emissions from bunkers please refer to the Danish IIR report (Nielsen et al. 2022).

The differences in CH_4 emissions between navigation and civil aviation are much larger than the differences in fuel consumption (and derived CO_2 emissions), and display a poor emission performance for international sea transport. In broad terms, the emission trends shown in Figure 3.3.22 are similar to the fuel consumption development.

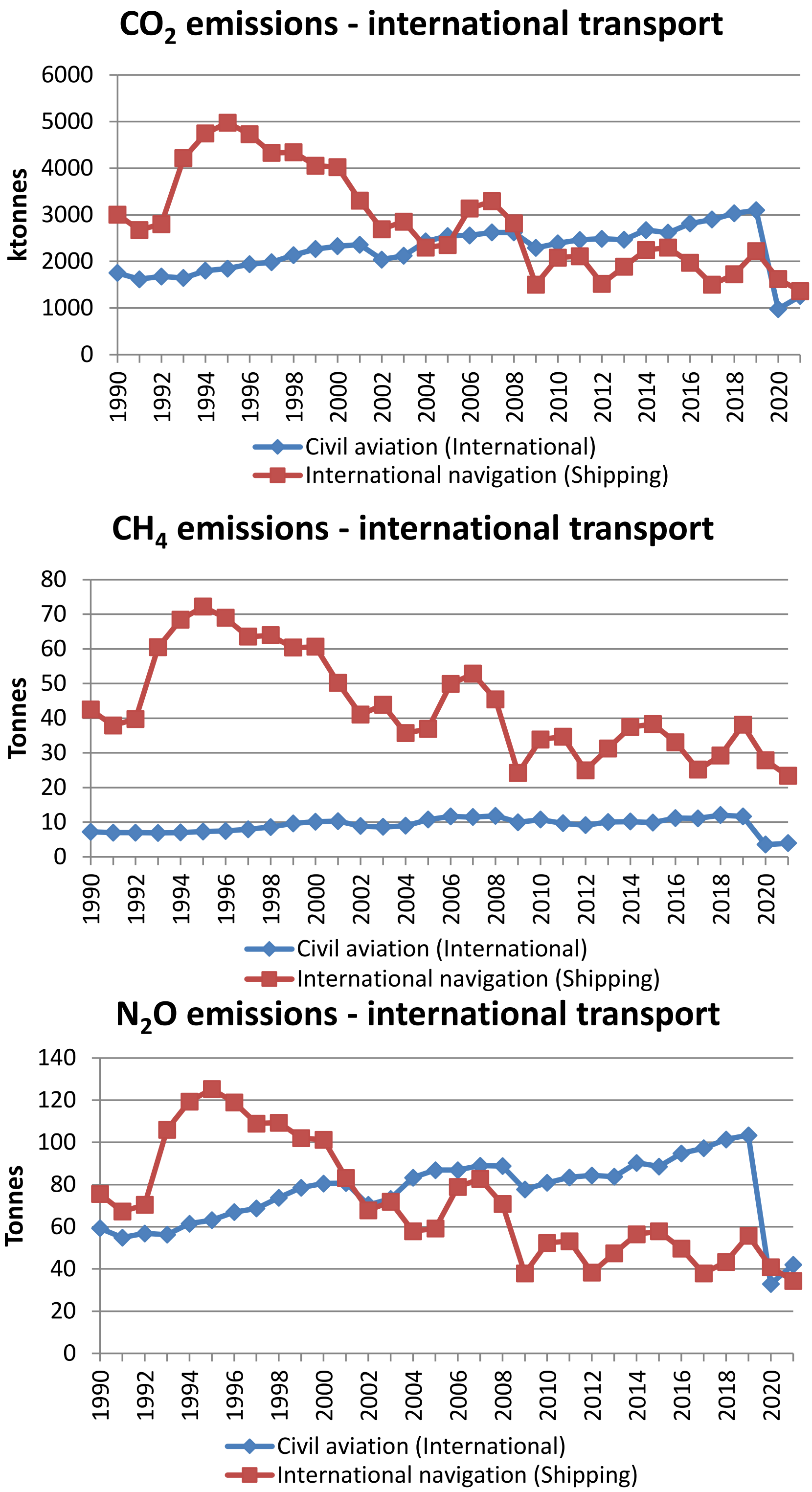


Figure 3.3.22 CO_2, CH_4 and N_2O emissions for international transport 1990-2021.

Emissions of SO_2, NO_X, NMVOC, CO, NH_3, TSP, PM_{10}, $PM_{2.5}$ and BC

For road transport and other mobile sources the emission figures of SO_2, NO_X, NMVOC, CO, NH_3, TSP, PM_{10}, $PM_{2.5}$ and BC in the time series 1990-2021 are given in Annex 3.B.16 (CRF format) and are shown for 1990 and 2021 in Annex 3.B.15 (CollectER format). For further explanations regarding these emissions, please refer to the Danish IIR report (Nielsen et al. 2022).

3.3.2 Activity data, emission factors and calculation methodologies for Road Transport

For road transport, the detailed methodology (Tier 3) is used to make annual estimates of the Danish emissions, as described in the EMEP/EEA Air Pollutant Emission Inventory Guidebook (EMEP/EEA, 2019). The calculations are made with DEMOS-Road (Danish Emission model system for Mobile Sources) model developed at DCE, Aarhus University, using the European COPERT 5 model methodology (EMEP/EEA, 2019). In COPERT, fuel consumption and emission simulations can be made for operationally hot engines, taking into account gradually stricter emission standards and emission degradation due to catalyst wear. Furthermore, the emission effects of cold-start and evaporation are simulated.

Vehicle fleet and mileage data

Corresponding to the COPERT 5 fleet classification, DEMOS-Road groups all present and future vehicles in the Danish fleet into vehicle classes, sub-classes and layers. The layer classification is a further division of vehicle sub-classes into groups of vehicles with the same average fuel consumption and emission behaviour, according to EU emission legislation levels. Table 3.3.5 gives an overview of the different model classes and sub-classes, and all model layers the complete list of layer level with implementation years are shown in Annex 3.B.1.

Table 3.3.5 Model vehicle classes and sub-classes and trip speeds.

			Trip speed [km pr h]		
Vehicle classes	Fuel type	Engine size/weight	Urban	Rural	Highway
PC	Gasoline	< 0.8 l.	40	70	100
PC	Gasoline	0.8 - 1.4 l.	40	70	100
PC	Gasoline	1.4 – 2 l.	40	70	100
PC	Gasoline	> 2 l.	40	70	100
PC	Diesel	< 0.8 l.	40	70	100
PC	Diesel	0.8 - 1.4 l.	40	70	100
PC	Diesel	< 1.4 - 2 l.	40	70	100
PC	Diesel	> 2 l.	40	70	100
PC	2-stroke		40	70	100
PC	LPG		40	70	100
PC	CNG		40	70	100
PC	Plug-in hybrid		40	70	100
LCV	Gasoline	<1305 kg	40	65	80
LCV	Gasoline	1305-1760 kg	40	65	80
LCV	Gasoline	>1760 kg	40	65	80
LCV	Diesel	<1305 kg	40	65	80
LCV	Diesel	1305-1760 kg	40	65	80
LCV	Diesel	>1760 kg	40	65	80
LCV	LPG	<1305 kg	40	65	80
LCV	LPG	1305-1760 kg	40	65	80
LCV	LPG	>1760 kg	40	65	80
LCV	CNG	<1305 kg	40	65	80
LCV	CNG	1305-1760 kg	40	65	80
LCV	CNG	>1760 kg	40	65	80
LCV	Plug-in hybrid	<1305 kg	40	65	80
LCV	Plug-in hybrid	1305-1760 kg	40	65	80
LCV	Plug-in hybrid	>1760 kg	40	65	80
Trucks	Gasoline		35	60	80
Trucks	Diesel/CNG	Rigid 3,5 - 7,5t	35	60	80
Trucks	Diesel/CNG	Rigid 7,5 - 12t	35	60	80
Trucks	Diesel/CNG	Rigid 12 - 14 t	35	60	80
Trucks	Diesel/CNG	Rigid 14 - 20t	35	60	80
Trucks	Diesel/CNG	Rigid 20 - 26t	35	60	80
Trucks	Diesel/CNG	Rigid 26 - 28t	35	60	80
Trucks	Diesel/CNG	Rigid 28 - 32t	35	60	80
Trucks	Diesel/CNG	Rigid >32t	35	60	80
Trucks	Diesel/CNG	TT/AT 14 - 20t	35	60	80
Trucks	Diesel/CNG	TT/AT 20 - 28t	35	60	80
Trucks	Diesel/CNG	TT/AT 28 - 34t	35	60	80
Trucks	Diesel/CNG	TT/AT 34 - 40t	35	60	80
Trucks	Diesel/CNG	TT/AT 40 - 50t	35	60	80
Trucks	Diesel/CNG	TT/AT 50 - 60t	35	60	80
Trucks	Diesel/CNG	TT/AT >60t	35	60	80
Urban buses	Gasoline		30	50	70
Urban buses	Diesel/CNG	< 15 tonnes	30	50	70
Urban buses	Diesel/CNG	15-18 tonnes	30	50	70
Urban buses	Diesel/CNG	> 18 tonnes	30	50	70
Coaches	Gasoline		35	60	80
Coaches	Diesel/CNG	< 15 tonnes	35	60	80
Coaches	Diesel/CNG	15-18 tonnes	35	60	80
Coaches	Diesel/CNG	> 18 tonnes	35	60	80
Mopeds	Gasoline		30	30	-
Motorcycles	Gasoline	2 stroke	40	70	100
Motorcycles	Gasoline	< 250 cc.	40	70	100
Motorcycles	Gasoline	250 – 750 cc.	40	70	100
Motorcycles	Gasoline	> 750 cc.	40	70	100

Fleet and annual mileage data are provided by DTU Transport for the vehicle categories present in COPERT 5 (Jensen, 2022a). DTU Transport use data from the Danish vehicle register kept by Statistics Denmark. The vehicle register data consist of vehicle type (passenger cars, vans, trucks, buses, mopeds, motorcycles), fuel type, vehicle weight, gross vehicle weight, engine size (passenger cars registered from 2005+), Euro norm, NEDC type approval fuel efficiency value (passenger cars registered from 1997+) and vehicle first registration year. The Euro norm information is very complete in the Danish vehicle register for vehicle first registrations 2001 onwards for trucks and buses and 2011 onwards in the case of passenger cars and vans. For vehicles with no EU norm information, the EU norm is assigned, associated with the date for first registration (entry into service) listed in Table 3.3.6.

In order to establish engine size data for passenger cars registered before 2005, a weight class-engine size transformation key is used examined by Cowi (2008) for new Danish cars from 1998. For the years before 1998, data for 1998 is used, and for the years 1999-2004, a linear interpolation between 1998 and 2005 weight class-engine size relations is used. For trucks, truck driver registration notes gathered by Statistics Denmark are used to split the fleet figures of ordinary trucks into number of solo trucks and truck-trailer combinations. Further, the registration notes make it possible to assume the average total vehicle weight of the truck trailer combination. For articulated trucks also, the registration notes make it possible to assume the average total vehicle weight of the full articulated truck.

Danish mileage data comes from the Danish Road Directorate based on the Danish vehicle inspection program. Total mileage per year and vehicle category are derived for the years 1985-2021, together with a more detailed mileage matrix examined for the year 2008 (based on detailed vehicle inspection data analysis). The detailed mileage matrix contains annual mileage per vehicle subcategory for new vehicles and for every vintage back in time, which determines the yearly mileage reduction percentages as a function of vehicle age. In a first step, the detailed mileage matrix is combined with corresponding fleet numbers in order to estimate intermediate total mileages for each year on a detailed fleet level. Next, each year's detailed (intermediate) mileage figures are scaled according to the difference between true and intermediate total mileage per vehicle subcategory.

DTU Transport (Jensen, 2022a) also provides information of the mileage split between urban, rural and highway driving based on traffic monitoring data. The respective average speeds come from The Danish Road Directorate (e.g. Winther & Ekman, 1998). Additional data for the moped fleet and motorcycle fleet disaggregation is given by The National Motorcycle Association (Markamp, 2013) and supplementary moped stock information is obtained from The Danish Bicycle Traders Association (Johnsen, 2018) and Prince (2021).

In addition, data from a survey made by the Danish Road Directorate (Hansen, 2010) has given information of the total mileage driven by foreign cars, vans, coaches and trucks on Danish roads in 2009 and a follow-up survey in 2014 has given additional information. For trucks, the mileage contribution from foreign vehicles has been added to the total mileage on Danish roads for Danish truck-trailers and articulated trucks in two gross vehicle weight categories, < 40 tonnes and > 40 tonnes. The data has been further processed by DTU Transport; by using appropriate assumptions, the mileage have been backcasted to 1985 and forecasted to 2021.

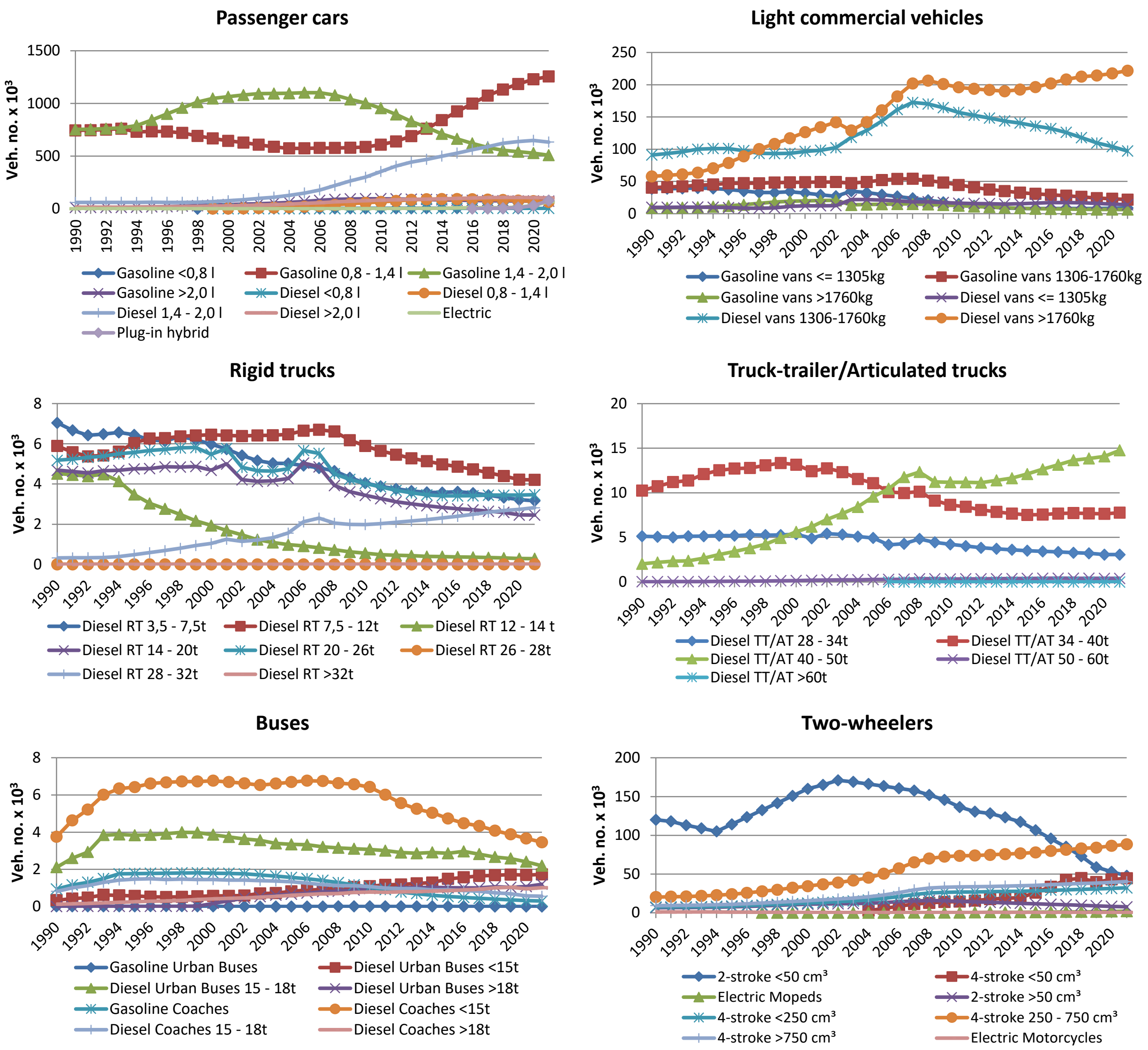


Figure 3.3.23 Number of vehicles in sub-classes in 1990-2021.

For passenger cars, the engine size differentiation is less certain for the years before 2005. The increase in the total number of passenger cars is mostly due to a growth in the number of diesel cars between 1.4 and 2 litres (from the 2000's up to now). Until 2005, there has been a decrease in the number of gasoline cars with an engine size between 0.8 and 1.4 litres. These cars, however, have also increased in numbers during the later years, while the number of 1.4-2 litres gasoline cars has decreased. Since the late 1990's small cars (< 0.8 l gasoline and <1.4 l. diesel) has slowly begun to penetrate the fleet.

There has been a considerable growth in the number of diesel light-duty vehicles from 1985 to 2006; the number of vehicles has however decreased somewhat after 2006 due to the restructuring of car taxes that made it less advantageous buying vans for private use.

For the truck-trailer and articulated truck combinations, there is a tendency towards the use of increasingly fewer but larger trucks throughout the time period. The decline in fleet numbers for many of the truck categories is due to the combined effects of the global financial crisis, the fleet shift towards fewer and larger trucks, international market competition (foreign transport companies are effectively gaining Danish market shares), and the reflagging of Danish commercial trucks to companies based in the neighbouring countries.

The sudden change in the level of urban bus and coach numbers from 1991 to 1995 is due to uncertain fleet data from Statistics Denmark.

The reason for the significant growth in the number of mopeds from 1994 to 2002 is the introduction of the so-called Moped 45 vehicle type. From 2004 onwards there is a gradual switch from 2-stroke to 4-stroke in new sales for this vehicle category. For motorcycles, the number of vehicles has grown throughout the 1990-2010 period, and from 2012-2021.

The vehicle numbers are summed up in EU emission layers for each year (Figure 3.3.24):

$$N_{j,y} = \sum_{i=FYear(j)}^{LYear(j)} N_{i,y} \qquad (1)$$

Where N = number of vehicles, j = layer, y = year, i = first year of registration.

Weighted annual mileages per layer are calculated as the sum of all mileage driven per first registration year divided by the total number of vehicles in the specific layer.

$$M_{j,y} = \frac{\sum_{i=FYear(j)}^{LYear(j)} N_{i,y} \cdot M_{i,y}}{\sum_{i=FYear(j)}^{LYear(j)} N_{i,y}} \qquad (2)$$

Since 2006, economical incitements have been given to private vehicle owners to buy Euro 5 diesel passenger cars and vans in order to bring down the particulate emissions from diesel vehicles. The estimated sales between 2006 and 2010 have been examined by the Danish EPA and are included in the fleet data behind the Danish inventory (Winther, 2011).

Vehicle numbers and weighted annual mileages per layer are shown in Annex 3.B.1 and 3.B.2 for 1990-2021. The trends in vehicle numbers per layer are also shown in Figure 3.3.24. The latter figure shows how vehicles complying with the gradually stricter EU emission levels (EURO 1-6, Euro I-VI etc.) have been introduced into the Danish motor fleet.

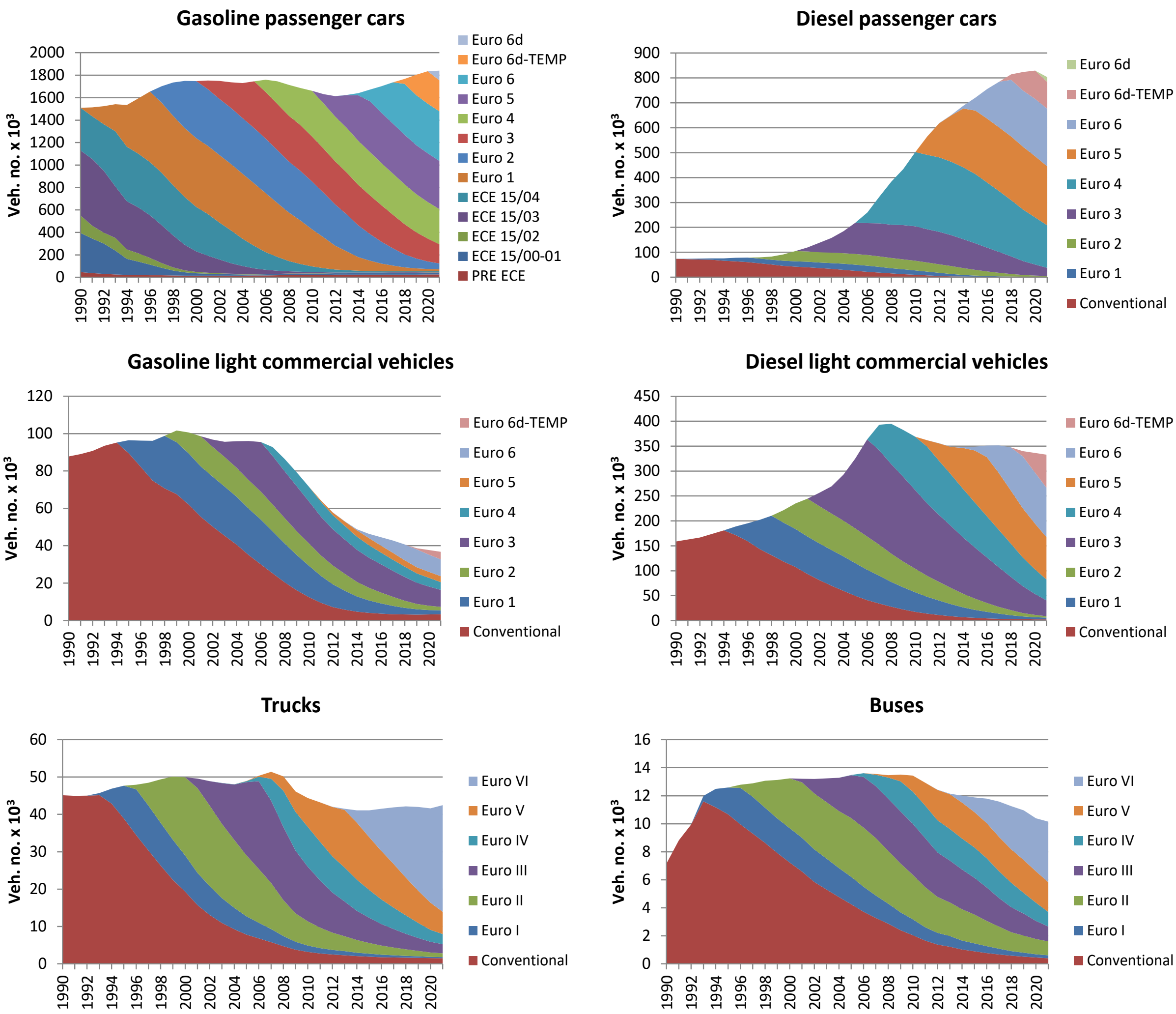


Figure 3.3.24 Layer distribution of vehicle numbers per vehicle type in 1990-2021.

Emission legislation

The EU 443/2009 regulation established new emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles. Some key elements of the adopted text are as follows:

- **Limit value curve:** the fleet average to be achieved by all cars registered in the EU is 130 gram CO_2 per kilometre (g per km). A so-called limit value curve implies that heavier cars are allowed higher emissions than lighter cars while preserving the overall fleet average.
- **Further reduction:** a further reduction of 10 g CO_2 per km, or equivalent if technically necessary, will be delivered by other technological improvements and by an increased use of sustainable biofuels.
- **Phasing-in of requirements:** in 2012, 65 % of each manufacturer's newly registered cars must comply on average with the limit value curve set by the legislation. This will rise to 75 % in 2013, 80 % in 2014, and 100 % from 2015 onwards.
- **Lower penalty payments for small excess emissions until 2018:** if the average CO_2 emissions of a manufacturer's fleet exceed its limit value in any year from 2012, the manufacturer has to pay an excess emissions premium for each car registered. This premium amounts to €5 for the first g per km of exceedance, €15 for the second g per km, €25 for the third g per km, and

€95 for each subsequent g per km. From 2019, already the first g per km of exceedance will cost €95.
- **Long-term target:** a target of 95g CO_2 per km is specified for the year 2021.
- **Eco-innovations:** Manufacturers can be granted a maximum of 7g per km of emission credits on average for their fleet if they equip vehicles with innovative technologies, based on independently verified data.

The EU 510/2011 regulation established new emission performance standards for new light commercial vehicles (vans). Some key elements of the regulation are as follows:

- **Target dates:** the EU fleet average of 175 g CO_2 per km will be phased in between 2014 and 2017. In 2014, an average of 70 %of each manufacturer's newly registered vans must comply with the limit value curve set by the legislation. This proportion will rise to 75 % in 2015, 80 % in 2016, and 100 % from 2017 onwards.
- **Limit value curve:** emissions limits are set according to the mass of vehicle, using a limit value curve. The curve is set in such a way that a fleet average of 175 grams of CO_2 per kilometre is achieved. A so-called limit value curve of 100 % implies that heavier vans are allowed higher emissions than lighter vans while preserving the overall fleet average. Only the fleet average is regulated, so manufacturers will still be able to make vehicles with emissions above the limit value curve provided these are balanced by other vehicles, which are below the curve.
- **Vehicles affected:** the vehicles affected by the legislation are vans, which account for around 12 % of the market for light-duty vehicles. This includes vehicles used to carry goods weighing up to 3.5t (vans and car-derived vans, known as N1) and which weigh less than 2610 kg when empty.
- **Long-term target:** a target of 147g CO_2 per km is specified for the year 2020.
- **Excess emissions premium for small excess emissions until 2018:** if the average CO_2 emissions of a manufacturer's fleet exceed its limit value in any year from 2014, the manufacturer has to pay an excess emissions premium for each van registered. This premium amounts to €5 for the first g per km of exceedance, €15 for the second g per km, €25 for the third g per km, and €95 for each subsequent g per km. From 2019, the first g per km of exceedance will cost €95. This value is equivalent to the premium for passenger cars.
- **Super-credits:** vehicles with extremely low emissions (below 50g per km) will be given additional incentives whereby each low-emitting van will be counted as 3.5 vehicles in 2014 and 2015, 2.5 in 2016 and 1.5 vehicles in 2017.
- **Eco-innovations:** Manufacturers can be granted a maximum of 7g per km of emission credits on average for their fleet if they equip vehicles with innovative technologies, based on independently verified data.
- **Other flexibilities:** manufacturers may group together to form a pool and act jointly in meeting the specific emissions targets. Independent manufacturers who sell fewer than 22,000 vehicles per year can also apply to the Commission for an individual target instead.

On 17 April 2019, the European Parliament and the Council adopted Regulation (EU) 2019/631 setting CO_2 emission performance standards for new passenger cars and for new light commercial vehicles (vans) in the EU.

This Regulation started applying on 1 January 2020, replacing and repealing the former Regulations setting CO_2 emission standards for cars ((EC) 443/2009) and vans ((EU) 510/2011).

The following description of the regulation (EU) 2019/631 is given on the EU Commission Climate Action web page (https://ec.europa.eu/clima/policies/transport/vehicles/regulation_en). The main elements of the regulation are:

Target levels

New EU fleet-wide CO_2 emission targets are set for the years 2025 and 2030, both for newly registered passenger cars and newly registered vans.

These targets are defined as a percentage reduction from the 2021 starting points:

- Cars: 15% reduction from 2025 on and 37.5% reduction from 2030 on
- Vans: 15% reduction from 2025 on and 31% reduction from 2030 on

The specific emission targets for manufacturers to comply with, are based on the EU fleet-wide targets, taking into account the average test mass of a manufacturer's newly registered vehicles.

Incentive mechanism for zero- and low-emission vehicles (ZLEV)

A ZLEV is defined in the regulation as a passenger car or a van with CO_2 emissions between 0 and 50 g/km.

To incentivise the uptake of ZLEV, a crediting system is introduced from 2025 on.

The specific CO_2 emission target of a manufacturer will be relaxed if its share of ZLEV registered in a given year exceeds the following benchmarks:

- Cars: 15 % ZLEV from 2025 on and 35 % ZLEV from 2030 on
- Vans: 15 % ZLEV from 2025 on and 30 % ZLEV from 2030 on

A one percentage point exceedance of the ZLEV benchmark will increase the manufacturer’s CO_2 target (in g CO_2 per km) by one percent. The target relaxation is capped at maximum 5 % to safeguard the environmental integrity of the regulation.

For calculating the ZLEV share in a manufacturer’s fleet, an accounting rule applies. This gives a greater weight to ZLEV with lower CO_2 emissions.

In addition, for cars only, during the period 2025 to 2030, a greater weight is given to ZLEV registered in Member States with a low ZLEV uptake in 2017, and this as long as the ZLEV share in the Member State’s fleet of newly registered cars does not exceed 5 %.

Pooling, exemptions and derogations

The provisions on pooling between manufacturers are the same as under the previous regulations. Pooling between car and van manufacturers is not possible.

The exemption of manufacturers registering less than 1,000 cars or vans per year, as well as the derogation possibility for "small volume" car and van manufacturers, have also been maintained.

The derogation possibility for "niche" car manufacturers, i.e. those registering between 10,000 and 300,000 cars per year, will end after the year 2028. In the years 2025 to 2028, the derogation target for those manufacturers will be 15 % below the 2021 derogation target.

Eco-innovations

The provisions regarding the "eco-innovation" credits for emission savings due to the application of innovative emission reduction technologies not covered by the standard test cycle CO_2 measurement are largely unchanged compared to the previous regulations.

New is that the efficiency improvements for air conditioning systems will become eligible as eco-innovation technologies as of 2025 and that the cap of 7 g per km may be adjusted by the Commission through a delegated act.

Governance

Two new elements have been introduced to reinforce the effectiveness of the regulation.

These concern

- the verification of CO_2 emissions of vehicles in-service and
- measures to ensure that the emission test procedure yields results which are representative of real-world emissions.

In-service verification

Manufacturers are required to ensure correspondence between the CO_2 emissions recorded in the certificates of conformity of their vehicles and the CO_2 emissions of vehicles in-service measured according to "World-Harmonized Light-Duty Vehicles Test Procedure" (WLTP).

This correspondence shall be verified by type-approval authorities in selected vehicles. The authorities shall also verify the presence of any strategies artificially improving the vehicle's performance in the type-approval tests.

On the basis of their findings, type-approval authorities shall, where needed, ensure the correction of the certificates of conformity and may take other necessary measures set out in the Type Approval Framework Regulation.

Deviations found in the CO_2 emissions of vehicles in service shall be reported to the Commission, who shall take them into account for the purpose of calculating the average specific emissions of a manufacturer.

Real-world emissions

To prevent the gap between emissions tested in the laboratory and real-world emissions from increasing, the Commission shall, from 2021 on, regularly collect data on the real-world CO_2 emissions and energy consumption of cars and vans using the on-board fuel consumption monitoring devices (OBFCM).

The Commission shall monitor how that gap evolves between 2021 and 2026 and, on that basis, assess the feasibility of a mechanism to adjust the manufacturer's average specific CO_2 emissions as of 2030.

The detailed procedures for collecting and processing the data shall be adopted by means of implementing acts.

Life-cycle emissions
By 2023, the Commission shall evaluate the possibility of developing a common methodology for the assessment and reporting of the full life-cycle CO_2 emissions of cars and vans.

Review
The Commission shall review the effectiveness of the regulation and report on this to the European Parliament and the Council.

This review shall cover i.a. the following:

- real world representativeness of the CO_2 emission and energy consumption values,
- deployment of ZLEV,
- roll-out of recharging and refuelling infrastructure,
- role of synthetic and advanced alternative fuels produced with renewable energy,
- emission reductions observed for the existing fleet,
- ZLEV incentive mechanism,
- impacts for consumers,
- aspects related to the just transition,
- impacts for consumers, aspects related to the just transition,
- 2030 targets and identification of a pathway for emission reductions beyond 2030.

As part of the review, the Commission shall assess the feasibility of developing real-world emission test procedures, as well as the possibility to assign revenues from the fines to a specific fund or relevant programme with the objective to ensure a just transition towards a climate neutral economy.

Finally, the Commission shall review the Car Labelling Directive by end 2020, covering both CO_2 and air pollutant emissions of cars and evaluating the options for introducing a fuel economy and CO_2 emissions label for vans.

The Regulation (EU) 2019/1242 setting CO_2 emission standards for heavy-duty vehicles entered into force on 14 August 2019.

The following description of the EU regulation 2019/1242 is taken from the EU Commission Climate Action web page (https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en). The main elements of the regulation are:

Target levels
From 2025 on, manufacturers will have to meet the targets set for the fleet-wide average CO_2 emissions of their new lorries registered in a given calendar year. Stricter targets will start applying from 2030 on.

The targets are expressed as a percentage reduction of emissions compared to EU average in the reference period (1 July 2019–30 June 2020):

- from 2025 onwards: 15% reduction
- from 2030 onwards: 30% reduction

The 2025 target can be achieved using technologies that are already available on the market. The 2030 target will be assessed in 2022 as part of the review of the regulation.

As a first step, the CO_2 emission standards will cover large lorries, which account for 65% to 70% of all CO_2 emissions from heavy-duty vehicles.

As part of the 2022 review, the Commission should assess the extension of the scope to other vehicle types such as smaller lorries, buses, coaches and trailers.

Incentive mechanism for zero- and low-emission vehicles (ZLEV)

The regulation includes an incentive mechanism for

- zero-emission vehicles (ZEV), lorries with no tailpipe CO_2 emissions
- low-emission vehicles (LEV), lorries with a technically permissible maximum laden mass of more than 16 t, with CO_2 emissions of less than half of the average CO_2 emissions of all vehicles in its group registered in the 2019 reporting period.

To incentivise the uptake of ZLEV and reward early action, a super-credits system applies from 2019 until 2024, and can be used to comply with the target in 2025. A multiplier of 2 applies for ZEV, and a multiplier between 1 and 2 applies for LEV, depending on their CO_2 emissions. An overall cap of 3 % is set to preserve the environmental integrity of the system.

From 2025 onwards, the super-credits system is replaced by a benchmark-based crediting system, with a benchmark set at 2 %. The 2030 benchmark level will have to be set in the context of the 2022 review.

As a result, the average specific CO_2 emissions of a manufacturer are adjusted downwards if the share of ZLEV in its entire new heavy-duty vehicles fleet exceeds the 2 % benchmark, out of which at least 0.75 percentage points have to be vehicles subject to the CO_2 targets, i.e. the largest vehicles. Each percentage point of exceedance of the benchmark will decrease the manufacturer's average specific CO_2 emissions by one percent.

In both systems, ZEV not subject to the CO_2 targets are accounted in the incentive mechanism. Buses and coaches are excluded from the scheme. The ZEV not subject to the CO_2 targets can contribute to a maximum of 1.5 % CO_2 emissions reduction.

Cost-effective achievement of targets

The regulation includes several elements to support cost-effective implementation:

- Banking and borrowing to take account of long production cycles, including a reward for early action, while maintaining the environmental integrity of the targets
- Full flexibility for manufacturers to balance emissions between the different groups of vehicles within their portfolio
- Vocational vehicles, such as garbage trucks and construction vehicles, are exempted due to their limited potential for cost-efficient CO_2 reduction.

Governance

The following measures will ensure the effectiveness and enforcement of the targets. They are based on the experience from cars and vans:

- Assess the robustness and representativeness of the reference CO_2 emissions as a basis for calculating the EU fleet-wide emissions targets
- Collect, publish and monitor real-world fuel consumption data reported by manufacturers, based on mandatory standardised fuel consumption meters
- Introduce in-service conformity tests and mandate the reporting of deviations and the introduction of a correction mechanism
  Apply financial penalties in case of non-compliance with the CO_2 targets. The level of the penalties is set to 4,250 euro per gCO_2 per tkm in 2025 and 6,800 euro per gCO_2 per tkm in 2030.

Review

The Commission shall review the effectiveness of the regulation and report on this to the European Parliament and the Council by 2022.

This review shall cover i.a.

- 2030 target and possible targets for 2035 and 2040
- Inclusion of other types of heavy-duty vehicles, including buses, coaches, trailers, vocational vehicles and considerations of EMS (European modular system)
- ZLEV incentive mechanism
- Real world representativeness of the CO_2 emission and energy consumption values
- Role of synthetic and advanced alternative fuels produced with renewable energy
- Possible introduction of a form of pooling
- Level of the excess emission premium.

By 2023, the Commission shall evaluate the possibility of developing a common methodology for the assessment and reporting of the full life-cycle CO_2 emissions of heavy-duty vehicles.

Monitoring and reporting of CO_2 emissions from heavy-duty vehicles

The following measures enable the implementation of the emission standards:

- Certification Regulation on the determination of the CO_2 emissions and fuel consumption of new lorries
- Regulation (EU) 2018/956 on monitoring and reporting

The monitoring and reporting regulation requires that, as of 1 January 2019:

- Member States monitor and report to the Commission information on the heavy-duty vehicles registered for the first time in the Union; and lorry manufacturers monitor and report to the Commission CO_2 emission and fuel consumption data as determined pursuant to the certification Regulation for each new vehicle produced for the EU market. This information will be calculated using the Vehicle Energy Consumption Calculation Tool (VECTO)

- The collected data on CO_2 emissions and fuel consumption together with other relevant technical information on the vehicles, including the aerodynamic drag, will be made publicly available by the European Environment Agency on behalf of the Commission, starting in 2021 to cover data monitored between 1 January 2019 and 30 June 2020.

The new system will complement the existing EU reporting system for cars and vans.

Vehicle Energy Consumption Calculation Tool (VECTO)

VECTO is a simulation software that can be used cost-efficiently and reliably to measure the CO_2 emissions and fuel consumption of heavy-duty vehicles for specific loads, fuels and mission profiles (e.g. long haul, regional delivery, urban delivery, etc.), based on input data from relevant vehicle components.

The tool has been developed by the Commission in close cooperation with stakeholders.

Related policy measures

This legislation complements other policy measures such as the Certification Regulation, Monitoring and Reporting Regulation, EU type-approval system, Eurovignette Directive, Fuel Quality Directive, Clean Vehicles Directive, Directive on maximum authorised weights and dimensions and Directive on the deployment of alternative fuels infrastructure.

For Euro 1-6 passenger cars and vans, the chassis dynamometer test cycle used in the EU for emission approval is the NEDC (New European Driving Cycle), see e.g. www.dieselnet.com. The test cycle is also used for fuel consumption measurements. The NEDC cycle consists of two parts, the first part being a 4-time repetition (driving length: 4 km) of the ECE test cycle. The latter test cycle is the so-called urban driving cycle[5] (average speed: 19 km per h). The second part of the test is the run-through of the EUDC (Extra Urban Driving Cycle) test driving segment, simulating the fuel consumption under rural and highway driving conditions. The driving length of EUDC is 7 km at an average speed of 63 km per h. More information regarding the fuel measurement procedure can be found in the EU-directive 80/1268/EØF.

The NEDC test cycle is not adequately describing real world driving behaviour, and consequently, for diesel cars and vans, there is an increasing mismatch between the step wise lowered EU emission limits the vehicles comply with during the NEDC test cycle, and the more or less constant emissions from the same vehicles experienced during real world driving. In order to bridge this emission inconsistency gap a new test procedure, the "World-Harmonized Light-Duty Vehicles Test Procedure" (WLTP), has been developed which simulates much more closely real world driving behaviour. The WLTP test procedure gradually take effect from 2017.

For the new Euro 6 vehicles it has been decided that emission measurements must also be made with portable emission measurement systems (PEMS) during real traffic driving conditions with random acceleration and deceleration patterns. During the new Real Driving Emission (RDE) test procedure in a temporary phase, the emissions of NO_x are not allowed to exceed the NEDC

[5] For Euro 3 and on, the emission approval test procedure was slightly changed. The 40 s engine warm up phase before start of the urban driving cycle was removed.

based Euro 6 emission limits by more than 110 % by 1 September 2017 for all new car models and by 1 September 2019 for all new cars (Euro 6d-TEMP). From 1 January 2020 in the final phase, the NO_x emission not-to-exceed levels are adjusted downwards to 50 % for all new car models and by 1 January 2021 for all new cars (Euro 6d). Implementation dates for vans are one year later.

In the road transport emission model, compromise dates for enter into service of the Euro 6d-TEMP technology are set to 1 September 2018 and 1 September 2019, for diesel cars and vans, respectively. For Euro 6d, the enter into service dates are set to 1 January 2021 and 1 January 2022 for cars and vans, respectively. (pers. comm. Katja Asmussen, Danish EPA, 2018).

For NOx, VOC (NMVOC + CH_4), CO and PM, the emissions from road transport vehicles have to comply with the emission limit values agreed by the EU. An overview of the different emission layers in the road transport emission model and the corresponding EU emission directive numbers are given in Table 3.3.6. The specific emission limits are shown in Annex 2.B.3.

Table 3.3.6 shows the EU directive dates for new type approvals and the date for first registration (entry into service) of existing, previously type approved vehicle models. The latter date is used in the model for vehicles with no EU norm information given in the car register. In most cases the entry into service date used in the model is the same as the entry into service date specified by the EU directive.

For passenger cars and light commercial vehicles, the emission directives distinguish between three vehicle classes according to vehicle reference mass[6]: Passenger cars and light duty trucks (<1305 kg) have the same emission limits but different legislation dates. Light duty trucks (1305-1760 kg) and light duty trucks (>1760 kg) have the same legislation dates but different emission limits.

For heavy-duty vehicles (trucks and buses), the emission limits are given in g pr kWh and the measurements are carried out for engines in a test bench, using the ECE R-49, EU ESC (European Stationary Cycle) and ETC (European Transient Cycle) test cycles, depending on the Euro norm and exhaust gas after-treatment system installed. For Euro VI engines the WHSC (World Harmonized Stationary Cycle) and WHTC (World Harmonized Transient Cycle) test cycles are used. For a description of the test cycles, see e.g. www.dieselnet.com.

In terms of the sulphur content in the fuels used by road transportation vehicles, the EU directive 2003/17/EF describes the fuel quality standards agreed by the EU. In Denmark, the sulphur content in gasoline and diesel was reduced to 10 ppm in 2005, by means of a fuel tax reduction for fuels with 10 ppm sulphur contents.

[6] Reference mass: net vehicle weight + mass of fuel and other liquids + 100 kg.

Table 3.3.6 Overview of emission layers in the road transport emission model and the related EU emission directives.

Vehicle category	Emission layer	EU directive	Type approval	First registration date
Passenger cars (gasoline)	PRE ECE	-	-	<1970-
	ECE 15/00-01	70/220 - 74/290	1972[a]	1970[a]
	ECE 15/02	77/102	1981[b]	1979[b]
	ECE 15/03	78/665	1982[c]	1981[c]
	ECE 15/04	83/351	1987[d]	1986[d]
Passenger cars (diesel)	Conventional	-	-	<1991-
Passenger cars	Euro 1	91/441	1.7.1992[e]	1.1.1991[e]
	Euro 2	94/12	1.1.1996	1.1.1997
	Euro 3	98/69	1.1.2000	1.1.2001
	Euro 4	98/69	1.1.2005	1.1.2006
	Euro 5	715/2007(692/2008)	1.9.2009	1.1.2011
	Euro 6	715/2007(692/2008)	1.9.2014	1.9.2015
	Euro 6d-TEMP	2016/646	1.9.2017	1.9.2018
	Euro 6d	2016/646	1.1.2020	1.1.2021
LCV < 1305 kg	Conventional	-	-	<1995
	Euro 1	91/441	1.10.1994	1.1.1995
	Euro 2	94/12	1.1.1998	1.1.1999
	Euro 3	98/69	1.1.2001	1.1.2002
	Euro 4	98/69	1.1.2006	1.1.2007
	Euro 5	715/2007(692/2008)	1.9.2010	1.1.2012
	Euro 6	715/2007(692/2008)	1.9.2015	1.9.2016
	Euro 6d-TEMP	2016/646	1.9.2018	1.9.2019
	Euro 6d	2016/646	1.1.2021	1.1.2022
LCV 1305-1760 kg & > 1760 kg	Conventional	-	-	<1995
	Euro 1	93/59	1.10.1994	1.1.1995
	Euro 2	96/69	1.1.1998	1.1.1999
	Euro 3	98/69	1.1.2001	1.1.2002
	Euro 4	98/69	1.1.2006	1.1.2007
	Euro 5	715/2007	1.9.2010	1.1.2012
	Euro 6	715/2007	1.9.2015	1.9.2016
	Euro 6d-TEMP	2016/646	1.9.2018	1.9.2019
	Euro 6d	2016/646	1.1.2021	1.1.2022
Heavy duty vehicles	Euro 0	88/77	1.10.1990	1.10.1990
	Euro I	91/542	1.10.1993	1.10.1993
	Euro II	91/542	1.10.1996	1.10.1996
	Euro III	1999/96	1.10.2000	1.10.2001
	Euro IV	1999/96	1.10.2005	1.10.2006
	Euro V	1999/96	1.10.2008	1.10.2009
	Euro VI	595/2009	1.1.2013	1.1.2014
Mopeds	Conventional	-	-	-
	Euro I	97/24	2000	2000
	Euro II	2002/51	2004	2004
	Euro III	2002/51	2014[f]	2014[f]
	Euro IV	168/2013	2017	2017
	Euro V	168/2013	2021	2021
Motor cycles	Conventional		0	0
	Euro I	97/24	2000	2000
	Euro II	2002/51	2004	2004
	Euro III	2002/51	2007	2007
	Euro IV	168/2013	2017	2017
	Euro V	168/2013	2021	2021

a,b,c,d: Expert judgement suggests that Danish vehicles enter into the traffic before EU directive first registration dates. The effective inventory starting years are a: 1970; b: 1979; c: 1981; d: 1986; e: The directive came into force in Denmark 1.10.1990.

Fuel consumption and emission factors

In practice, the emissions from vehicles in traffic are different from the legislation limit values and, therefore, the latter figures are not suited for total emission calculations. Besides difference in test versus real world driving behaviour, as discussed in the previous section, the emission limit values do not reflect the emission impact of cumulated mileage driven, and engine and exhaust after treatment maintenance levels for the vehicle fleet as a whole.

Therefore, in order to represent the Danish fleet and to support average national emission estimates, the selected emission factors must be derived from numerous emission measurements, using a broad range of real world driving patterns and a sufficient number of test vehicles. It is similarly important to have separate fuel consumption and emission data for cold-start emission calculations and gasoline evaporation (hydrocarbons).

The fuel consumption and emission factors used in DEMOS-Road come from the COPERT 5 model[7]. The source for these data is various European measurement programmes. In general, the COPERT data are transformed into trip-speed dependent fuel consumption and emission factors for all vehicle categories and layers by using trip speeds as shown in Table 3.3.5. The factors are listed in Annex 2.B.4.

It should be noted that for PHEV (plug-in hybrid electric vehicles) cars and vans, the utility factor is set to 0.5, i.e. 50 % of total mileage is assumed to be battery driven, according to assumptions made by DEA (2021)[8]. The fuel consumption and emission factors for plug-in vehicles used in the Danish national emission inventories for road transport, and shown in the present NIR, only contain the part of fuel consumption and emissions related to the combustion of fossil fuel (gasoline) in the vehicles. The emissions related to the generation of the electricity used by battery electric vehicles and plug-in vehicles are included under stationary sources in the Danish emission inventories as prescribed by the UNFCCC reporting guidelines.

Adjustment for vehicle fuel efficiency

For passenger cars, COPERT 5 include measurement based fuel consumption factors until Euro 4. A calculation function is provided for newer cars that one hand compensate for the trend towards more fuel efficient vehicles being sold during the later years and on the other hand compensate for the increasing fuel gap between fuel consumption measured during vehicle type approval and real world fuel consumption.

The COPERT calculation function and supporting data material basis is, however, not able to account for the fuel gaps between fuel consumption measured during vehicle type approval and real world fuel consumption for vehicles after 2014, as monitored by e.g. the International Council on Clean Transportation (ICCT), Tietge et al. (2019).

[7] For vans, fuel consumption factors are not stratified according to vehicle weight classes in the COPERT model. For this vehicle category fuel consumption factor data are obtained from the HBEFA (Handbook of Emission Factors) model version 4.1 (e.g. Matzer et al., 2019).
[8] The electric driven mileage shares for Danish urban, rural and highway driving conditions are derived by weighing in electric driven mileage shares for urban, rural and highway driving conditions obtained from HBEFA.

The baseline COPERT 5 fuel consumption factors for Euro 4, Euro 5 and Euro 6 passenger cars are adjusted in the following way.

In the Danish fleet and mileage database kept by DTU Transport, the type approval fuel efficiency value based on the NEDC driving cycle (TA_{NEDC}) is registered for each single car. Further, DTU Transport calculates a modified fuel efficiency value (FC_{inuse}) with the calculation function provided by COPERT 5 that better reflects the fuel consumption in real ("inuse") traffic conditions.

The latter function uses TA_{NEDC}, vehicle weight, engine size and regression coefficients by first registration year, as input parameters (EMEP/EEA, 2019). For each new registration year, i, fuel type, f, and engine size, k, number based average values of TA_{NEDC} and FC_{inuse} are summed up and referred to as $\overline{TA_{NEDC}}(i,f,k)$ and $\overline{TA_{inuse}}(i,f,k)$. For vehicle new registrations after 2014, regression coefficients are used for 2014.

The FC_{inuse} function has been developed from a vehicle database consisting of new registered cars from 2006-2014 (Tietge et al. 2017). Hence, as previously mentioned, The FC_{inuse} function is not able to account for the fuel gaps after 2014, between type approval and real world fuel consumption as monitored by ICCT (Tietge et al., 2019).

To obtain $\overline{FC_{inuse}}(i,f,k)$ values for vehicle new registrations 2015-2020, the $\overline{FC_{inuse}}(i,f,k)$ values for 2014 are adjusted for the years 2015-2020[9] with an index function (indexed from 2014), C_{ICCT} (i, f), based on the reported ICCT fuel gap figures by fuel type for the new registration years 2014-2020.

For new cars registered in 2021, no valid type approval fuel efficiency values can be obtained from the Danish fleet and mileage database kept by DTU Transport. Instead the type approval fuel efficiency values for new cars in 2020 is used for 2021 also. For 2021 the aggregated value of 104.1 g CO_2/km is used. This value is well above the EU 95 g CO_2/km target, but this exceedance can very well be justified due to increases in new sales of electric cars and plug-in hybrids in Denmark in 2021.

For years beyond 2021 annual fuel efficiency, improvement rates are used for new cars depending on fuel type as suggested by DEA (2022b).

For vans, trucks, urban buses and coaches, annual fuel efficiency improvement rates are used for future new vehicles depending on fuel type as suggested by DEA (2022b).

Adjustment for EGR, SCR and filter retrofits

In COPERT 5, emission factors are available for Euro V heavy duty vehicles using exhaust gas recirculation (EGR) and selective catalyst reduction (SCR) exhaust emission aftertreatment systems, respectively. The estimated new sales of Euro V diesel trucks equipped with EGR and SCR during the 2006-2010 time periods has been examined by Hjelgaard and Winther (2011). These inventory fleet data are used in the Danish inventory to calculate weighted emission factors for Euro V trucks in different size categories.

[9] The ICCT monitoring report include new cars up to 2017. For new cars from 2018-2020, fuel gap figures are used for cars from 2017.

During the 2000's urban environmental zones have been established in Danish cities in order to bring down the particulate emissions from diesel fuelled heavy duty vehicles. Driving in these environmental zones prescribe the use of diesel particulate filters. The Danish EPA has provided the estimated number of Euro I-III urban buses and Euro II-III trucks and tourist buses, which have been retrofitted with filters during the 2000's (Winther, 2011). It is assumed that the particulate emissions from these retrofitted vehicles are the same as the particulate emissions from Euro V.

From the Danish vehicle register, information exist of the number of pre-Euro 5 diesel passenger cars and vans which have been retrofitted with open particle filters from 2006 onwards. These retrofit data are included in the Danish inventory by assuming that particulate emissions are lowered by 30 % compared with the emissions from the same Euro technology with no filter installed.

For all vehicle categories/technology levels not represented by measurements, the emission factors are produced by using reduction factors. The latter factors are determined by assessing the EU emission limits and the relevant emission approval test conditions, for each vehicle type and Euro class.

Adjustment for Euro 5 diesel passenger cars

In COPERT 5 new emission factors are available for those Euro 5 diesel passenger cars for which engine control software has been installed in order to reduce the emissions, as a result of the diesel scandal.

The Euro 5 vehicles in question were brought to vehicle workshops during the vehicle recall program from 2016-2018. A short description of the recall program and the cars included is given below:

- Engine software was updated in 70,946 cars, evenly shared by 1/3 in each of the years 2016-2018
- Vehicle first registration years of the updated cars were between 2009-2016
- Engine sizes of the updated cars were < 1.4 l (9 %) and 1.4-2 l (91 %).

In DEMOS-Road, each year's updates were distributed into first registration year-engine size categories, according to their fleet shares in the respective first registration year-engine size categories.

The number of included cars in the software update program was provided by the Danish Safety Technology Authority (Bonde, 2021) and engine size and model year information was provided by Volkswagen (Hjortshøj, 2021).

Adjustment for deterioration

For three-way catalyst cars, the emissions of NO_X, NMVOC and CO gradually increase due to catalyst wear and are, therefore, modified as a function of total mileage by the so-called deterioration factors. Even though the emission curves may be serrated for the individual vehicles, on average, the emissions from catalyst cars stabilize after a given cut-off mileage is reached due to OBD (On Board Diagnostics) and the Danish inspection and maintenance programme.

For each year, the deterioration factors are calculated per first registration year by using deterioration coefficients and cut-off mileages, as given in EMEP/EEA (2019), for the corresponding layer. The deterioration coefficients are given for the two driving cycles ″Urban Driving Cycle″ (UDF) and ″Extra Urban Driving Cycle″ (EUDF: urban and rural), with trip speeds of 19 and 63 km per hour, respectively.

Firstly, the deterioration factors are calculated for the corresponding trip speeds of 19 and 63 km per hour in each case determined by the total cumulated mileage less than or exceeding the cut-off mileage. The Formulas 3 and 4 show the calculations for the ″Urban Driving Cycle″:

$$UDF = U_A \cdot MTC + U_B \text{, MTC < } U_{MAX} \quad (3)$$

$$UDF = U_A \cdot U_{MAX} + U_B \text{, MTC >= } U_{MAX} \quad (4)$$

where UDF is the urban deterioration factor, U_A and U_B the urban deterioration coefficients, MTC = total cumulated mileage and U_{MAX} urban cut-off mileage.

In the case of trip speeds below 19 km per hour the deterioration factor, DF, equals UDF, whereas for trip speeds exceeding 63 km per hour, DF=EUDF (Danish rural and highway trip speed; c.f. Table 3.3.5). For trip speeds between 19 and 63 km per hour (Danish urban trip speed; c.f. Table 3.3.5) the deterioration factor, DF, is found as an interpolation between UDF and EUDF. Secondly, the deterioration factors, one for each of the three road types, are aggregated into layers by taking into account vehicle numbers and annual mileage levels per first registration year:

$$DF_{j,y} = \frac{\sum_{i=FYear(j)}^{LYear(j)} DF_{i,y} \cdot N_{i,y} \cdot M_{i,y}}{\sum_{i=FYear(j)}^{LYear(j)} DF_{i,y} \cdot N_{i,y}} \quad (5)$$

where DF is the deterioration factor.

For N_2O and NH_3, COPERT 5 takes into account deterioration as a linear function of mileage for gasoline fuelled EURO 1-6 passenger cars and light duty vehicles. The level of emission deterioration also relies on the content of sulphur in the fuel. The deterioration coefficients are given in EMEP/EEA (2019), for the corresponding layer. A cut-off mileage of 250 000 km is behind the calculation of the modified emission factors, and for the Danish situation the low sulphur level interval is assumed to be most representative. The deterioration factors are shown in Annex 3.B.6 for 2021.

Calculation of emissions and fuel consumption for hot engines

Emissions and fuel consumption results for operationally hot engines are calculated in DEMOS-Road for each year, layer and road type. DEMOS-Road use the COPERT V detailed calculation methodology. The calculation procedure is to combine fuel consumption and emission factors (and deterioration factors for catalyst vehicles), number of vehicles, annual mileage levels and the relevant road-type shares given in Table 3.3.5. For non-catalyst vehicles, this yields:

$$E_{j,k,y} = EF_{j,k,y} \cdot S_k \cdot N_{j,y} \cdot M_{j,y} \quad (6)$$

Here E = fuel consumption/emission, EF = fuel consumption/emission factor, S = road type share and k = road type.

For catalyst vehicles the calculation becomes:

$$E_{j,k,y} = DF_{j,k,y} \cdot EF_{j,k,y} \cdot S_k \cdot N_{j,y} \cdot M_{j,y} \qquad (7)$$

Calculation of extra emissions and fuel consumption for cold engines

Extra emissions of NO_x, VOC, CH_4, CO, PM, N_2O, NH_3 and fuel consumption from cold start are calculated separately in DEMOS-Road, using the detailed calculation methodology and cold start emission factors from COPERT 5. For SO_2 and CO_2, the extra emissions are derived from the cold start fuel consumption results.

Each trip is associated with a certain cold-start emission level and is assumed to take place under urban driving conditions. The number of trips is distributed evenly across the months. First, cold emission factors are calculated as the hot emission factor times the cold:hot emission ratio. Secondly, the extra emission factor during cold start is found by subtracting the hot emission factor from the cold emission factor. Finally, this extra factor is applied on the fraction of the total mileage driven with a cold engine (the β-factor) for all vehicles in the specific layer.

The cold:hot ratios depend on the average trip length and the monthly ambient temperature distribution. The Danish temperatures for 2021 are given in Rubek et al. (2022). For previous years, temperature data are taken from similar reports available from The Danish Meteorological Institute (www.dmi.dk). The cold:hot ratios are equivalent for gasoline fuelled conventional passenger cars and vans, and for diesel passenger cars and vans, respectively, see EMEP/EEA (2019). For conventional gasoline and all diesel vehicles the extra emissions become:

$$CE_{j,y} = \beta \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr - 1) \qquad (8)$$

Where CE is the cold extra emissions, β = cold driven fraction, CEr = Cold:Hot ratio.

For catalyst cars, the cold:hot ratio is also trip speed dependent. The ratio is, however, unaffected by catalyst wear. The Euro I cold:hot ratio is used for all later catalyst technologies. However, in order to comply with gradually stricter emission standards, the catalyst light-off temperature must be reached in even shorter periods of time for later EURO standards. Correspondingly, the β-factor for gasoline vehicles is reduced step-wise for Euro II vehicles and their successors.

For catalyst vehicles, the cold extra emissions are found from:

$$CE_{j,y} = \beta_{red} \cdot \beta_{EUROI} \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr_{EUROI} - 1) \qquad (9)$$

where β_{red} = the β reduction factor.

For CH_4, specific emission factors for cold driven vehicles are included in COPERT 5. The β and β_{red} factors for VOC are used to calculate the cold driven fraction for each relevant vehicle layer. The NMVOC emissions during cold start are found as the difference between the calculated results for VOC and CH_4.

For N_2O and NH_3, specific cold start emission factors are also proposed by COPERT 5. For catalyst vehicles, however, just like in the case of hot emission factors, the emission factors for cold start are functions of cumulated mileage (emission deterioration). The level of emission deterioration also relies on the content of sulphur in the fuel. The deterioration coefficients are given in EMEP/EEA (2019), for the corresponding layer. For cold start, the cut-off mileage and sulphur level interval for hot engines are used, as described in the deterioration factors paragraph.

Calculation of evaporative emissions from gasoline vehicles

For each year, evaporative emissions of hydrocarbons are calculated for hot and warm running loss, hot and warm soak and diurnal evaporation. The calculations in DEMOS-Road follow the Tier 2 approach in COPERT 5. The basic emission factors are season related (predefined by four ambient temperature intervals), for Danish climate conditions the temperature intervals [-5, 10], [0, 15] and [10, 25] ^{o}C are used. The emission factors are shown in more details in EMEP/EEA (2019).

Running loss emissions originate from vapour generated in the fuel tank while the vehicle is running. The distinction between hot and warm running loss emissions depends on engine temperature, i.e. the engine being either hot or cold. The emissions are calculated as annual mileage (broken down into cold and hot mileage totals using the β-factor) times the respective emission factors. For vehicles equipped with evaporation control (catalyst cars) only hot running loss emissions occur.

$$E_{j,y}^{R} = N_{j,y} \cdot \frac{M_{j,y}}{l_{trip}} \cdot ((1-\beta) \cdot HR + \beta \cdot WR) \quad (10)$$

Where E^R is running loss emissions, l_{trip} = the average trip length, and HR and WR are the hot and warm running loss emission factors, respectively.

Hot and warm soak emissions also occur for carburettor vehicles (no evaporation control), whereas for catalyst cars (evaporation control) only hot soak emissions occur. The soak emissions are calculated as number of trips (broken down into cold and hot trip numbers using the β-factor) times respective emission factors:

$$E_{j,y}^{S} = N_{j,y} \cdot \frac{M_{j,y}}{l_{trip}} \cdot ((1-\beta) \cdot HS + \beta \cdot WS) \quad (11)$$

Where E^S is the soak emission, l_{trip} = the average trip length, and HS and WS are the hot and warm soak emission factors, respectively.

Average maximum and minimum temperatures per month are used in combination with diurnal emission factors to estimate the diurnal emissions from both carburettor and catalyst vehicles E^D:

$$E_{j,y}^{D} = 365 \cdot N_{j,y} \cdot e^{D} \quad (12)$$

Each year's total is the sum of each layer's running loss, soak loss and diurnal emissions.

Energy balance between inventory and sales

The calculated fuel consumption in DEMOS-Road must equal the statistical fuel sale totals according to the UNFCCC and UNECE emissions reporting format. The statistical fuel sales for road transport are derived from the Danish Energy Authority data (see DEA, 2022a).

For gasoline, the DEA sales data for road transport are adjusted at first, in order to account for e.g. non-road and recreational craft fuel consumption, which are not directly stated in the statistics. Please refer to paragraph 3.3.3 for further information regarding the transformation of DEA fuel data. Next, the fuel and emission results for all gasoline vehicles are scaled with the percentage difference between the bottom-up gasoline fuel consumption on Danish roads and total gasoline fuel sold.

For diesel, the DEA sales data for road transport are adjusted at first, in order to account for recreational craft fuel consumption, which are not directly stated in the statistics.

The DEA data for diesel consist of fuel sold in Denmark and used on Danish roads and fuel sold in Denmark and used abroad (diesel border sales). The latter diesel fuel contribution is estimated by the Danish Ministry of Taxation based on studies on fuel price differences across borders, fuel discount for haulage contractors and fuel tanking behavior of truck and bus operators as well as private cars (see e.g. the Danish Ministry of Taxation, 2015).

The diesel border sales (diesel used abroad) is allocated to truck-trailer and articulated trucks (TT/AT trucks) in two total vehicle weight categories, < 40 tonnes and > 40 tonnes, and coaches.

The distribution of the diesel used abroad is split into the three vehicle categories by using the relative fuel consumption used in Denmark by foreign TT/AT trucks (< 40 tonnes and > 40 tonnes) and coaches (calculated based on mileage driven in Denmark by foreign trucks and coaches (paragraph 3.3.2) and corresponding fuel consumption factors).

The calculated "border" scaling factors of the TT/AT trucks and coaches in the model, i.e. the ratio between the total model fuel consumption (model fuel consumption in Denmark and model fuel consumption abroad) and the model fuel consumption in Denmark for these vehicle categories are shown in (Figure 3.3.25).

The total model fuel consumption for all vehicle categories is subsequently calculated in a first step, as the product of fuel consumption factors and corresponding total mileage, the latter being adjusted for mileage driven outside Denmark, as described above in the case of TT/AT trucks and coaches (adjusted bottom up diesel fuel consumption).

Next, the percentage difference between the first step model diesel fuel consumption (adjusted bottom up diesel fuel consumption) and the total diesel fuel sold in Denmark is used to scale fuel and emission results for all diesel vehicles regardless of vehicle category (Figure 3.3.26). The data behind the Figures 3.3.25 and 3.3.26 are also listed in Annex 3.B.8.

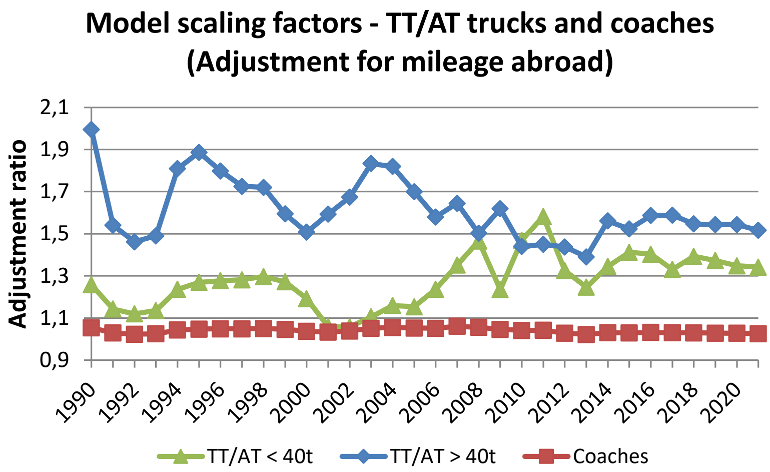


Figure 3.3.25 Fuel and emission adjustment ratios for TT/AT trucks and coaches: Bottom-up fuel consumption plus diesel used abroad vs bottom-up fuel consumption.

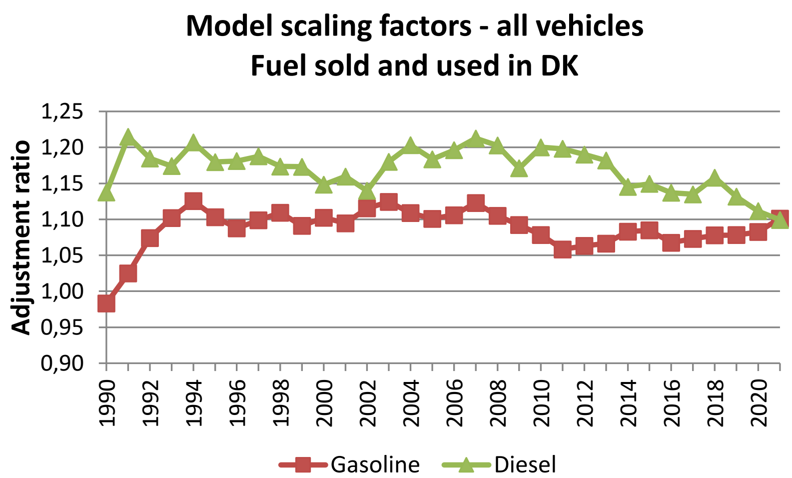


Figure 3.3.26 Gasoline and diesel fuel ratios (fuel and emission adjustment factors) regardless of vehicle category: Fuel sold and used in Denmark vs bottom-up fuel consumption used in Denmark.

The reasons for the differences between DEA sales figures and bottom-up fuel estimates shown in Figure 3.3.26 are mostly due to a combination of the uncertainties related to COPERT 5 fuel consumption factors, allocation of vehicle numbers in sub-categories, annual mileage, trip speeds and mileage splits for urban, rural and highway driving conditions.

The final fuel consumption and emission factors are shown in Annex 3.B.7 for 1985-2021. The total fuel consumption and emissions are shown in Annex 3.B.8, per vehicle category and as grand totals, for 1985-2021 (and CRF format in Annex 3.B.16. In Annex 3.B.15, fuel consumption and emission factors as well as total emissions are given in CollectER format for 1990 and 2021.

In the following Figures 3.3.27 - 3.3.29, the fuel and km related emission factors for CO_2 (km related only), CH_4 and N_2O are shown per vehicle type for the Danish road transport (from 1990-2021).

In 2006 and 2008, respectively, bio ethanol and biodiesel became available from a limited number of gas filling stations in Denmark, and today bio ethanol and biodiesel (FAME) is added to all fuel commercially available. Following the IPCC guideline definitions, bio fuels are in principle regarded as CO_2

neutral for the transport sector as such. A small part of carbon (and the associated CO_2 emissions) in biodiesel, however, have a fossil origin due to the use of fossil-derived methanol in the biodiesel production process. This is accounted for in the emission inventories by following the biodiesel fossil carbon content calculation methodology provided by Sempos (2019).

The sulphur content for bio ethanol/biodiesel is assumed to be zero and hence, the aggregated CO_2 (and SO_2) factors for gasoline/diesel have been adjusted, on the basis of the energy content of neat gasoline/diesel and bio ethanol/biodiesel, respectively, in the available fuels.

At present, the Danish road transport fuels only have low biofuel (BF) shares (Table 3.3.7), and hence, no thermal efficiency changes are expected for the fuels. Consequently, the energy based fuel consumption factors (MJ/km) derived from COPERT 5 are used also in this case.

As a function of the current ethanol/biodiesel energy percentage, $BF\%_E$, (Table 3.3.7) the average fuel related CO_2 emission factors, $emf_{CO2,E}(BF\%)$ become:

$$EF_{CO2,E}(BF\%) = EF_{CO2,E}(BF0) \cdot (100 - BF\%_E) \tag{13}$$

Where:

$EF_{CO2,E}(BF\%)$ = average fuel related CO_2 emission factor (g MJ^{-1}) for current BF%

$EF_{CO2,E}(BF0)$ = fuel related CO_2 emission factor (g MJ^{-1}) for fossil fuels

The kilometer based average CO_2 emission factor is subsequently calculated as the product of the fuel related CO_2 emission factor from equation 3 and the energy based fuel consumption factor, $FC_{CO2,E}(BF0)$, derived from COPERT 5:

$$EF_{CO2,km}(BF\%) = EF_{CO2,E}(BF\%) \cdot FC_E(BF0) \tag{14}$$

A literature review carried out in the Danish research project REBECA revealed no significant changes in emission factors between neat gasoline and E5 gasoline-ethanol blends for the combustion related emission components; NO_x, CO and VOC (Winther et al., 2012). Hence, due to the current low ethanol content in today’s road transport gasoline, no modifications of the neat gasoline based COPERT emission factors are made in the inventories in order to account for ethanol usage.

REBECa results published by Winther (2009) have shown that the emission impact of using diesel-biodiesel blends is very small at low biodiesel blend ratios. Consequently, no bio fuel emission factor adjustments are needed for diesel vehicles as well. However, adjustment of the emission factors for diesel vehicles will be made if the biodiesel content of road transport diesel fuel increases to a more significant level in the future.

The fuel related CO_2 emission factors for neat gasoline, diesel, CNG and LPG, and for bio ethanol, biodiesel and bio CNG, and the aggregated CO_2 factors are shown in Table 3.3.7. For gasoline and compressed natural gas (CNG) the CO_2 emission factors are country-specific. For gasoline, the emission factor source is Fenhann and Kilde (1994). For CNG, the CO_2 emission factor is estimated by the Danish gas transmission company, Energinet.dk, based on gas analysis data (Energinet.dk, 2022). For liquefied petroleum gas (LPG), the emission factor source is EMEP/EEA (2019). For diesel the emission factor source is IPCC (2006) [10].

Table 3.3.7 Fuel-specific CO_2 emission factors and biofuel shares for road transport in Denmark.

	Emission factors (g/MJ)																
Fuel type	1990-2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Neat diesel	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1
Neat gasoline	73	73	73	73	73	73	73	73	73	73	73	73	73	73	73	73	73
CNG	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8
LPG	63.1	63.1	63.1	63.1	63.1	63.1	63.1	63.1	63.1	63.1	63.1	63.1	63.1	63.1	63.1	63.1	63.1
Biodiesel	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Bio ethanol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bio CNG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diesel avg.	74.1	74.1	74.1	74.1	74.0	74.1	71.8	69.7	69.5	69.5	69.6	69.6	69.8	69.9	69.5	69.5	69.5
Gasoline avg.	73	72.9	72.8	72.8	72.8	71.8	70.7	70.5	70.6	70.6	70.7	70.7	70.7	70.7	70.7	68.4	68.5
CNG avg.	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	56.2	55.1	53.8	52.7	51.1	47.6	44.4
	Biofuel share (BF%) of Danish road transport fuels																
	1990-2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	0	0.09	0.14	0.12	0.20	0.66	3.2	5.2	5.4	5.4	5.3	5.3	5.2	5.1	5.4	6.5	6.5

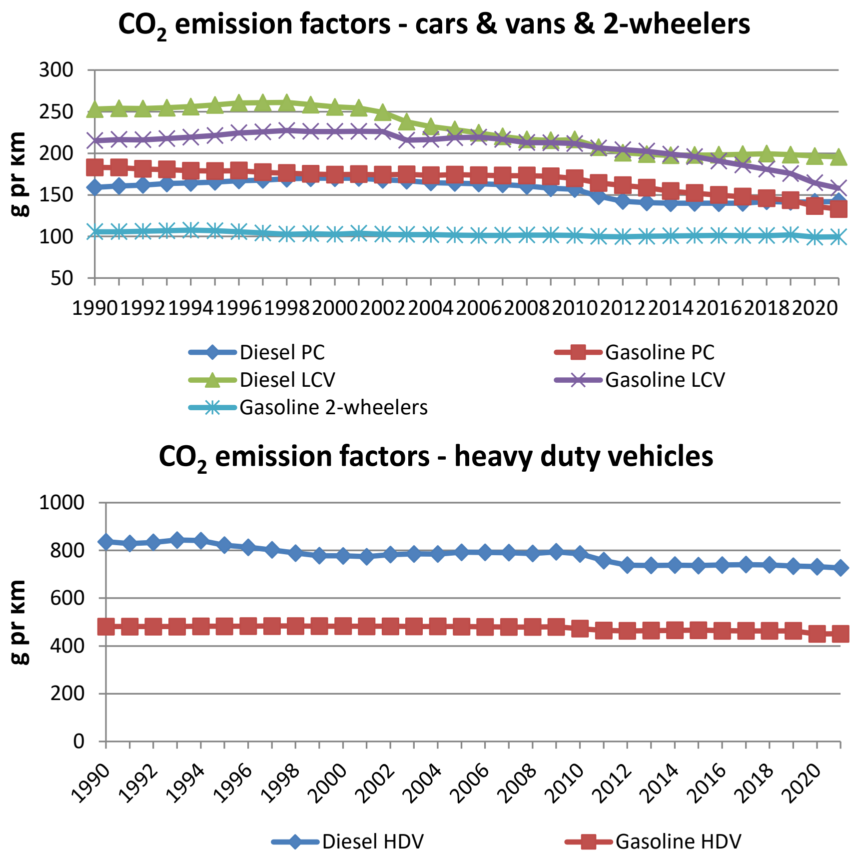


Figure 3.3.27 Km related CO_2 emission factors per vehicle type for Danish road transport (1990-2021).

[10] A country-specific emission factor for diesel used in road transportation is not available from Danish refineries. Instead, the diesel EF for Danish stationary combustion is assessed, which is from the EU ETS. The average CO_2 EF of diesel burned in stationary Danish sources during 2008-2016 is 74.1 kg/GJ, an EF identical to the IPCC (2006) default data.

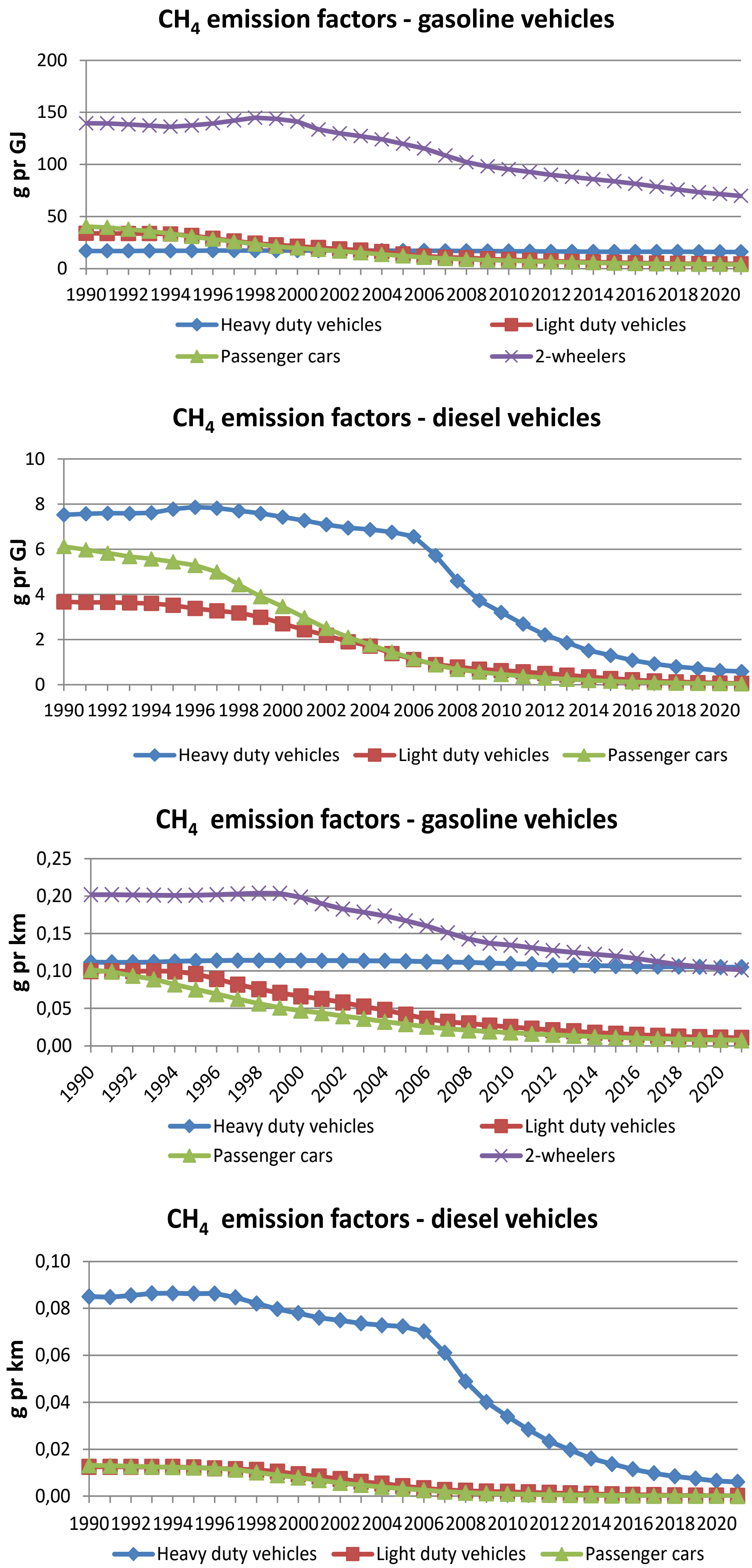


Figure 3.3.28 Fuel and km related CH_4 emission factors per vehicle type for Danish road transport (1990-2021).

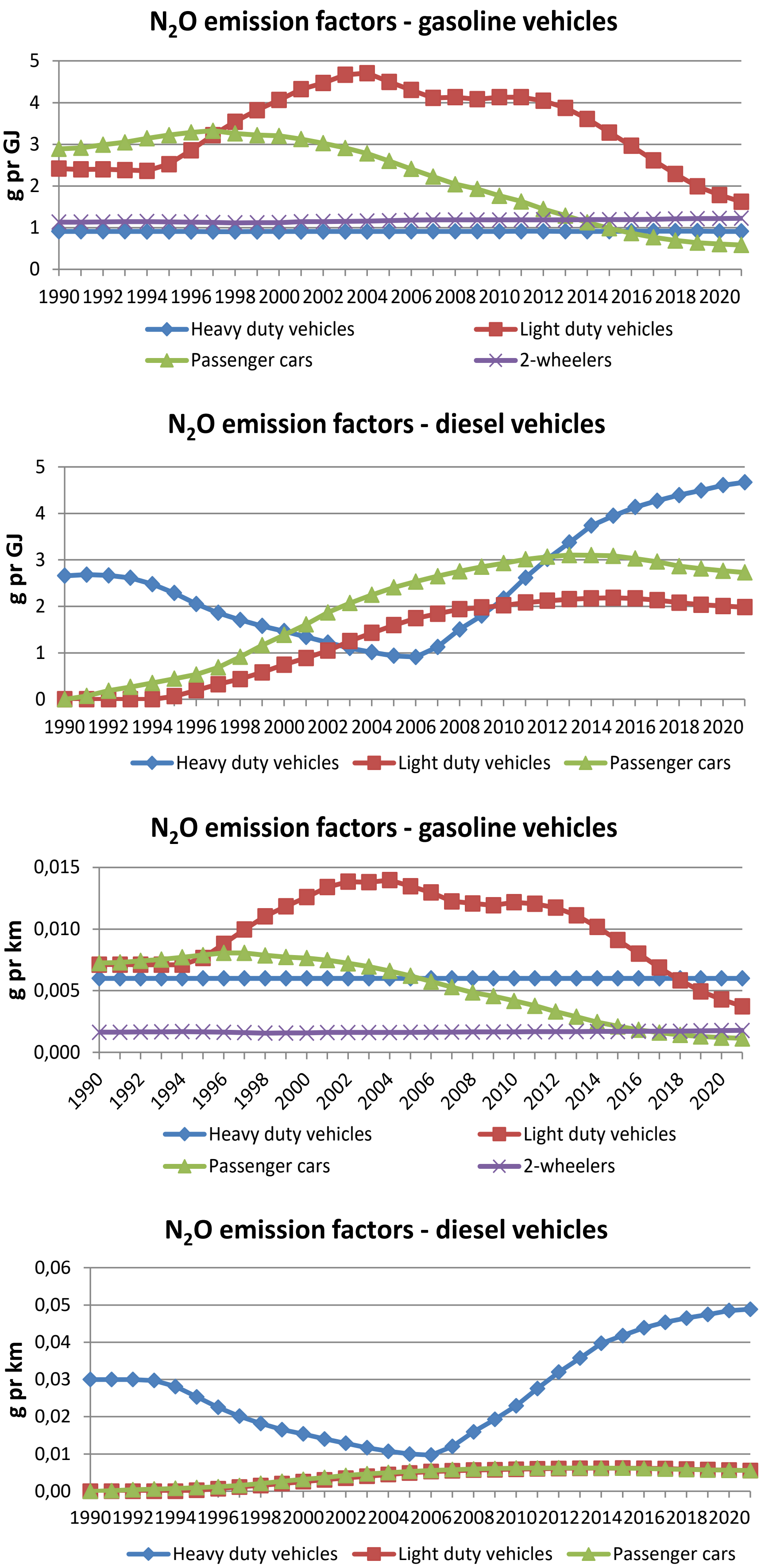


Figure 3.3.29 Fuel and km related N_2O emission factors per vehicle type for Danish road transport (1990-2021).

3.3.3 Activity data and emission factors for other mobile sources

The emission inventories for other mobile sources are divided into several sub-sectors: Civil aviation, national navigation, national fishing, railways, military, and non road mobile machinery in agriculture, forestry, industry, commercial/institutional and residential.

The emission calculations are made for each sub-sector in the DEMOS model using the detailed method as described in the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2019)[11].

Civil Aviation

The activity data used in DEMOS-Aviation consists of air traffic statistics provided by the Danish Civil Aviation and Railway Authority and Copenhagen Airport. Fuel statistics for jet fuel consumption and aviation gasoline are obtained from the Danish energy statistics (DEA, 2022a).

For 2001 onwards, the Danish Civil Aviation and Railway Authority provides data records per flight (city-pairs). Each flight record consists of e.g. ICAO codes for aircraft type, origin and destination airport, maximum takeoff mass (MTOM), flight call sign and aircraft registration number.

In DEMOS-Aviation, each aircraft type is paired with a representative aircraft type, for which fuel consumption and emission data exist in the EMEP/EEA databank. As a basis, the type relation table is taken from the Eurocontrol AEM model, which is the primary source for the present EMEP/EEA fuel consumption and emission data. Supplementary aircraft types are assigned to representative aircraft types based on the type relation table already established in the previous version of DEMOS-Aviation (e.g. Winther, 2022a).

Additional aircraft types not present in the type relation table are identified by using different aircraft dictionaries and internet look-ups. In order to select the most appropriate aircraft representative type, the main selection criteria are the identified aircraft type, aircraft maximum takeoff mass, engine types, and number of engines. During this sequence, small aircraft with piston engines using aviation gasoline are excluded from the calculations.

Annex 3.B.10 shows the correspondence table between the actual aircraft type codes and representative aircraft types behind the Danish inventory. Annex 3.B.10 also show the number of LTO's per representative aircraft type for domestic and international flights starting from Copenhagen Airport and other airports, respectively[12], in a time series from 2001-2021. The airport split is necessary to make due to the differences in LTO emission factors (cf. section 3.3.4).

The same type of LTO activity data for the flights for Greenland and the Faroe Islands are shown in Annex 3.B.10 also, further detailed into origin-destination airport pairs and associated flight distances. This level of detail meets the demand from UNFCCC to provide precise documentation for the part of the inventory for the Kingdom of Denmark being outside the Danish mainland.

[11] For military and other sea vessels than ferries, the simple fuel based method is used.

[12] Excluding flights for Greenland and the Faroe Islands. These flights are separately listed in Annex 3.B.10.

The ideal flying distance (great circle distance) between the city-pairs is calculated by DCE in a separate database. The calculation algorithm uses a global latitude/altitude coordinate table for airports. In cases when airport coordinates are not present in the DCE database, these are looked up on the internet and entered into the database accordingly. The actual distance flown are in reality longer than great circle distance between two airports, and this is adjusted for in DEMOS-Aviation, as explained in section 3.3.4.

For inventory years prior to 2001, detailed LTO/aircraft type statistics are obtained from Copenhagen Airport (for this airport only), while information of total takeoff numbers for other Danish airports is provided by the Danish Civil Aviation and Railway Authority. The assignment of representative aircraft types for Copenhagen Airport is done as described above. For the remaining Danish airports, representative aircraft types are not directly assigned. Instead, appropriate average assumptions are made relating to the fuel consumption and emission data part.

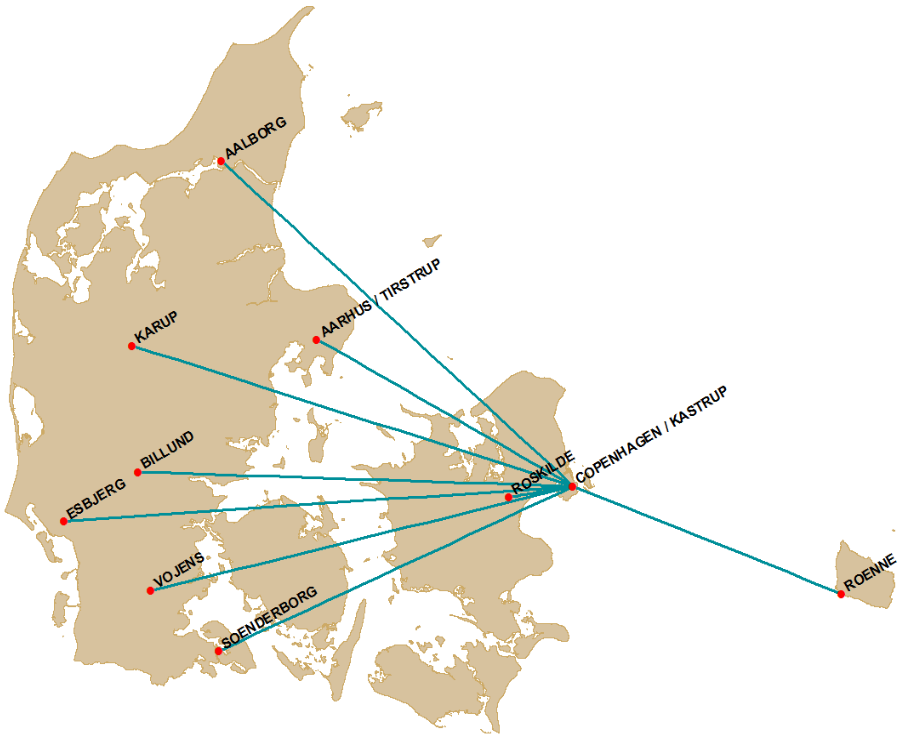
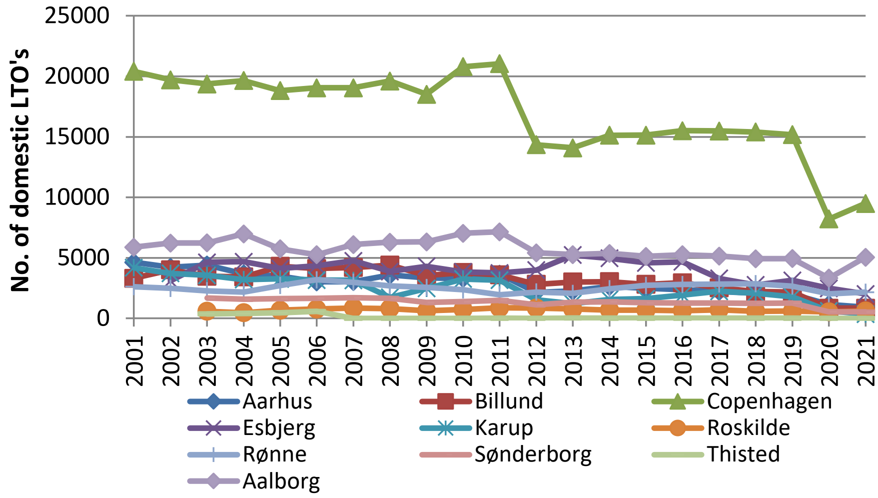


Figure 3.3.30 Most frequent domestic flying routes for large aircraft in Denmark.

Copenhagen Airport is the starting or end point for most of the domestic aviation made by large aircraft in Denmark (Figure 3.3.30; routes to Greenland/Faroe Islands are not shown). Even though many domestic flights not touching Copenhagen Airport are also reported in the flight statistics kept by the Danish Civil Aviation and Railway Authority, these flights, however, are predominantly made with small piston engine aircraft using aviation gasoline. Hence, the consumption of jet fuel by flights not using Copenhagen Airport is merely marginal.



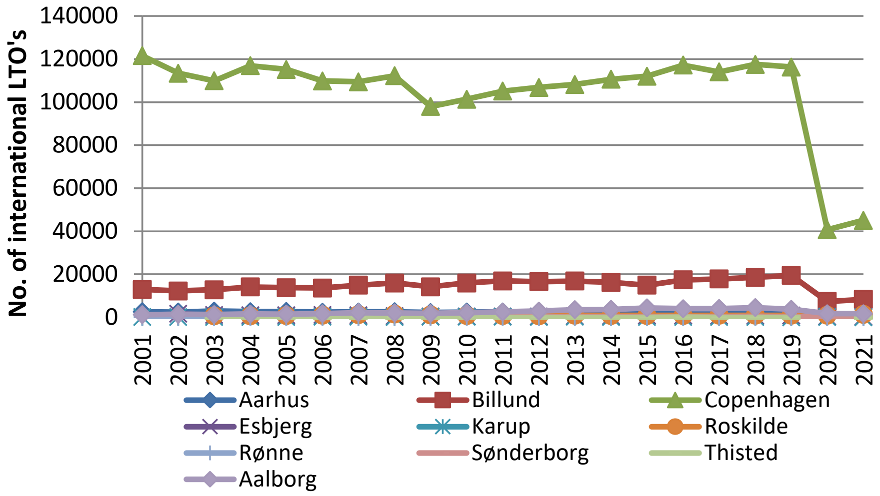


Figure 3.3.31 No. of LTO's for the most important airports in Denmark 2001-2021.

Figure 3.3.31 shows the number of domestic and international LTO's for Danish airports[13], in a time series from 2001-2021.

Non-road mobile machinery and recreational craft

Non-road mobile machinery are used in the agricultural, forestry, industrial, commercial/institutional and residential sectors, and the activity data are gathered from numerous sources. The activity data for non road mobile machinery are described in the following together with activity data for recreational craft.

Detailed tractor fleet data for 2003-2020 and total numbers 1950-2002 for tractors in the Danish motor register are provided by Statistics Denmark (2021a, 2021b).

Total numbers for tractors (tractors in motor register and other tractors) for 1982-2005 are provided by Statistics Denmark (2021c). Total numbers for tractors (tractors in motor register and other tractors) for 1974-1981 are found in consecutive statistical publications e.g. Agricultural statistics 1974 (Statistics Denmark, 1975), as well as supplementary stock numbers per fuel type (diesel and gasoline).

[13] Flights for Greenland and the Faroe Islands are included under domestic in the figure.

Supplementary new sales data in kW classes are provided by the Association of Danish Agricultural Machinery Dealers for 1982-2018. Engine load factors and annual working hours for tractors come from Bak et al. (2003).

Number of forestry machines, engine size, annual working hours and average life times are provided by the Danish Forest Association (Clemmensen, 2022).

For the most important types of building and construction machinery used in industry annual new sales data for 1996 onwards has been provided by the Association of Danish Agricultural Machinery Dealers (Fasting, 2022).

Fork lift sales data has been provided by the Association of Producers and Distributors of Fork Lifts in Denmark for 1976-2019. Further, WITS (World Industrial Truck Sales) and FEM (Federation European Material) fork lift sales figures for Denmark in 2000-2020 as well as branch distribution information has been provided by Toyota Material Handling (Christensen, 2021).

For telescopic loaders, branch distribution information has been provided by Scantruck (Faurby, 2021).

From engine manufacturers engine load factors have been provided based on electronic engine power registrations (Sjøgren 2016; Mikkelsen 2016) in the case of building and construction machinery. Further, equipment size - engine size relations, equipment scrapping curves and annual working hours as a function of machinery age has been included in the model (Sjøgren 2016; Mikkelsen 2016; Brun 2018; Christensen 2018).

The share of Stage IIIB and IV diesel engines used in the building and construction sector with preinstalled diesel particle filters, has been estimated in different engine size classes, based on questionnaire answers from the most important mobile machinery manufacturers and Danish machinery importers (Winther, 2022c).

For the most important types of household and gardening machinery used in commercial/institutional and residential, annual new sales data for 2006 onwards is provided by the Association for Industrial Technics, Tools and Automation (BITVA: Brancheforeningen for industriel teknik, værktøj og automation). Until 2018 new sales data was provided by the Dealers Association of Electric Tools and Gardening Machinery (LTEH: Leverandørforeningen for Transportabelt Elværktøj og Havebrugsmaskiner). Further, equipment size - engine size relations, equipment scrapping curves and annual working hours as a function of machinery age has been provided by LTEH (Nielsen and Schösser, 2016).

The total number of refrigerating units for long distance transport trucks has been estimated for 1990 and 2021 by Teknologisk Institut (1992, 2022). Based on these data, a linear development in the number of refrigerating units from 1990 to 2021 has been assumed. For distribution lorries, the total number of refrigerating units for distribution lorries has been estimated for 1990 by the Teknologisk Institut (1992), and a proportional increase in the number of units has been assumed based on the development in the number of Danish inhabitants from 1990 to 2021.

For a remaining group of non road mobile machinery types with low emission contributions (e.g. pumps, generators, compressors), total stock numbers from 1990 to 2021 has been estimated based on 1990 stock numbers from Teknologisk Institut (1992, 1993) and a proportional development of the stock numbers with GDP. For these machinery types, load factors, engine sizes and annual working hours has been gathered by Winther et al. (2006).

The stock development from 1990-2021 for the most important types of machinery are shown in Figures 3.3.32-3.3.39 below. The stock data are also listed in Annex 2.B.11, together with figures for load factors, engine sizes and annual working hours. As regards stock data for the remaining machinery types, please refer to (Winther et al., 2006).

It is important to note that key experts in the field of industrial non-road activities assume a significant decrease in the activities for 2009 due to the global financial crisis. This reduction is in the order of 25 % for 2009 for industrial non-road activities in general (pers. comm. Per Stjernqvist, Volvo Construction Equipment 2010). For fork lifts 5 % and 20 % activity reductions are assumed for 2008 and 2009, respectively (pers. comm. Peter H. Møller, Rocla A/S).

For tractors used in Agriculture, Industry and Commercial/Institutional and for harvesters, the total number per year are shown in the Figures 3.3.32-3.3.33, respectively.

For the tractors used in agriculture and for harvesters, the developments towards fewer vehicles and larger engines, shown in Figure 3.3.34, are very clear. From 1990 to 2020, tractor and harvester numbers decrease by around 48 % and 73 %, respectively, whereas the average increase in engine size for tractors is 96 % and 326 % for harvesters, in the same time period.

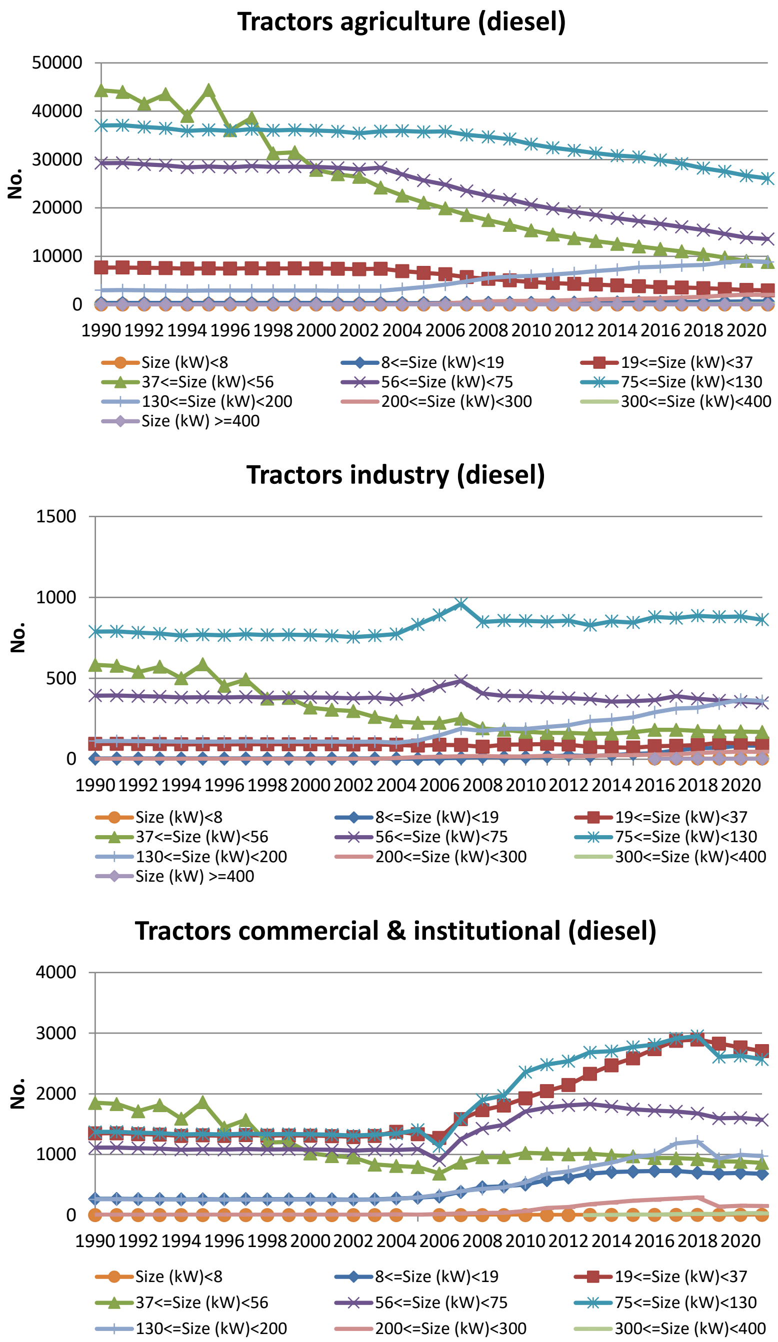
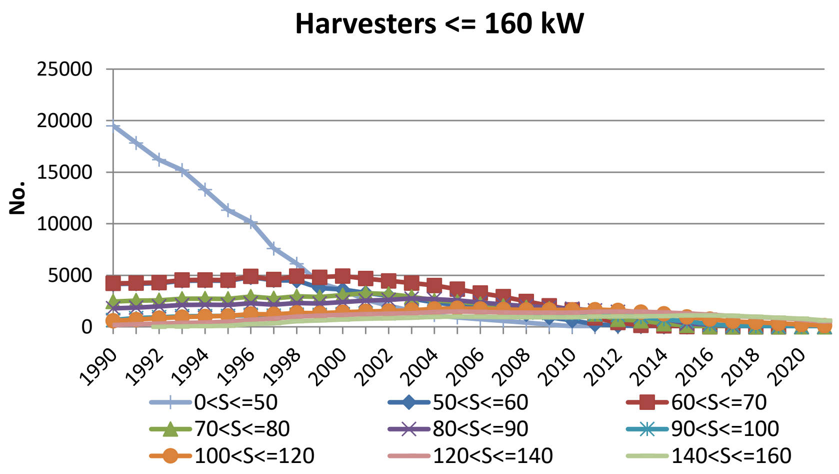


Figure 3.3.32 Total numbers in kW classes for tractors in agriculture, industry and commercial/institutional from 1990 to 2021.



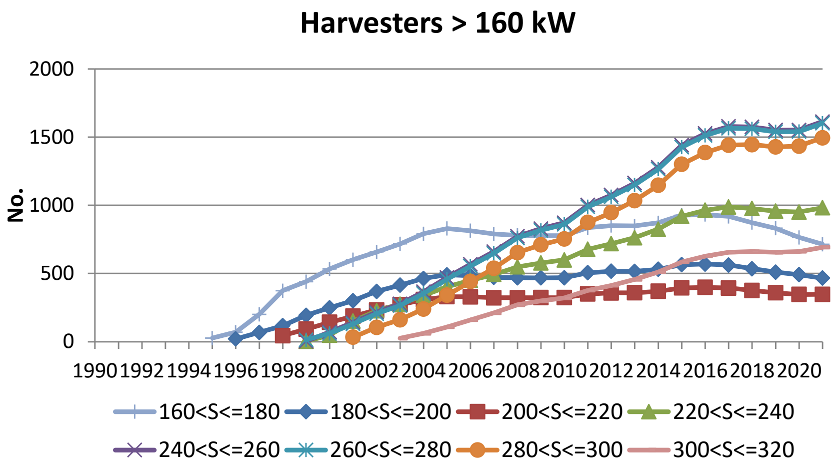
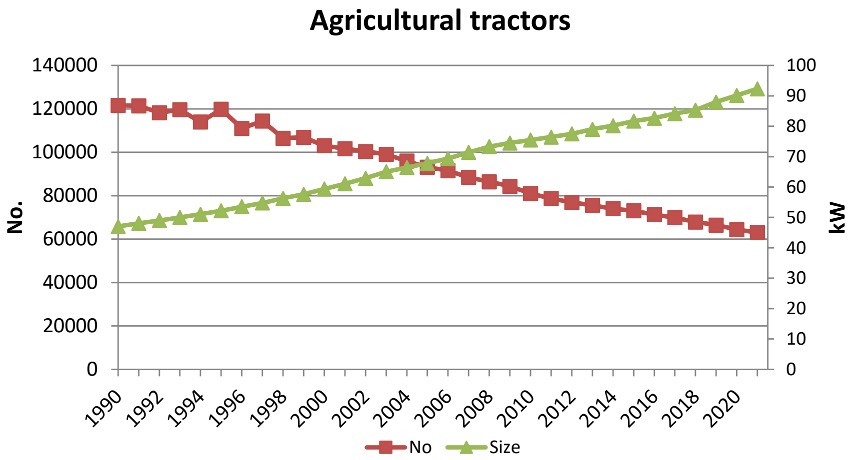


Figure 3.3.33 Total numbers in kW classes for harvesters from 1990 to 2021.



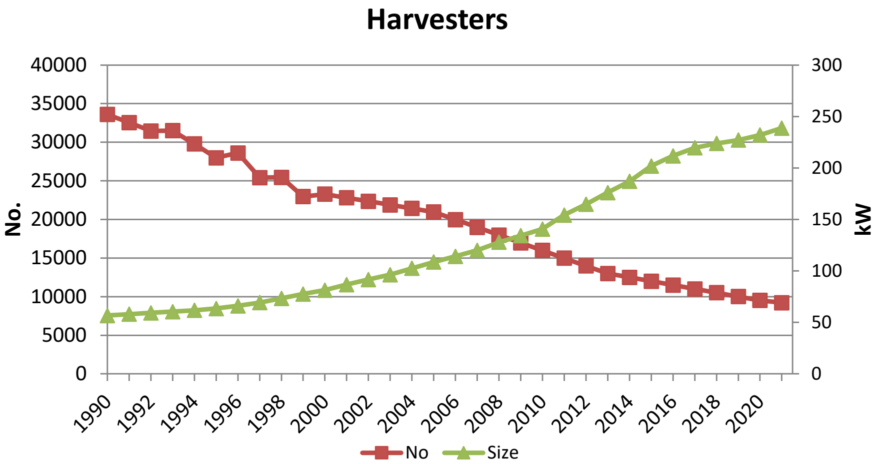


Figure 3.3.34 Total numbers and average engine size for agricultural tractors and harvesters (1990 to 2021).

The most important non road machinery types for industry are different types of construction machinery and fork lifts. The Figures 3.3.35 and 3.3.36 show the 1990-2021 stock development for specific types of construction machinery and diesel fork lifts. Due to lack of data, 1996-1999 average sales data for construction machinery is used for 1995 and back. However, it is assumed that telescopic loaders first enter into use in 1986 (Jensen, Scantruck 2016). For most of the machinery types, there is an increase in machinery numbers from 1990 onwards, due to increased construction activities.

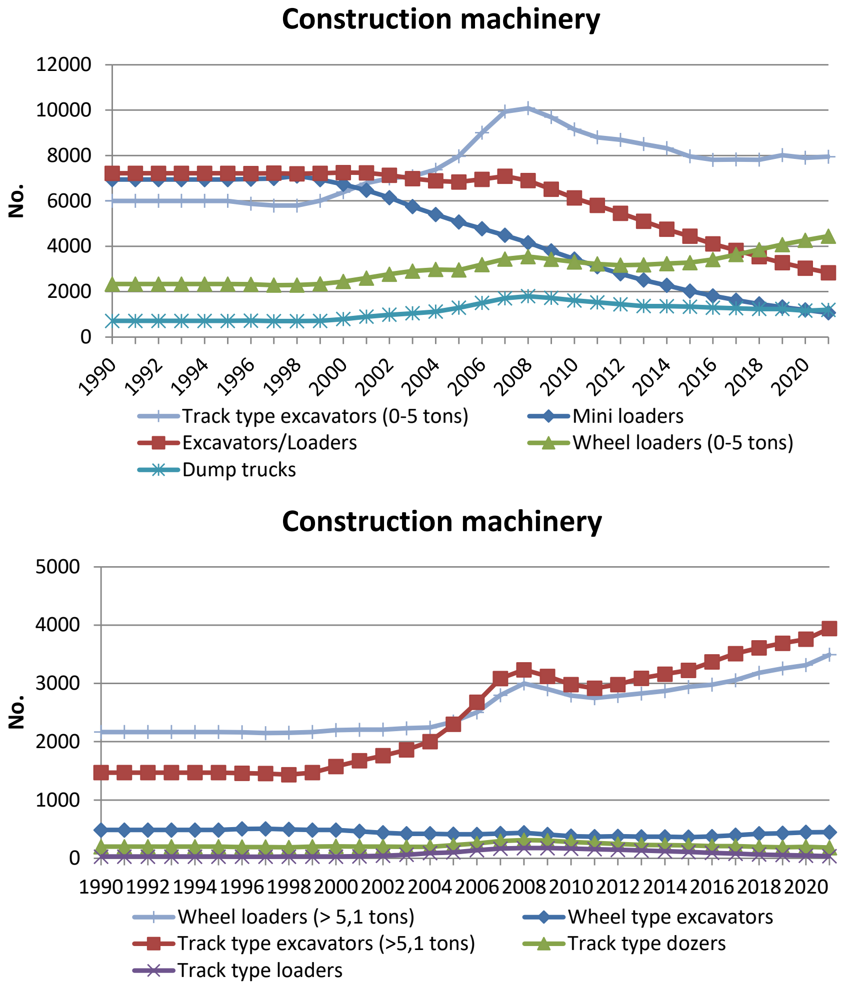
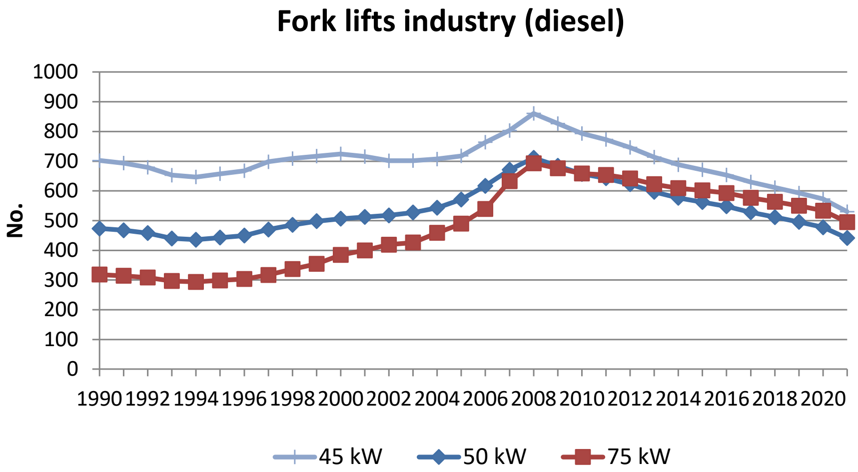


Figure 3.3.35 1990-2021 stock development for specific types of construction machinery.



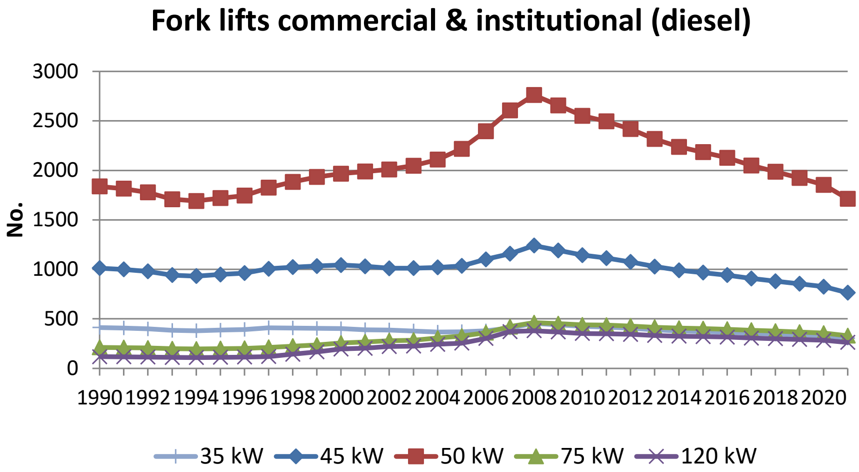


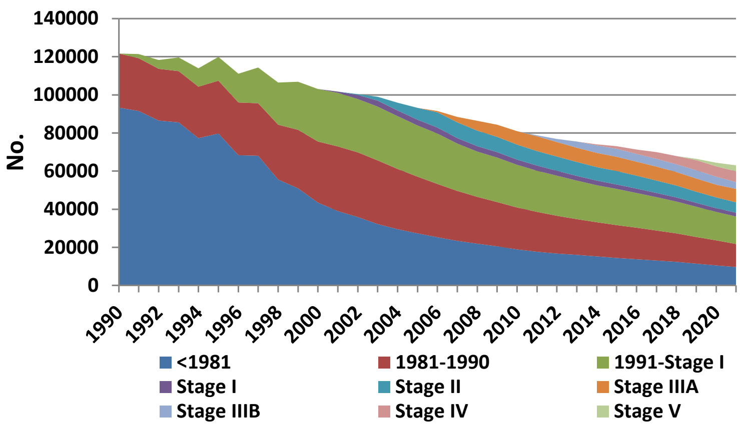
Figure 3.3.36 Total numbers of diesel fork lifts in kW classes from 1990 to 2021.

Figure 3.3.37 shows the emission layer distribution for the total stock of tractors, harvesters, construction machinery (most important types, Figure 3.3.35) and diesel fork lifts from 1990-2021.

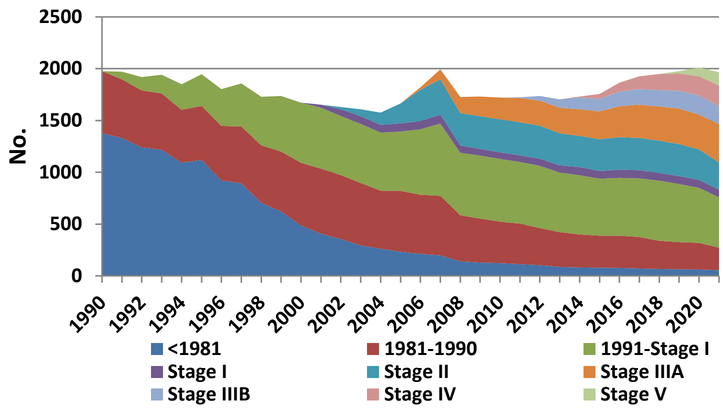
The penetration of the different pre-Euro engine classes, and engine stages complying with the gradually stricter EU stage I-IV emission limits is very visible from Figure 3.3.37.

The EU emission directive stage implementation years relate to engine size, and hence, for all four machinery groups the emission level shares into specific size segments will differ slightly from the picture shown in Figure 3.3.37.

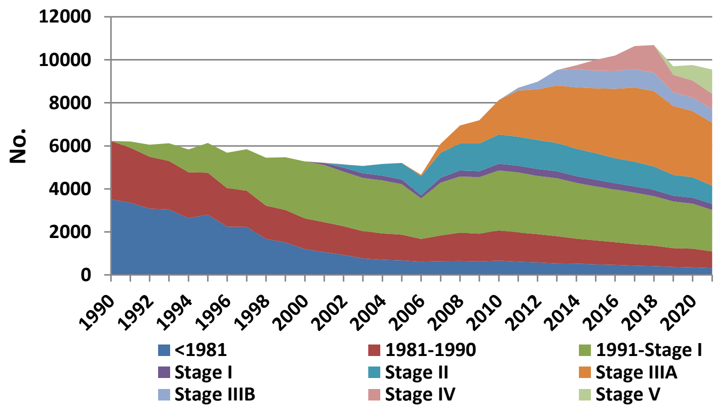
Tractors agriculture (diesel)



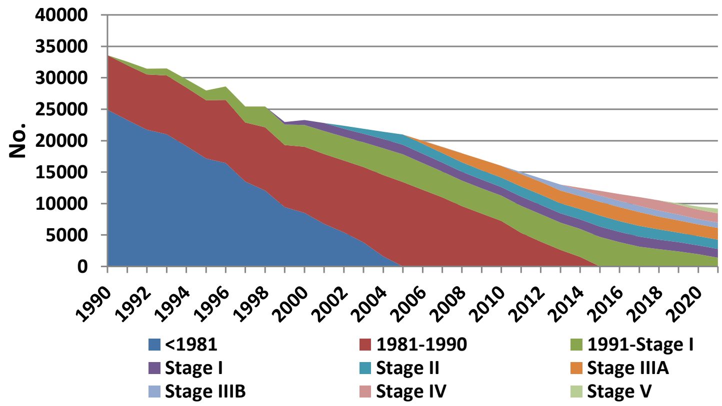
Tractors industry (diesel)



Tractors commercial & institutional (diesel)



Harvesters



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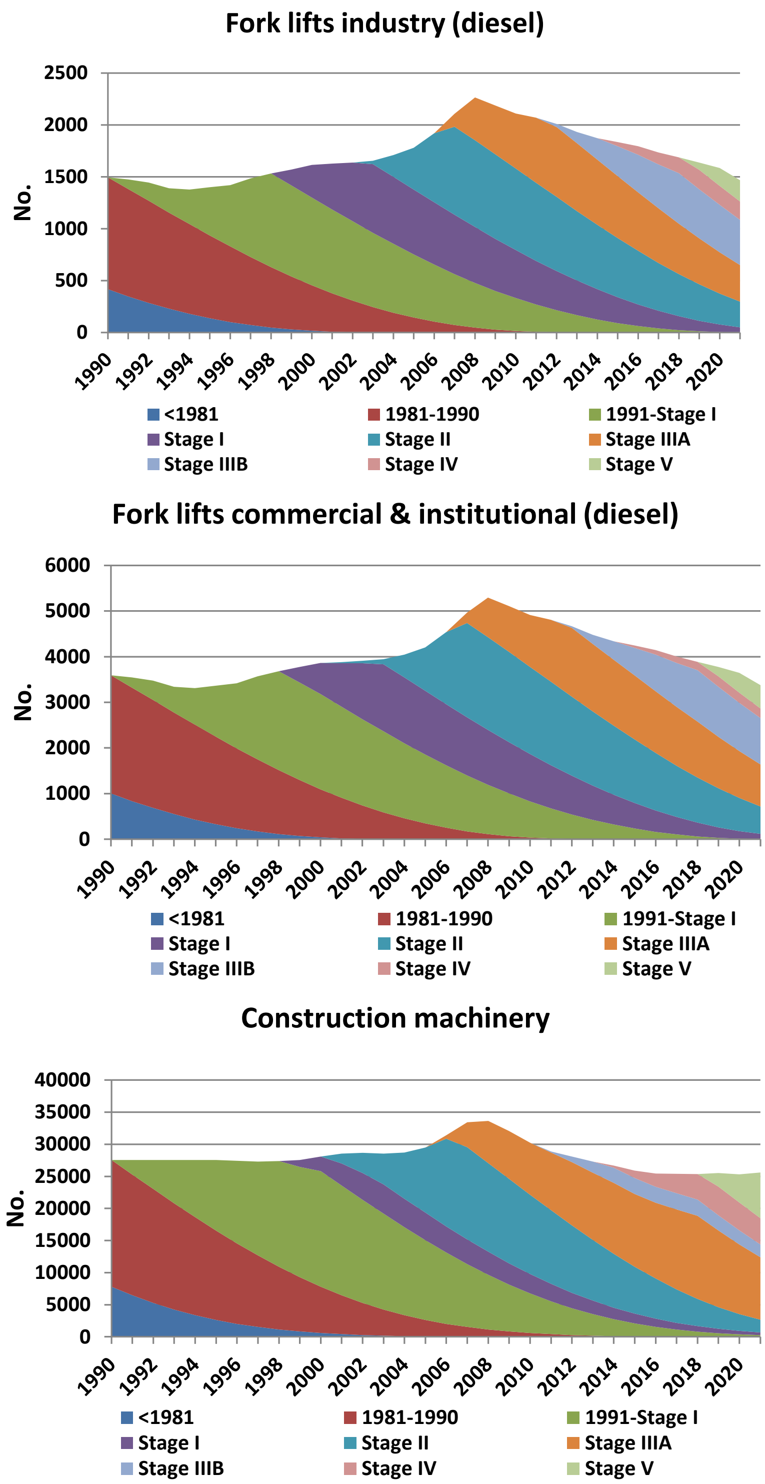

Figure 3.3.37 Layer distribution for tractors, harvesters, construction machinery and diesel fork lifts (1990 to 2021).

The 1990-2021 stock development for the most important household and gardening machinery types is shown in Figure 3.3.38. The activities made with private and professional equipment types are grouped into the Residential (1.A.4b) and Commercial/Institutional (1.A.4.a) inventory sectors, respectively.

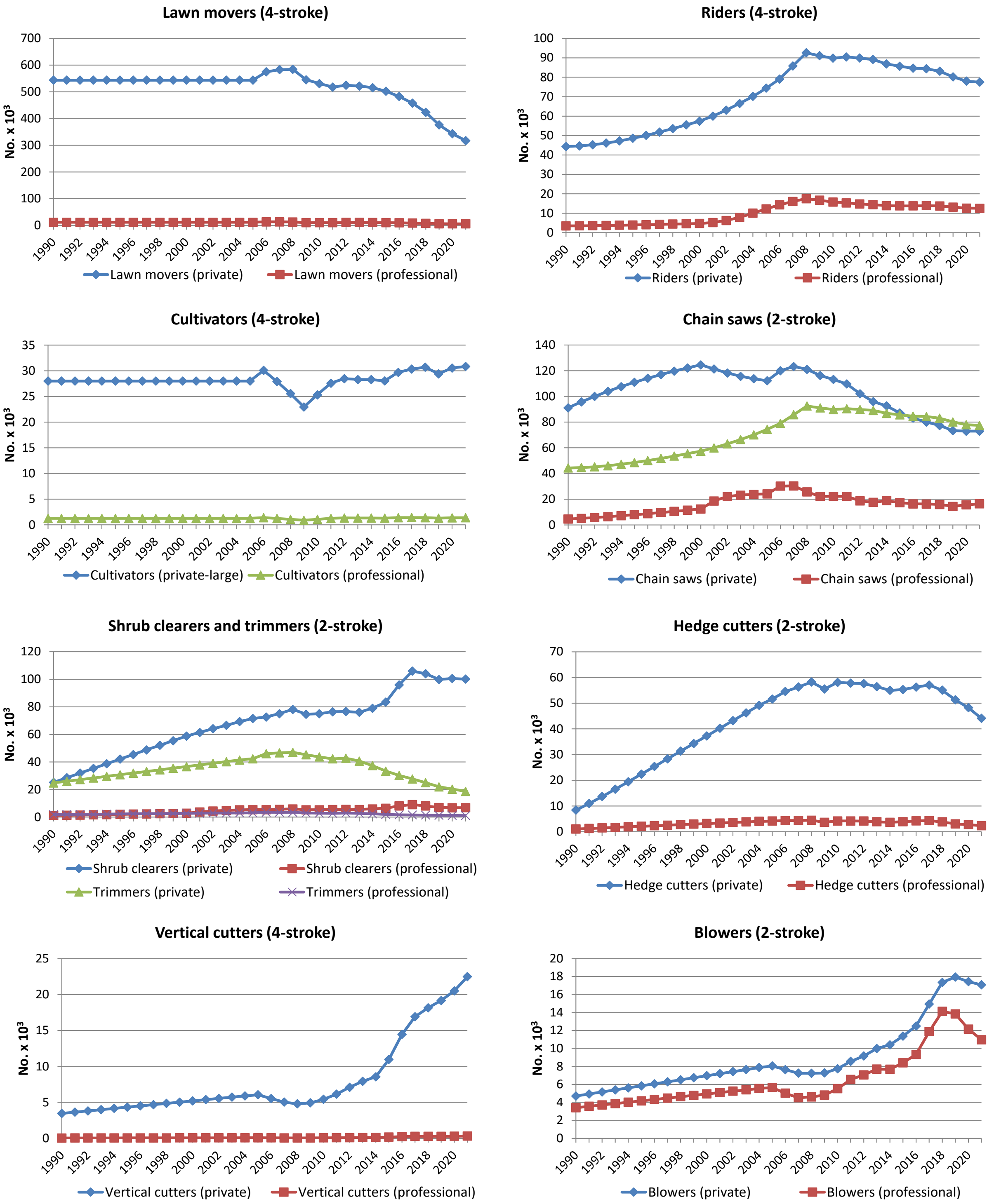

Figure 3.3.38 Stock development 1990-2021 for the most important household and gardening machinery types.

The total stock development for the most important household and gardening machinery types is shown in Figure 3.3.39 split into 2-stroke and 4-stroke machinery for Residential (1.A.4b) and Commercial/Institutional (1.A.4.a). For the same stock division, the emission layer distribution is also shown in Figure 3.3.39. The penetration of new technologies occur faster for working machinery in Commercial/Institutional (1.A.4.a) compared with Residential (1.A.4.b), due to the shorter maximum life times for the working equipment used by professionals.

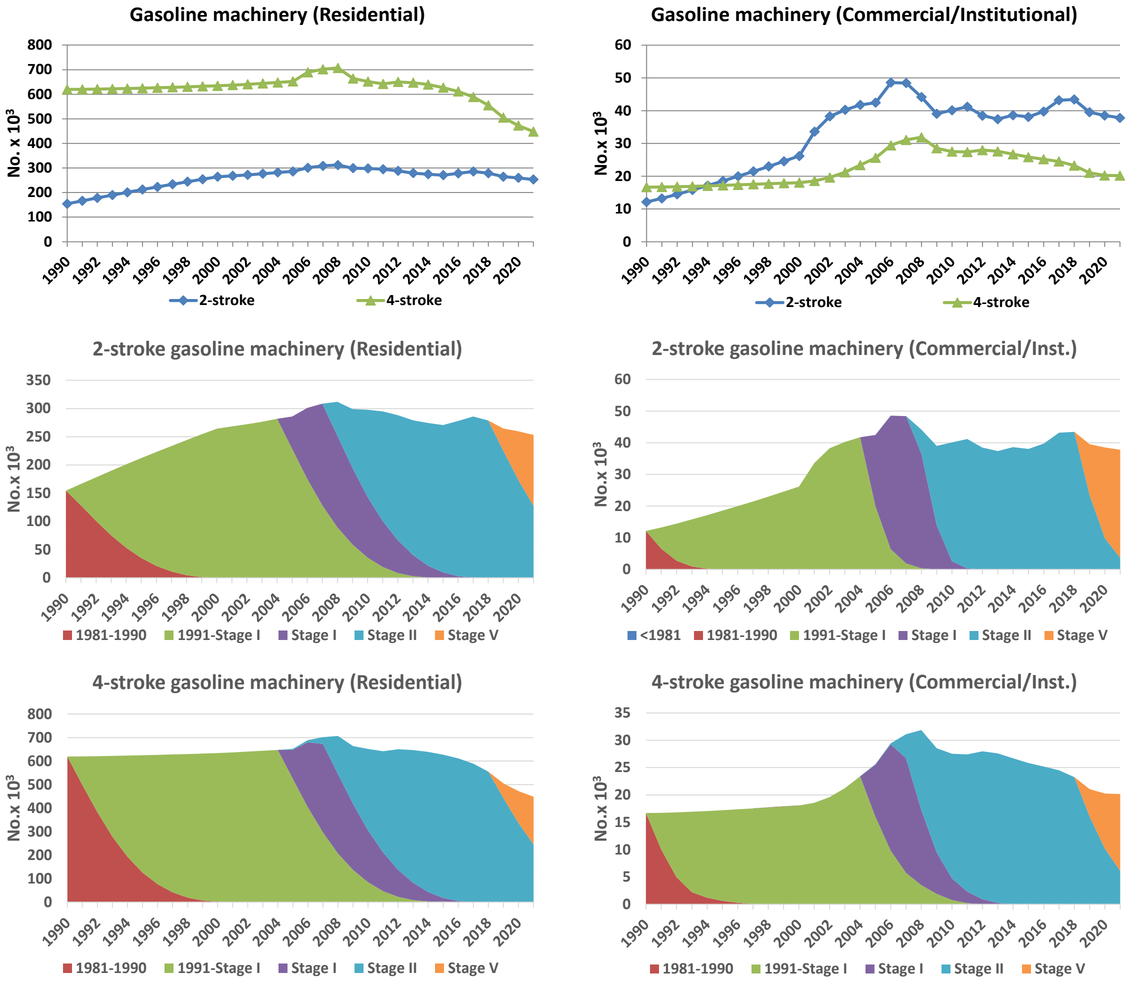

Figure 3.3.39 Layer distribution for the most important household and gardening machinery types split into residential and commercial/institutional (1990-2021).

Figure 3.3.40 shows the development in numbers of different recreational craft from 1990-2021. The 2004 stock data for recreational craft are repeated for 2005+, due to lack of data from the Danish Sailing Association.

For diesel boats, increases in stock and engine size are expected during the whole period, except for the number of motor boats (< 27 ft.) and the engine sizes for sailing boats (<26 ft.), where the figures remain unchanged. A decrease in the total stock of sailing boats (<26 ft.) by 21 % and increases in the total stock of yawls/cabin boats and other boats (<20 ft.) by around 25 % are expected. Due to a lack of information specific to Denmark, the shifting rate from 2-stroke to 4-stroke gasoline engines is based on a German non-road study (IFEU, 2004).

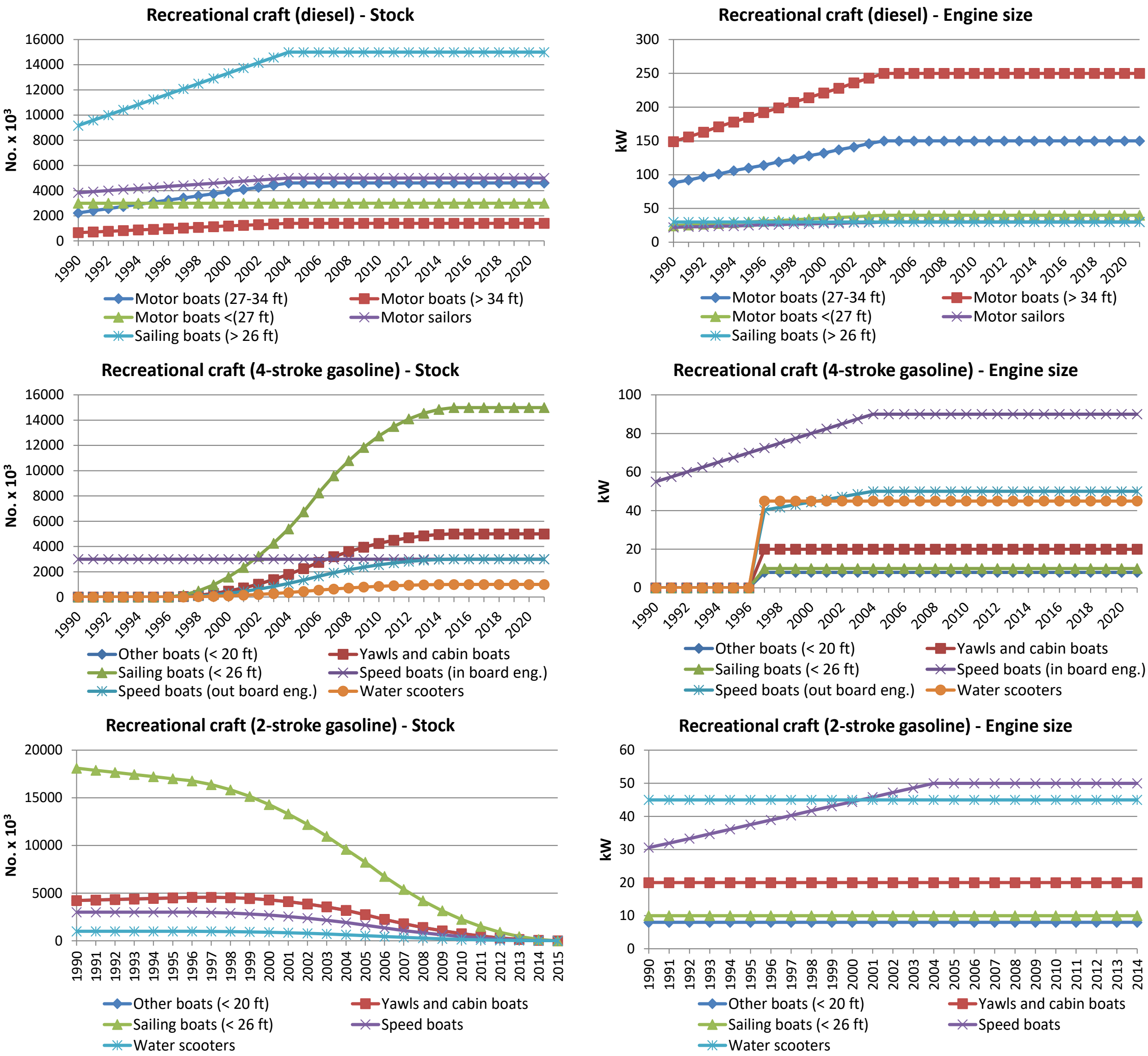

Figure 3.3.40 1990-2021 Stock and engine size development for recreational craft.

National Navigation

National navigation include the activities made by domestic ferries, fuel sold in Denmark and used for freight transport between Denmark and Greenland or the Faroe Island, and fuel used for the remaining part of the traffic between two Danish ports.

Table 3.3.8 lists the most important domestic ferry routes (regional ferries) in Denmark in the period 1990-2021. For these ferry routes and the years 1990-2005, the following detailed traffic and technical data have been gathered by Winther (2008): Ferry name, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size, share of annual trips and sailing time (single trip).

For 2006-2021, the above mentioned traffic and technical data for specific ferries have been provided by Nielsen (2022) in the case of Mols-Linien (Sjællands Odde-Ebeltoft, Sjællands Odde-Århus, Kalundborg-Århus, Køge-Rønne, Tårs-Spodsbjerg), by Jørgensen (2017) for Færgen A/S (Køge-Rønne, Tårs-Spodsbjerg, Kalundborg-Samsø), by Kruse (2015) for Samsø Rederi (Hou-Sælvig), by Mortensen (2015) for Færgeselskabet Læsø (Frederikshavn-Læsø) and by Eriksen (2017) for Ærøfærgerne (Svendborg-Ærøskøbing). For

Esbjerg/Hanstholm/Hirtshals-Torshavn traffic and technical data have been provided by Dávastovu (2010).

Table 3.3.8 Regional ferry routes comprised in the Danish inventory.

Ferry service	Service period
Esbjerg-Torshavn	1990-1995, 2009+
Halsskov-Knudshoved	1990-1999
Hanstholm-Torshavn	1991-1992, 1999+
Hirtshals-Torshavn	2010
Hou-Sælvig	1990+
Hundested-Grenaa	1990-1996
Frederikshavn-Læsø	1990+
Kalundborg-Juelsminde	1990-1996
Kalundborg-Samsø	1990+
Kalundborg-Århus	1990+
Korsør-Nyborg, DSB	1990-1997
Korsør-Nyborg, Vognmandsruten	1990-1999
København-Rønne	1990-2004
Køge-Rønne	2004+
Sjællands Odde-Ebeltoft	1990+
Sjællands Odde-Århus	1999+
Svendborg-Ærøskøbing	1990+
Tårs-Spodsbjerg	1990+

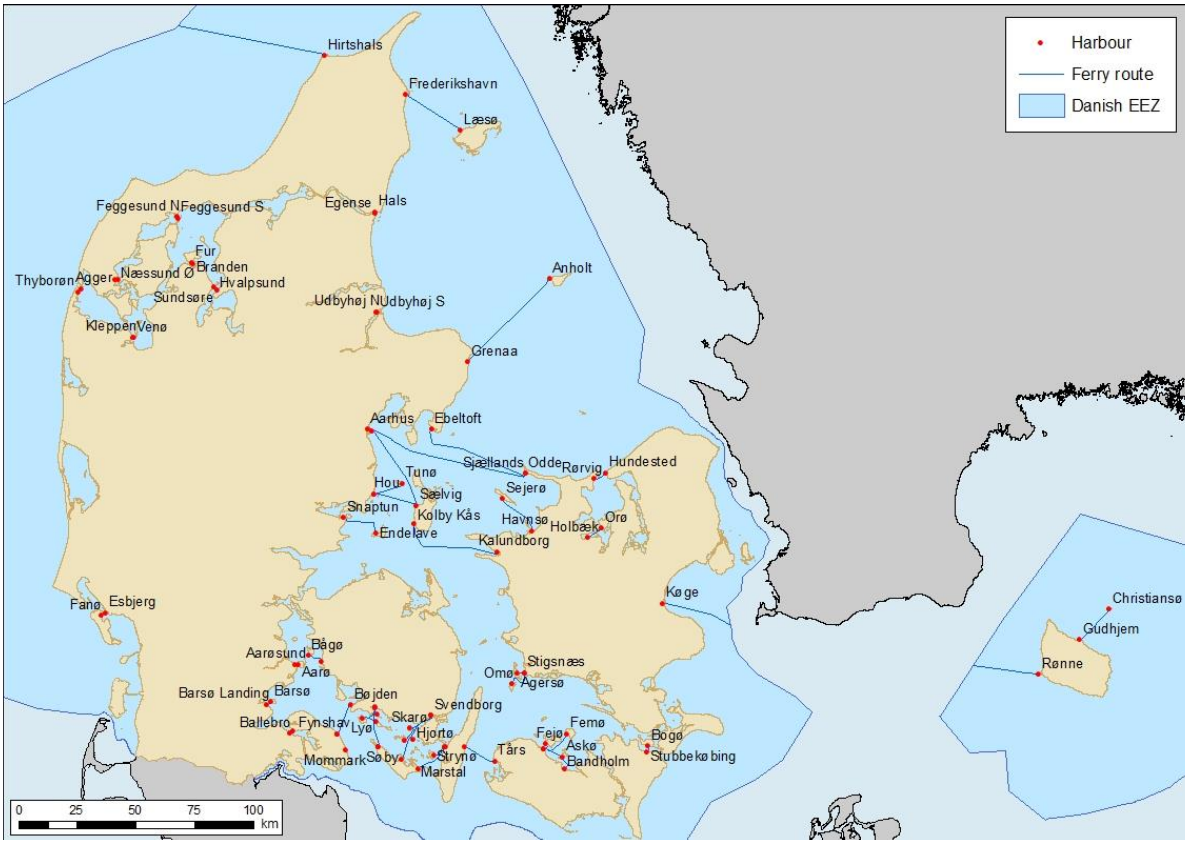

Figure 3.3.41 Ferry routes in Denmark (2021).

Table 3.3.9 lists the small ferry routes (island and short cut ferries) included in the Danish inventory for the period 1990-2020. For these ferry routes and the years 1990-2020, the following detailed traffic and technical data have been gathered by Rasmussen (2017) and Andersen (2019): Ferry name, engine size (MCR), engine year, share of annual trips and sailing time (single trip). Supplementary data for engine type, fuel type and average load factor is provided by Kristensen (2017).

Table 3.3.9 Small ferry routes comprised in the Danish inventory.

Ferry service	Service period
Assens-Baagø	1990+
Ballebro-Hardeshøj	1990+
Bandholm-Askø	1990+
Barsø Landing-Barsø	2018+
Branden-Fur	1990+
Bøjden-Fynshav	1990+
Esbjerg-Fanø	1990+
Feggesund overfart	1990+
Fejø-Kragenæs	1990+
Femø-Kragenæs	1990+
Frederikssund-Roskilde	1999-2000
Fåborg-Avernakø-Lyø	1990+
Fåborg-Søby	1990+
Grenaa-Anholt	1990+
Gudhjem-Christiansø	2015+
Hals-Egense	1994+
Havnsø-Sejerø	1990+
Holbæk-Orø	1990+
Horsens-Endelave	1990+
Hov-Tunø	1990+
Hundested-Rørvig	1990+
Hvalpsund-Sundsøre	1990+
Kastrup-Rønne	1990
Kleppen-Venø	1990+
Korsør-Lohals	1990+
Kragenæs-Askø	2020+
København-Århus	1992-1993
Næssund overfart	1990+
Rudkøbing-Marstal	-2013
Rudkøbing-Strynø	1990+
Stigsnæs-Agersø	1990+
Stigsnæs-Omø	1990+
Stubbekøbing-Bogø	1990+
Svendborg-Skarø-Drejø	1990+
Sælvig-Aarhus	2021+
Søby-Fynshav	2009+
Søby-Mommark	-2009
Thyborøn-Agger	1990+
Udbyhøj Nord - Udbyhøj Syd	2017+
Aarø-Aarøsund	1990+

The number of round trips per ferry route from 1990 to 2021 is provided by Statistics Denmark (2022). Figure 3.3.41 show all ferry routes in use in 2021 (Esbjerg/Hanstholm/Hirtshals-Torshavn not shown).

For all ferry routes, detailed data in terms of ferry name, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size, number of trips and sailing time (single trip) is shown in Annex 3.B.12 for the years 1985-2021. There is a lack of historical traffic data for 1985-1989, and hence, data for 1990 are used for these years, to support the fuel consumption and emission calculations.

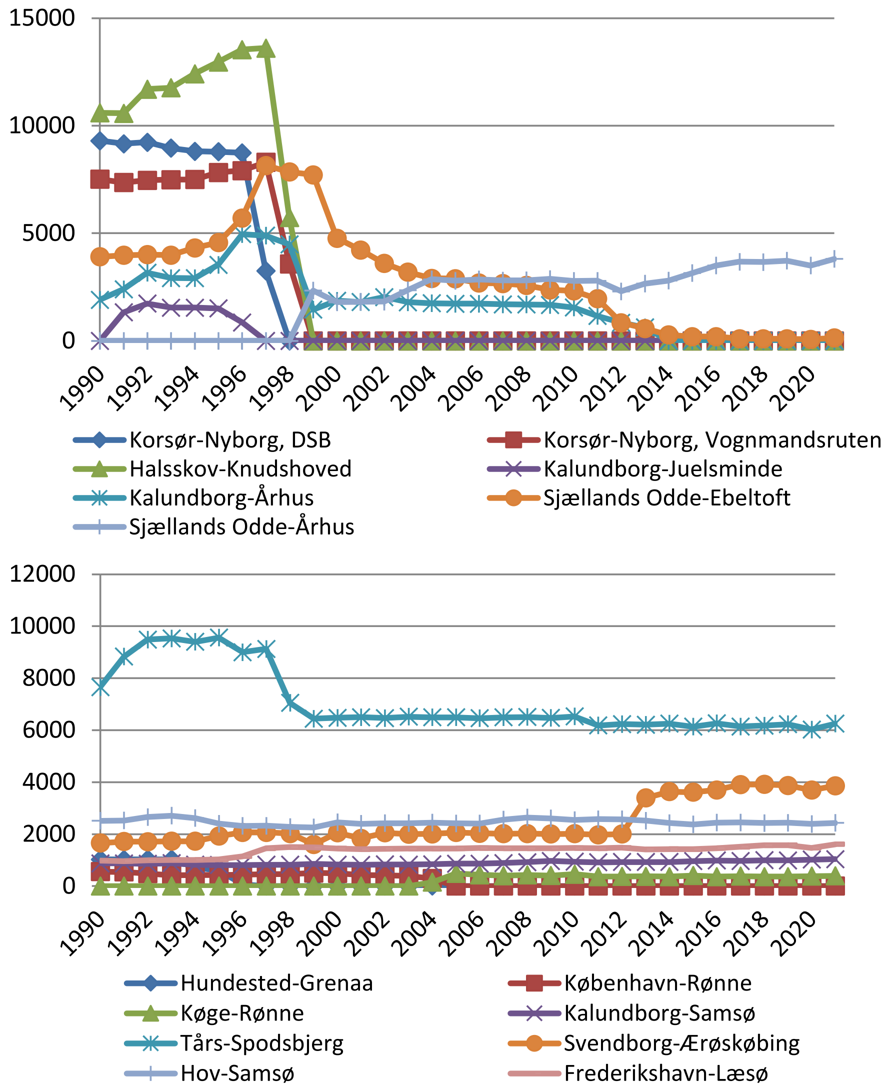

Figure 3.3.42 No. of round trips for the most important ferry routes in Denmark 1990-2021.

It is seen from Table 3.3.8 (and Figure 3.3.42) that several ferry routes were closed in the time period from 1996-1998, mainly due to the opening of the Great Belt Bridge (connecting Zealand and Funen) in 1997. Hundested-Grenaa and Kalundborg-Juelsminde was closed in 1996, Korsør-Nyborg (DSB) closed in 1997, and Halsskov-Knudshoved and Korsør-Nyborg (Vognmandsruten) was closed in 1998. The ferry line København-Rønne was replaced by Køge-Rønne in 2004 and from 1999, a new ferry connection was opened between Sjællands Odde and Århus.

The fuel sold for freight transport by Royal Arctic Line between Aalborg (Denmark) and Greenland is included under other national sea transport in the Danish inventories. In this case all fuel is being bought in Denmark (Rasmussen, 2022). The fuel used by freight transport between Denmark and the Faroe Islands (Eimskip) is bought outside Denmark (Helgason, 2022). Hence, this fuel consumption is not included in the Danish inventories at all.

Fuel used for the remaining part of the traffic between two Danish ports, other national sea transport, is taken as the difference between 1) DEA national fuel sales for national sea transport minus fuel consumption at Danish off shore installations (off shore reduced fuel sales[14]) and 2) the bottom-up calculated fuel consumption for Danish ferries.

For years when the fuel estimates for ferries (not including the ferry to the Faroe Islands) are higher than the "off shore reduced" fuel sold for national sea transport, fuel is taken from fisheries in the case of marine diesel (1985-1999). For heavy fuel oil, the missing fuel amount is taken from stationary sources (1985-1986, 1988, 1994-1996) and international sea transport (2015 onwards).

The LNG fuel calculated for Danish ferries is slightly higher than the LNG fuel sales for national navigation reported in the DEA fuel statistics. Subsequently, an inventory fuel balance is made to account for the total LNG fuel sold reported in the DEA fuel statistics.

National Fishing

For fishing vessels, electronic log data for 1985-2020 are provided by the Danish Fisheries Agency (Hernov, 2021) and for 2021 by Aarhus University (Andersen, 2022) for each fishing trip made by Danish registered fishing vessels.

The log data register the following: Vessel registration number, build year, type, overall length (OAL), brutto tonnes (BT), total installed engine power (kW) and hours at sea.

Average engine load factors (%) are taken from Winther and Martinsen (2020) based on data provided by Hanstholm Fisheries Association (Amdissen, 2020).

Figure 3.3.43 show hours at sea for the Danish fishing vessels split into OAL classes for the years 1990-2021.

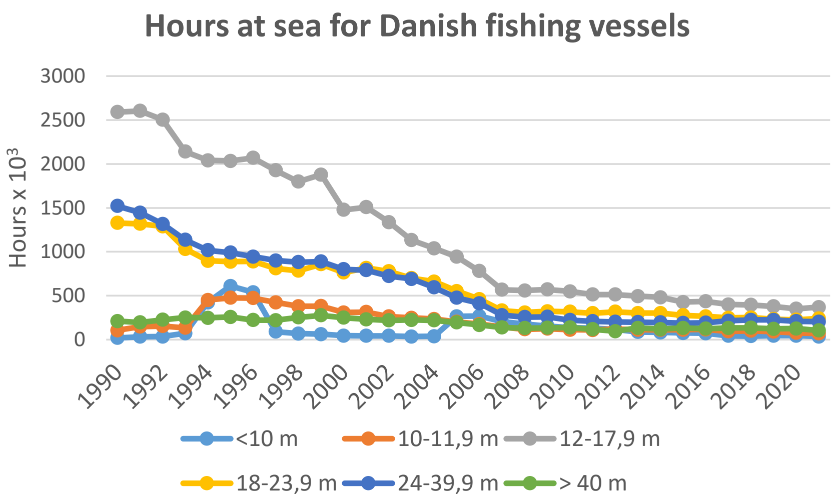

Figure 3.3.43 Total hours at sea for Danish fishing vessels 1990-2021.

For Danish fishing vessels, data for total hours at sea and engine loads (%) are shown in Annex 3.B.12 split into OAL classes for the years 1985-2021.

[14] According to the Danish Energy Authority, the latter diesel fuel sales are reported as sold for national navigation by the fuel sales reporting oil companies.

Railways

The activity data for railways used in the DEMOS-Rail model consists of the total energy use for Danish railways activities from 1985-2021 provided by DEA (2022a), train km statistics for private railway lines provided by Danish Civil Aviation and Railway Authority (Schelde, 2022), and detailed train specific data provided by the private railway companies.

For several private railway companies the following data has been collected for each railway line operated by the companies: Litra type, Litra new sales year, Euro emission level, fuel type, fuel consumption factors, number of seats/standing rooms, and percentage distribution of annual Litra km driven per Litra type (Hjortsø, 2022; Hansen, 2022; Jensen, 2022b). For railway lines not able to provide data, and for the earliest years in the time series in general, supplementary data has been gathered from relevant web pages (e.g. www.jernbanen.dk).

The railway activities by other companies than private railway companies is predominantly made by Danish State Railways. The fuel consumption for these latter railway activities are calculated in DEMOS-Rail as the difference between DEA national fuel sales for railways and the bottom-up calculated fuel consumption for private railway companies.

Military

The activity data for military activities consists of fuel consumption information from DEA (2022a).

International navigation

For international sea transport (international navigation), the fuel basis is in principle fuel sold in Danish ports for vessels with a foreign destination (i.e. outside the Kingdom of Denmark), as prescribed by the IPCC guidelines. However, it must be noted that fuel sold for sailing activities between Denmark and Greenland/Faroe Islands are reported as international in the DEA energy statistics. Hence, for inventory purposes in order to follow the IPCC guidelines, the fuel estimated for the ferry routes Esbjerg/Hanstholm/Hirtshals-Torshavn, and fuel bought by Royal Arctic Line is transferred from international sea transport to national sea transport in fuel sales, prior to inventory fuel input.

For all sectors, fuel consumption figures are given in Annex 3.B.15 for the years 1990 and 2021 in CollectER format, and fuel consumption time series are given in Annex 3.B.16 in NFR format.

Emission legislation

For other mobile sources, the engines have to comply with the emission legislation limits agreed by the EU and different UN organisations in terms of NO_x, CO, VOC and TSP emissions and fuel sulphur content. In terms of greenhouse gases, the emission legislation requirements for VOC influence the emissions of CH_4, the latter emission component forming a part of total VOC. Only for ships, legislative limits for specific fuel consumption have been internationally agreed in order to reduce the emissions of CO_2.

For non-road mobile machinery, recreational craft and railway locomotives/motor cars, the emission directives list specific emission limit values (g per kWh) for CO, VOC, NO_x (or VOC + NO_x) and TSP, depending on engine size (kW for diesel, ccm for gasoline) and date of implementation (referring to engine market date).

For diesel, the directives 97/68 and 2004/26 (Table 3.3.10) relate to Stage I-IV non-road mobile machinery other than agricultural and forestry tractors and the directives have different implementation dates for machinery operating under transient and constant loads. The latter directive also comprises emission limits for Stage IIIA and IIIB railways machinery (Table 3.3.14). For Stage I-IV tractors the relevant directives are 2000/25 and 2005/13 (Table 3.3.10).

For emission approval of the EU Stage I, II and IIIA engine technologies, emissions (and fuel consumption) measurements are made using the steady state test cycle ISO 8178 C1, referred to as the Non-Road Steady Cycle (NRSC), see e.g. www.dieselnet.com. In addition to the NRSC test, the newer Stage IIIB and IV (and optionally Stage IIIA) engine technologies are tested under more realistic operational conditions using the new Non-Road Transient Cycle (NRTC).

For gasoline non road mobile machinery, the directive 2002/88 distinguishes between Stage I and II hand-held (SH) and not hand-held (NS) types of machinery (Table 3.3.11). Emissions are tested using one of the specific constant load ISO 8178 test cycles (D2, G1, G2, G3) depending on the type of machinery.

For Stage V non road mobile machinery, EU directive 2016/1628 relate to diesel non-road mobile machinery other than agricultural tractors and railways machinery (Table 3.3.10) and gasoline non-road mobile machinery (Table 3.3.11). EU directive 167/2013 relate to Stage V agricultural and forestry tractors (Table 3.3.10). The Stage V emission limits are also shown in Annex 3.B.11.

Table 3.3.10 Overview of EU emission directives relevant for diesel fuelled non-road mobile machinery.

Stage	Engine size	CO	VOC	NO_x	$VOC+NO_x$	PM	Diesel machinery			Diesel Tractors	
								Implement. date		EU	Implement.
	[kW]	[g/kWh]					EU Directive	Transient	Constant	Directive	Date
Stage I											
A	130<=P<560	5	1.3	9.2	-	0.54	97/68	1/1 1999	-	2000/25	1/7 2001
B	75<=P<130	5	1.3	9.2	-	0.7		1/1 1999	-		1/7 2001
C	37<=P<75	6.5	1.3	9.2	-	0.85		1/4 1999	-		1/7 2001
Stage II											
E	130<=P<560	3.5	1	6	-	0.2	97/68	1/1 2002	1/1 2007	2000/25	1/7 2002
F	75<=P<130	5	1	6	-	0.3		1/1 2003	1/1 2007		1/7 2003
G	37<=P<75	5	1.3	7	-	0.4		1/1 2004	1/1 2007		1/1 2004
D	18<=P<37	5.5	1.5	8	-	0.8		1/1 2001	1/1 2007		1/1 2002
Stage IIIA											
H	130<=P<560	3.5	-	-	4	0.2	2004/26	1/1 2006	1/1 2011	2005/13	1/1 2006
I	75<=P<130	5	-	-	4	0.3		1/1 2007	1/1 2011		1/1 2007
J	37<=P<75	5	-	-	4.7	0.4		1/1 2008	1/1 2012		1/1 2008
K	19<=P<37	5.5	-	-	7.5	0.6		1/1 2007	1/1 2011		1/1 2007
Stage IIIB											
L	130<=P<560	3.5	0.19	2	-	0.025	2004/26	1/1 2011	-	2005/13	1/1 2011
M	75<=P<130	5	0.19	3.3	-	0.025		1/1 2012	-		1/1 2012
N	56<=P<75	5	0.19	3.3	-	0.025		1/1 2012	-		1/1 2012
P	37<=P<56	5	-	-	4.7	0.025		1/1 2013	-		1/1 2013
Stage IV											
Q	130<=P<560	3.5	0.19	0.4	-	0.025	2004/26	1/1 2014	1/1 2014	2005/13	1/1 2014
R	56<=P<130	5	0.19	0.4	-	0.025		1/10 2014	1/10 2014		1/10 2014
Stage V[A]											
NRE-v/c-7	P>560	3.5	0.19	3.5		0.045	2016/1628		2019	167/2013[B]	2019
NRE-v/c-6	130≤P≤560	3.5	0.19	0.4		0.015			2019		2019
NRE-v/c-5	56≤P<130	5.0	0.19	0.4		0.015			2020		2020
NRE-v/c-4	37≤P<56	5.0			4.7	0.015			2019		2019
NRE-v/c-3	19≤P<37	5.0			4.7	0.015			2019		2019
NRE-v/c-2	8≤P<19	6.6			7.5	0.4			2019		2019
NRE-v/c-1	P<8	8.0			7.5	0.4			2019		2019
Generators	P>560	0.67	0.19	3.5		0.035			2019		2019

A = For selected machinery types, Stage V includes emission limit values for particle number.

B = Article 63 in 2016/1628 revise Article 19 in 167/2013 to include Stage V limits as described in 2016/1628.

Table 3.3.11 Overview of the EU Emission Directives relevant for gasoline fuelled non-road mobile machinery.

	Category	Engine size [ccm]	CO [g pr kWh]	HC [g pr kWh]	NO_X [g pr kWh]	$HC+NO_X$ [g pr kWh]	Implement. date
EU Directive 2002/88	Stage I						
Hand held	SH1	S<20	805	295	5.36	-	1/2 2005
	SH2	20≤S<50	805	241	5.36	-	1/2 2005
	SH3	50≤S	603	161	5.36	-	1/2 2005
Not hand held	SN3	100≤S<225	519	-	-	16.1	1/2 2005
	SN4	225≤S	519	-	-	13.4	1/2 2005
	Stage II						
Hand held	SH1	S<20	805	-	-	50	1/2 2008
	SH2	20≤S<50	805	-	-	50	1/2 2008
	SH3	50≤S	603	-	-	72	1/2 2009
Not hand held	SN1	S<66	610	-	-	50	1/2 2005
	SN2	66≤S<100	610	-	-	40	1/2 2005
	SN3	100≤S<225	610	-	-	16.1	1/2 2008
	SN4	225≤S	610	-	-	12.1	1/2 2007
EU Directive 2016/1628	Stage V						
Hand held (<19 kW)	NRSh-v-1a	S<50	805	-	-	50	2019
	NRSh-v-1b	50≤S	805	-	-	72	2019
Not hand held (P<19 kW)	NRS-vr/vi-1a	80≤S<225	610	-	-	10	2019
	NRS-vr/vi-1b	S≥225	610	-	-	8	2019
Not hand held (19=<P<30 kW)	NRS-v-2a	S≤1000	610	-	-	8	2019
	NRS-v-2b	S>1000	4.40*	-	-	2.70*	2019
Not hand held (30=<P<56 kW)	NRS-v-3	any	4.40*	-	-	2.70*	2019

* Or any combination of values satisfying the equation $(HC+NO_x) \times CO^{0.784} \leq 8.57$ and the conditions CO ≤ 20.6 g/kWh and $(HC+NO_x) \leq 2.7$ g/kWh.

For recreational craft, Directive 2003/44 comprises the Stage 1 emission legislation limits for diesel engines, and for 2-stroke and 4-stroke gasoline engines, respectively. The CO and VOC emission limits depend on engine size (kW) and the inserted parameters presented in the calculation formulas in Table 3.3.12. For NO_X, a constant limit value is given for each of the three engine types. For TSP, the constant emission limit regards diesel engines only.

In Table 3.3.13, the Stage II emission limits are shown for recreational craft. CO and $HC+NO_x$ limits are provided for gasoline engines depending on the rated engine power and the engine type (stern-drive vs. outboard) while CO, $HC+NO_x$, and particulate emission limits are defined for compression ignition (CI) engines depending on the rated engine power and the swept volume.

Table 3.3.12 Overview of the EU Emission Directive 2003/44 for recreational craft.

Engine type	Impl. date	$CO=A+B/P^n$			$HC=A+B/P^n$			NO_X	TSP
		A	B	n	A	B	n		
2-stroke gasoline	1/1 2007	150.0	600.0	1.0	30.0	100.0	0.75	10.0	-
4-stroke gasoline	1/1 2006	150.0	600.0	1.0	6.0	50.0	0.75	15.0	-
Diesel	1/1 2006	5.0	0.0	0	1.5	2.0	0.5	9.8	1.0

Table 3.3.13 Overview of the EU Emission Directive 2013/53 for recreational craft.

Diesel engines					
Swept Volume, SV l/cyl.	Rated Engine Power, P_N kW	Impl. Date	CO g/kWh	HC + NO_x g/kWh	PM g/kWh
SV < 0.9	P_N < 37				
	37 <= P_N < 75 (*)	18/1 2017	5	4.7	0.30
	75 <= P_N < 3 700	18/1 2017	5	5.8	0.15
0.9 <= SV < 1.2	P_N < 3 700	18/1 2017	5	5.8	0.14
1.2 <= SV < 2.5		18/1 2017	5	5.8	0.12
2.5 <= SV < 3.5		18/1 2017	5	5.8	0.12
3.5 <= SV < 7.0		18/1 2017	5	5.8	0.11
Gasoline engines					
Engine type	Rated Engine Power, P_N kW		CO g/kWh	HC + NO_x g/kWh	PM g/kWh
Stern-drive and inboard engines	P_N <= 373	18/1 2017	75	5	-
	373 <= P_N <= 485	18/1 2017	350	16	-
	P_N > 485	18/1 2017	350	22	-
Outboard engines and PWC engines (**)	P_N <= 4.3	18/1 2017	500 – (5.0 x P_N)	15.7 + (50/$PN^{0.9}$)	-
	4.3 <= P_N <= 40	18/1 2017	500 – (5.0 x P_N)	15.7 + (50/$PN^{0.9}$)	-
	P_N > 40	18/1 2017	300		-

(*) Alternatively, this engine segment shall not exceed a PM limit of 0.2 g/kWh and a combined HC + NO_x limit of 5.8 g/kWh.
(**) Small and medium size manufacturers making outboard engines <= 15 kW have until 18/1 2020 to comply.

Table 3.3.14 Overview of the EU Emission Directives relevant for railway locomotives and motorcars.

				CO	HC	NO_x	HC+NO_x	PM	
	EU directive	Engine size [kW]		g/kWh					Imp. date
Locomotives	2004/26	Stage IIIA							
		130<=P<560	RL A	3.5	-	-	4	0.2	1/1 2007
		560<P	RH A	3.5	0.5	6	-	0.2	1/1 2009
		2000<=P and piston displacement >= 5 l/cyl.	RH A	3.5	0.4	7.4	-	0.2	1/1 2009
	2004/26	Stage IIIB	RB	3.5	-	-	4	0.025	1/1 2012
	2016/1628	Stage V							
		0<P	RLL-v/c-1	3.5	-	-	4	0.025	2021
Motor cars	2004/26	Stage IIIA							
		130<P	RC A	3.5	-	-	4	0.2	1/1 2006
	2004/26	Stage IIIB							
		130<P	RC B	3.5	0.19	2	-	0.025	1/1 2012
	2016/1628	Stage V							
		0<P	RLR-v/c-1	3.5	0.19	2	-	0.015	2021

Aircraft engine emissions of NO_x, CO, VOC and smoke are regulated by ICAO (International Civil Aviation Organization). The engine emission certification standards are contained in Annex 16 — Environmental Protection, Volume II — to the Convention on International Civil Aviation (ICAO Annex 16, 2008, plus amendments). The emission standards relate to the total emissions (in grams) from the so-called LTO (Landing and Take Off) cycle divided by the rated engine thrust (kN). The ICAO LTO cycle contains the idealised aircraft movements below 3000 ft (915 m) during approach, landing, airport taxiing, take off and climb out.

For smoke, all aircraft engines manufactured from 1 January 1983 have to meet the emission limits agreed by ICAO. For NO_x, CO, VOC The emission legislation is relevant for aircraft engines with a rated engine thrust larger than 26.7 kN. In the case of CO and VOC, the ICAO regulations apply for engines manufactured from 1 January 1983.

For NO_x, the emission regulations fall in five categories

- For engines of a type or model for which the date of manufacture of the first individual production model was before 1 January 1996, and for which the production date of the individual engine was before 1 January 2000.
- For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 1996, or for individual engines with a production date on or after 1 January 2000.
- For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 2004.
- For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 2008, or for individual engines with a production date on or after 1 January 2013.
- For engines of a type or model for which the date of manufacture of the first individual production model is on or after 1 January 2014.

The regulations published by ICAO are given in the form of the total quantity of pollutants (D_p) emitted in the LTO cycle divided by the maximum sea level thrust (F_{oo}) and plotted against engine pressure ratio at maximum sea level thrust.

The limit values for NO_x are given by the formulae in Table 3.3.15.

Table 3.3.15 Current certification limits for NO_x for turbo jet and turbo fan engines.

	Engines first produced before 1.1.1996 & for engines manufactured before 1.1.2000	Engines first produced on or after 1.1.1996 & for engines manufactured on or after 1.1.2000	Engines for which the date of manufacture of the first individual production model was on or after 1 January 2004	Engines first produced on or after 1.1.2047 & for engines manufactured on or after 1.1.2013	Engines for which the date of manufacture of the first individual production model was on or after 1.1.2014
Applies to engines >26.7 kN	$Dp/F_{oo} = 40 + 2\pi_{oo}$	$Dp/F_{oo} = 32 + 1.6\pi_{oo}$			
Engines of pressure ratio less than 30					
Thrust more than 89 kN			$Dp/F_{oo} = 19 + 1.6\pi_{oo}$	$Dp/F_{oo} = 16.72 + 1.4080\pi_{oo}$	$7.88 + 1.4080\pi_{oo}$
Thrust between 26.7 kN and not more than 89 kN			$Dp/F_{oo} = 37.572 + 1.6\pi_{oo} - 0.208F_{oo}$	$Dp/F_{oo} = 38.54862 + (1.6823\pi_{oo}) – (0.2453F_{oo}) – (0.00308\pi_{oo}F_{oo})$	$Dp/F_{oo} = 40.052 + 1.5681\pi_{oo} - 0.3615F_{oo} - 0.0018 \pi_{oo} \times F_{oo}$
Engines of pressure ratio more than 30 and less than 62.5 (104.7)					
Thrust more than 89 kN			$Dp/F_{oo} = 7+2.0\pi_{oo}$	$Dp/F_{oo} = -1.04+ (2.0*\pi_{oo})$	
Thrust between 26.7 kN and not more than 89 kN			$Dp/F_{oo} = 42.71 +1.4286\pi_{oo} - 0.4013F_{oo} +0.00642\pi_{oo}F_{oo}$	$Dp/F_{oo} = 46.1600 + (1.4286\pi_{oo}) – (0.5303F_{oo}) – (0.00642\pi_{oo}F_{oo})$	
Engines with pressure ratio 62.5 or more					
Engines with pressure ratio 82.6 or more			$Dp/F_{oo} = 32+1.6\pi_{oo}$	$Dp/F_{oo} = 32+1.6\pi_{oo}$	
Engines of pressure ratio more than 30 and less than (104.7)					
Thrust more than 89 kN					$Dp/F_{oo} = -9.88 + 2.0\pi_{oo}$
Thrust between 26.7 kN and not more than 89 kN					$Dp/F_{oo} = 41.9435 + 1.505\pi_{oo} - 0.5823F_{oo} + 0.005562\pi_{oo} \times F_{oo}$
Engines with pressure ratio 104.7 or more					$Dp/F_{oo} = 32 + 1.6\pi_{oo}$

Source: International Standards and Recommended Practices, Environmental Protection, ICAO Annex 16 Volume II 3rd edition July 2008, plus amendments: Amendment 7 (17 November 2011), Amendment 8 (July 2014),
where:
D_p = the sum of emissions in the LTO cycle in g.
F_{oo} = thrust at sea level take-off (100 %).
π_{oo} = pressure ratio at sea level take-off thrust point (100 %).

The equivalent limits for HC and CO are D_p/F_{oo} = 19.6 for HC and D_p/F_{oo} = 118 for CO (ICAO Annex 16 Vol. II paragraph 2.2.2). Smoke is limited to a regulatory smoke number = 83 $(F_{oo})^{-0.274}$ or a value of 50, whichever is the lower.

A further description of the technical definitions in relation to engine certification as well as actual engine exhaust emission measurement data can be found in the ICAO Engine Exhaust Emission Database. The latter database is accessible from “www.easa.europa.eu/domains/environment/icao-aircraft-engine-emissions-databank” hosted by the European Aviation Safety Agency (EASA).

On 8 February 2016, at the tenth meeting of the International Civil Aviation Organization (ICAO) Committee for Environmental Protection (CAEP) a performance standard was agreed for new aircraft that will mandate improvements in fuel efficiency and reductions in carbon dioxide (CO_2) emissions. The standards will on average require a 4 % reduction in the cruise fuel consumption of new aircraft starting in 2028 compared to 2015 deliveries, with the actual reductions ranging from 0 to 11 %, depending on the maximum takeoff mass (MTOM) of the aircraft (ICCT, 2017).

The CO_2 certification standards are contained in a new Volume III - CO_2 Certification Requirement - to Annex 16 of the Convention on civil aviation (ICAO, 2017).

Embedded applicability dates are:

- **Subsonic jet aeroplanes**, including their derived versions, of greater than 5 700 kg maximum take-off mass for which the application for a type certificate was submitted on or after 1 January 2020, except for those aeroplanes of less than or equal to 60 000 kg maximum take-off mass with a maximum passenger seating capacity of 19 seats or less;
- **Subsonic jet aeroplanes**, including their derived versions, of greater than 5 700 kg and less than or equal to 60 000 kg maximum take-off mass with a maximum passenger seating capacity of 19 seats or less, for which the application for a type certificate was submitted on or after 1 January 2023;
- **All propeller-driven aeroplanes**, including their derived versions, of greater than 8 618 kg maximum take-off mass, for which the application for a type certificate was submitted on or after 1 January 2020;
- **Derived versions of non-CO_2-certified subsonic jet aeroplanes** of greater than 5 700 kg maximum certificated take-off mass for which the application for certification of the change in type design was submitted on or after 1 January 2023;
- **Derived versions of non-CO_2 certified propeller-driven aeroplanes** of greater than 8 618 kg maximum certificated take-off mass for which the application for certification of the change in type design was submitted on or after 1 January 2023;
- **Individual non-CO_2-certified subsonic jet aeroplanes** of greater than 5 700 kg maximum certificated take-off mass for which a certificate of airworthiness was first issued on or after 1 January 2028; and
- **Individual non-CO_2-certified propeller-driven aeroplanes** of greater than 8 618 kg maximum certificated take-off mass for which a certificate of airworthiness was first issued on or after 1 January 2028.

Marpol 73/78 Annex VI agreed by IMO (International Maritime Organisation) concerns the control of NO_x emissions (Regulation 13 plus amendments) and SO_x and particulate emissions (Regulation 14 plus amendments) from ships (DNV, 2009). Recently the so called Energy Efficiency Design Index (EEDI) fuel efficiency regulations for new built ships was included in Chapter 4 of Annex VI in the Marpol convention for the purpose of controlling the CO_2 emissions from ships (Lloyd's Register, 2012).

The baseline NO_x emission regulation of Annex VI apply for diesel engines with a power output higher than 130 kW, which are installed on a ship constructed on or after 1 January 2000 and diesel engines with a power output higher than 130 kW which undergo major conversion on or after 1 January 2000.

The baseline NO_x emission limits for ship engines in relation to their rated engine speed (n) given in RPM (Revolutions Per Minute) are the following:

- 17 g pr kWh, $n < 130$ RPM
- 45 x n-0.2 g pr kWh, $130 \leq n < 2000$ RPM
- 9.8 g pr kWh, $n \geq 2000$ RPM

The further amendment of Annex VI Regulation 13 contains a three tiered approach in order to strengthen the emission standards for NO_x. The three tier approach comprises the following:

- Tier I: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2000 and prior to 1 January 2011 (initial regulation).
- Tier II: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2011.
- Tier III[15]: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2016 operating in the North American ECA or the United States Caribbean Sea ECA and diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2021 operating in the Baltic Sea and North Sea ECA.

The three tier NO_x emission limit functions are shown in Table 3.3.16.

Table 3.3.16 Tier I-III NO_x emission limits for ship engines in MARPOL Annex VI.

	NO_x limit	RPM (n)
Tier I	17 g pr kWh	n < 130
	45 · n-0.2 g pr kWh	130 ≤ n < 2000
	9,8 g pr kWh	n ≥ 2000
Tier II	14.4 g pr kWh	n < 130
	44 · n-0.23 g pr kWh	130 ≤ n < 2000
	7.7 g pr kWh	n ≥ 2000
Tier III	3.4 g pr kWh	n < 130
	9 · n-0.2 g pr kWh	130 ≤ n < 2000
	2 g pr kWh	n ≥ 2000

Further, the NO_x Tier I limits are to be applied for existing engines with a power output higher than 5000 kW and a displacement per cylinder at or above 90 litres, installed on a ship constructed on or after 1 January 1990 but prior to 1 January 2000.

In relation to the sulphur content in heavy fuel and marine gas oil used by ship engines, Table 3.3.17 shows the EU and IMO (Regulation 14 plus amendments) legislation in force for SECA (Sulphur Emission Control Area) areas and outside SECA's.

Table 3.3.17 Current legislation in relation to marine fuel quality.

Legislation	Marine area	Heavy fuel oil		Gas oil	
		S- %	Implement. date	S- %	Implement. date
EU-directive 93/12		None		0.2[1]	01.10.1994
EU-directive 1999/32		None		0.2	01.01.2000
EU-directive 2005/33[2]	SECA - Baltic sea	1.5	11.08.2006	0.1	01.01.2008
	SECA - North sea	1.5	11.08.2007	0.1	01.01.2008
	Outside SECA's	None		0.1	01.01.2008
MARPOL Annex VI	SECA – Baltic sea	1.5	19.05.2006		
	SECA – North sea	1.5	21.11.2007		
	Outside SECA	4.5	19.05.2006		
MARPOL Annex VI amendments	SECA's	1	01.03.2010		
	SECA's	0.1	01.01.2015		
	Outside SECA's	3.5	01.01.2012		
	Outside SECA's	0.5	01.01.2020		

[1] Sulphur content limit for fuel sold inside EU.
[2] From 1.1.2010 fuel with a sulphur content higher than 0.1 % must not be used in EU ports for ships at berth exceeding two hours.

[15] For ships operating in a designated Emission Control Area. Outside a designated Emission Control Area, Tier II limits apply.

In Marpol 83/78 Annex VI (Chapter 4), the EEDI fuel efficiency regulations are mandatory from 1st January 2013 for new built ships larger than 400 GT.

EEDI is a design index value that expresses how much CO_2 is produced per work done (g CO_2 per tonnes.nm[16]). At present, the IMO EEDI scheme comprises the following ship types; bulk carriers, gas carriers, tankers, container ships, general cargo ships, refrigerated and combination cargo carriers.

The EEDI percentage reductions that need to be achieved for new built ships relative to existing ships, are shown in Table 5.11 stratified according to ship type and dead weight tonnes (DWT) in the temporal phases (new built year in brackets); 0 (2013-14), 1 (2015-19), 2 (2020-24) and 3 (2025+).

Table 3.3.18 EEDI percentage reductions for new built ships relative to existing ships.

Ship type	Size	Phase 0 1-Jan-2013 to 31-Dec-2014	Phase 1 1-Jan-2015 to 31-Dec-2019	Phase 2 1-Jan-2020 to 31-Dec-2024	Phase 3 1-Jan-2025 onwards
Bulk carrier	20,000 DWT and above	0	10	20	30
	10,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
Gas carrier	10,000 DWT and above	0	10	20	30
	2,000 – 10,000 DWT	n/a	0-10*	0-20*	0-30*
Tanker	20,000 DWT and above	0	10	20	30
	4,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
Container ship	15,000 DWT and above	0	10	20	30
	10,000 – 15,000 DWT	n/a	0-10*	0-20*	0-30*
General cargo ship	15,000 DWT and above	0	10	15	30
	3,000 – 15,000 DWT	n/a	0-10*	0-15*	0-30*
Refrigerated cargo carrier	5,000 DWT and above	0	10	15	30
	3,000 – 5,000 DWT	n/a	0-10*	0-15*	0-30*
Combination carrier	20,000 DWT and above	0	10	20	30
	4,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*

It is envisaged that also Ro-ro cargo, ro-ro passenger and cruise passenger ships will be included in the EEDI scheme in the near future.

For non-road machinery, the EU directive 2003/17/EC gives a limit value of 10 ppm sulphur in diesel (from 2011).

Emission factors

The CO_2 emission factors for other fuels than diesel, LNG, LPG and GTL are country-specific and come from Fenhann and Kilde (1994).

For diesel the CO_2 emission factor is taken from IPCC (2006). For LNG, the CO_2 emission factor is estimated by the Danish gas transmission company, Energinet.dk, based on gas analysis data (Energinet.dk, 2022). For LPG, the emission factor source is EMEP/EEA (2019).

country-specific emission factor for diesel used in road transportation is not available from Danish refineries, instead, the diesel EF for stationary combustion is used, which is from EU ETS. The average CO_2 EF of diesel burned in stationary sources during 2008-2016 is 74.1 kg/GJ, identical EF to the IPCC default data.

For GTL the CO_2 emission factor comes from Winther (2022b).

[16] nm: nautical mile.

The N_2O emission factors are taken from the EMEP/EEA guidebook; EMEP/EEA (2019) for road transport and non-road mobile machinery, and IPCC (2006) for national sea transport and fisheries as well as aviation.

In the case of military ground equipment, due to lack of fleet/activity and emission data, aggregated CH_4 emission factors for gasoline and diesel are derived from total road traffic emission results. For piston engine aircraft using aviation gasoline, the CH_4 emission factors are derived from VOC factors from EMEP/EEA (2019) and a NMVOC/CH_4 split, based on the NMVOC/CH_4 split for conventional gasoline engines used in Danish road transport.

For railways VOC emission factors are derived from specific Danish VOC measurements from the Danish State Railways (Mølgård, 2022). For private railway lines, VOC emission factors are estimated for the different train type technologies using diesel or GTL. The CH_4 emission factors for railways are derived from the VOC emission factors using a NMVOC/CH_4 split, based on expert judgement.

For agriculture, forestry, industry, household gardening and recreational craft, the VOC emission factors are derived from various European measurement programmes; see IFEU (2004, 2009), Notter and Schmied (2015) and Winther et al. (2006). The NMVOC/CH_4 split is taken from IFEU (2009).

For national sea transport and fisheries, the VOC emission factors come from the Danish TEMA2015 emission model (Ministry of Transport, 2015).

Specifically for the ferries used by Mols Linjen, VOC emission factors are provided by Kristensen (2008), originating from engine measurements (Hansen et al., 2004; Wismann, 1999; PHP, 1996). Complimentary VOC emission factor data for new ferries used by Mols Linjen is provided by Kristensen (2013) and engine load specific VOC emission data is provided by Nielsen (2019).

For island and short-cut ferries using GTL, VOC emission factors are taken from Winther (2022b).

For the LNG fuelled ferry in service on the Hou-Sælvig route, CH_4 and NMVOC emission factors are taken from Bengtsson et al. (2011).

For marine engines using diesel or residual oil, VOC/CH_4 splits are taken from EMEP/EEA (2019). For marine engines using GTL, the VOC/CH_4 split for diesel from EMEP/EEA (2019) is used due to lack of data.

For national sea transport, international sea transport and fisheries, total fuel consumption and aggregated emission factors per fuel type are shown Annex 3.B.13 for the years 1985-2021. For ferries, total fuel consumption and emission factors per ferry per route are shown Annex 3.B.13 for 2021. For fisheries total engine MWh's produced, total fuel consumption, fuel balance factors and emission factors are shown Annex 3.B.13 for 1985-2021.

The source for aviation (jet fuel) CH_4 emission factors is the EMEP/EEA guidebook (EMEP/EEA, 2019). For a number of different representative aircraft types, the EMEP/EEA guidebook comprises fuel flow and NO_x, CO and VOC emission indices for the four LTO modes and distance based emission factors for cruise. For auxiliary power units (APU), ICAO (2011) is the data source for APU load specific NO_x, CO and VOC emission factors for different APU aircraft groups to be linked with the different representative aircraft types. VOC/CH_4 splits for aviation are taken from EMEP/EEA (2019).

Annex 3.B.14 list the lower heating values (LHV) for the inventory fuel types together with their references. The LHV's are used to transform emission factors from g/kg fuel into g/MJ or fuel results from kg into MJ if needed in the inventories.

For all sectors, emission factors for the years 1990 and 2021 are given in CollectER format in Annex 3.B.15.

Table 3.3.19 shows the aggregated emission factors for CO_2, CH_4 and N_2O in 2021 used to calculate the emissions from other mobile sources in Denmark.

Table 3.3.19 The aggregated emission factors for CO_2, CH_4 and N_2O in 2021 used to calculate the emissions from other mobile sources in Denmark.

					Emission factors[17]		
SNAP ID	Category	Fuel type	Tier level	CH_4 % of VOC	CH_4 g pr GJ	CO_2 g pr GJ	N_2O g pr GJ
080100	Military	Diesel	Tier 1	9.8	0.30	74.10	3.52
080100	Military	Gasoline	Tier 1	5.0	5.14	73.00	0.62
080100	Military	Jet fuel	Tier 1	9.6	2.65	72.00	2.30
080200	Railways	Diesel	Tier 3	3.7	0.91	74.10	2.24
080200	Railways	GTL	Tier 3	3.7	1.41	74.10	2.24
080300	Recreational craft	Bio ethanol	Tier 3	2.8	11.21	0.00	1.61
080300	Recreational craft	Biodiesel	Tier 3	2.4	2.36	4.20	2.97
080300	Recreational craft	Diesel	Tier 3	2.4	2.36	74.10	2.97
080300	Recreational craft	Gasoline	Tier 3	2.8	11.21	73.00	1.61
080402	National sea traffic	Diesel	Tier 3	2.0	1.23	74.10	1.87
080402	National sea traffic	GTL	Tier 3	2.0	1.03	71.10	1.74
080402	National sea traffic	LNG	Tier 3	74.0	263.14	56.80	3.96
080402	National sea traffic	Residual oil	Tier 3	2.0	1.36	78.00	1.95
080403	Fishing	Diesel	Tier 3	2.0	1.11	74.10	1.82
080404	International sea traffic	Diesel	Tier 1	2.0	1.26	74.10	1.87
080404	International sea traffic	Residual oil	Tier 1	2.0	1.39	78.00	1.96
080501	Air traffic. Dom. < 3000 ft.	AvGas	Tier 1	2.0	8.62	73.00	2.00
080501	Air traffic. Dom. < 3000 ft.	Jet fuel	Tier 3	10.0	1.67	72.00	10.57
080502	Air traffic. Int. < 3000 ft.	Jet fuel	Tier 3	10.0	2.46	72.00	4.83
080503	Air traffic. Dom. > 3000 ft.	Jet fuel	Tier 3	0.0	0.00	72.00	2.30
080504	Air traffic. Int. > 3000 ft.	Jet fuel	Tier 3	0.0	0.00	72.00	2.30
080600	Agriculture	Bio ethanol	Tier 3	12.2	151.88	0.00	1.62
080600	Agriculture	Diesel	Tier 3	2.4	0.81	74.10	3.57
080600	Agriculture	Gasoline	Tier 3	12.2	151.88	73.00	1.62
080700	Forestry	Bio ethanol	Tier 3	6.0	240.84	0.00	0.46
080700	Forestry	Diesel	Tier 3	2.4	0.36	74.10	3.71
080700	Forestry	Gasoline	Tier 3	6.0	240.84	73.00	0.46
080800	Industry	Bio ethanol	Tier 3	3.6	56.89	0.00	1.49
080800	Industry	Diesel	Tier 3	2.4	0.78	74.10	3.49
080800	Industry	Gasoline	Tier 3	3.6	56.89	73.00	1.49
080800	Industry	LPG	Tier 3	5.0	1.75	63.10	3.50
080900	Household and gardening	Bio ethanol	Tier 3	2.3	52.37	0.00	1.16
080900	Household and gardening	Gasoline	Tier 3	2.3	52.37	73.00	1.16
081100	Commercial and institutional	Bio ethanol	Tier 3	4.0	36.03	0.00	1.30
081100	Commercial and institutional	Diesel	Tier 3	2.4	0.78	74.10	3.49
081100	Commercial and institutional	Gasoline	Tier 3	4.0	36.03	73.00	1.30
081100	Commercial and institutional	LPG	Tier 3	5.0	1.75	63.10	3.50
080501	Air traffic. Dom. < 3000 ft., CPH	AvGas	Tier 1	2.0	8.62	73.00	2.00
080501	Air traffic. Dom. < 3000 ft., CPH	Jet fuel	Tier 3	10.0	1.41	72.00	6.28
080502	Air traffic. Int. < 3000 ft., CPH	Jet fuel	Tier 3	10.0	2.08	72.00	3.00
080503	Air traffic. Dom. > 3000 ft., CPH	Jet fuel	Tier 3	0.0	0.00	72.00	2.30
080504	Air traffic. Int. > 3000 ft., CPH	Jet fuel	Tier 3	0.0	0.00	72.00	2.30

[17] References. CO_2: Country-specific, Energinet.dk (LNG), EMEP/EEA (LPG), IPCC (diesel), Winther (2022, GTL). N_2O: EMEP/EEA. CH_4: Railways: Danish State Railways, DCE; Agriculture/Forestry/Industry/Household-Gardening: IFEU (2004, 2009, 2014), Notter and Schmied (2015); National sea traffic/Fishing/International sea traffic: Ministry of Transport (2015), specific data from Mols Linjen, Bengtsson et al. (2011), EMEP/EEA; domestic and international aviation: EMEP/EEA.

Factors for deterioration, transient loads and gasoline evaporation for non-road mobile machinery

The emission effects of engine wear are taken into account for diesel and gasoline engines by using the so-called deterioration factors. For diesel engines alone, transient factors are used in the calculations, to account for the emission changes caused by varying engine loads. The evaporative emissions of NMVOC are estimated for gasoline fuelling and tank evaporation. The factors for deterioration, transient loads and gasoline evaporation are taken from IFEU (2004, 2009, 2014), and are shown in Annex 3.B.10. For more details regarding the use of these factors, please refer to paragraph 3.3.4 or Winther et al. (2006).

Engine load adjustment factors for marine engines

For marine engines, specific fuel consumption (sfc) and emission factors are found to vary with engine load, and hence engine load adjustment factors, LAF, are used in the fleet activity calculations for ferries and fishing vessels to account for these engine load changes. For sfc and NO_x, N_2O, CO, VOC and PM, engine load adjustment functions are provided by IMO (2015) based on Starcrest (2013). Only sfc is adjusted in the calculations, due to the actual engine load levels for ferries and fishing vessels in the Danish inventories. The load adjustment factors are shown in Annex 3.B.12.

For a few ferries operated by Mols Linjen actual engine loads and engine load specific emission data provided by Nielsen (2019) is used to calculate precise sfc and emission factors of NO_x, CO and VOC.

3.3.4 Calculation methods for other mobile sources

Civil aviation

For aviation, the domestic and international estimates are made separately for landing and takeoff (LTOs < 3000 ft), and cruising (> 3000 ft).

By using the LTO mode specific fuel flow and emission indices from EMEP/EEA (2019), the fuel consumption and emission factors for the full LTO cycle are estimated for each of the representative aircraft types used in the Danish inventory.

The fuel consumption for one LTO cycle is calculated according to the following sum formula:

$$FC_{LTO}^{a} = \sum_{m=1}^{5} t_m \cdot ff_{a,m} \qquad (15)$$

Where FC = fuel consumption (kg), m = LTO mode (approach/landing, taxi in, taxi out, take off, climb out), t = times in mode (s), ff = fuel flow (kg per s), a = representative aircraft type.

The emissions for one LTO cycle are estimated as follows:

$$E_{LTO}^{a} = \sum_{m=1}^{5} FC_{a,m} \cdot EI_{a,m} \qquad (16)$$

Where EI = emission index (g per kg fuel). Due to lack of specific airport data for approach/descent, take off and climb out, standardised times-in-modes of 4, 0.7 and 2.2 minutes are used as defined by ICAO (ICAO, 1995). For taxi in and taxi out, specific times-in-modes data are provided by Eurocontrol for the airports present in the Danish inventory. The taxi times-in-modes data are shown in Annex 3.B.10 for the years 2001-2021.

The fuel consumption and emissions for aircraft auxiliary power units (APU's) are calculated with the same method used to estimate LTO fuel consumption and emissions for aircraft main engines (formulas 15 and 16). ICAO (2011) is the data source for APU load specific fuel flows (kg per s) and emission rates (g per kg fuel) for different APU aircraft groups (characterised by seating capacity and age). APU times-in-modes for arrival, start-up, boarding and main engine start are also provided by ICAO (2011), whereas push back time intervals are taken from an emission study made in Copenhagen Airport (Ellermann et al., 2011; Winther et al., 2015).

For each representative aircraft type, the calculated fuel consumption and emission factors per LTO are shown in Annex 3.B.10 for Copenhagen Airport and other airports (aggregated) for 2021. APU data for fuel flows, emission rates and times-in-modes are also shown in Annex 3.B.10, together with the correspondence table for APU group-representative aircraft type.

The calculations for cruise use the distance specific fuel consumption and emissions given by EMEP/EEA (2019) per representative aircraft type. Data interpolations or extrapolations are made – in each case determined by the actual flown distance between the origin and the destination airports.

The actual flown distance between two airports can be derived as a function of the great circle distance (GCD) between the airports in question. The relation between actual distance and GCD flown is taken from the German TREMOD AV model (Knörr et al., 2012). For GCD <= 100 NM (<= 185.2 km), 60 km must be added to the great circle distance (GCD) in order to find actual distance flown. For GCD > 100 NM (>185.2 km), 4 % additional flown distance is added for the part of GCD > 100 NM (>185.2 km):

- Actual flown distance (GCD <= 185.2 km) = GCD + 60 km
- Actual flown distance (GCD > 185.2 km) = (GCD – 185.2 km) x 1,04 + 185.2 km + 60 km

If the actual flown distance, y, is smaller than the maximum distance for which fuel consumption and emission data are given in the EMEP/EEA data bank the fuel consumption or emission E (y) becomes:

$$E(y) = E_{x_i} + \frac{(y - x_i)}{x_{i+1} - x_i} \cdot (E_{x_{i+1}} - E_{x_i}) \quad y<x_{max},\ i = 0,1,2\ldots max-1 \qquad (17)$$

In (17) x_i and x_{max} denominate the separate distances and the maximum distance, respectively, with known fuel consumption and emissions. If the actual flown distance, y, exceeds x_{max} the maximum figures for fuel consumption and emissions must be extrapolated and the equation then becomes:

$$E(y) = E_{x_{\max}} + \frac{(y - x_{\max})}{x_{\max} - x_{\max-1}} \cdot (E_{x_{\max}} - E_{x_{\max-1}}) \quad y>x_{\max} \tag{18}$$

Total results are summed up and categorised according to each flight's destination airport code in order to distinguish between domestic and international flights.

Annex 3.B.10 shows the average fuel consumption and emission factors per representative aircraft type for cruise flying, as well as total distance flown, for 2021[18]. The factors are split between Copenhagen Airport and other airports and distinguish between domestic and international flights.

Specifically for flights between Denmark and Greenland or the Faroe Islands, for each representative aircraft type, the flight distances are directly shown in Annex 3.B.10, which go into the cruise calculation expressions 17 and 18.

The overall fuel precision (fuel balance) in the model is 1.00 in 2021, derived as the fuel ratio between model estimates and statistical sales. The fuel difference is accounted for by adjusting cruising fuel consumption and emissions in the model according to domestic and international cruising fuel shares.

For inventory years before 2001, the calculation procedure is to estimate each year's fuel consumption and emissions for LTO based on LTO/aircraft type statistics from Copenhagen Airport, and total take off numbers for other airports provided by the Danish Transport and Construction Agency. Due to lack of aircraft type specific LTO data, fuel consumption and emission factors derived for domestic LTO's in Copenhagen Airport is used for all LTO's in other airports. In a next step, the total fuel consumption for cruise (true cruise fuel consumption) is found year by year as the statistical fuel consumption total minus the calculated fuel consumption for LTO.

For each inventory year, intermediate cruise fuel consumption figures split into four parts (Copenhagen/Other airports; domestic/international) are found as proportional values between part specific LTO fuel consumption values estimated as described previously, and part specific cruise:LTO fuel consumption ratios for 2001 derived from the detailed city-pair emission inventory.

Each inventory year's true cruise fuel consumption is finally split into four parts by using the intermediate cruise fuel consumption values as a distribution key. As emission factor input data for cruise, aggregated fuel related emission factors for 2001 are derived from the detailed city-pair emission inventory.

Non-road mobile machinery and recreational craft

Prior to adjustments for deterioration effects and transient engine operations, the fuel consumption and emissions in year X, for a given machinery type, engine size and engine age, are calculated as:

$$E_{Basis}(X)_{i,j,k} = N_{i,j,k} \cdot HRS_{i,j,k} \cdot P \cdot LF_i \cdot EF_{y,z} \tag{19}$$

[18] Excluding flights for Greenland and the Faroe Islands.

Where E_{Basis} = fuel consumption/emissions in the basic situation, N = number of engines, HRS = annual working hours, P = average rated engine size in kW, LF = load factor, EF = fuel consumption/emission factor in g pr kWh, i = machinery type, j = engine size, k = engine age, y = engine-size class and z = emission level. The basic fuel consumption and emission factors are shown in Annex 3.B.11.

The deterioration factor for a given machinery type, engine size and engine age in year X depends on the engine-size class (only for gasoline), y, and the emission level, z. The deterioration factors for diesel and gasoline 2-stroke engines are found from:

$$DF_{i,j,k}(X) = \frac{K_{i,j,k}}{LT_i} \cdot DF_{y,z} \qquad (20)$$

Where DF = deterioration factor, K = engine age, LT = lifetime, i = machinery type, j = engine size, k = engine age, y = engine-size class and z = emission level.

For gasoline 4-stroke engines the deterioration factors are calculated as:

$$DF_{i,j,k}(X) = \sqrt{\frac{K_{i,j,k}}{LT_i}} \cdot DF_{y,z} \qquad (21)$$

The deterioration factors inserted in (20) and (21) are shown in Annex 3.B.11. No deterioration is assumed for fuel consumption (all fuel types) or for LPG engine emissions and, hence, DF = 1 in these situations.

The transient factor for any given machinery type, engine size and engine age in year X, relies only on emission level and load factor, and is denominated as:

$$TF_{i,j,k}(X) = TF_z \qquad (22)$$

Where i = machinery type, j = engine size, k = engine age and z = emission level.

The transient factors inserted in (22) are shown in Annex 3.B.11. No transient corrections are made for gasoline and LPG engines and, hence, TF_z = 1 for these fuel types.

As a part of some engine manufacturer's emission reduction strategy, a part of the Stage IIIB and IV machines used in building and construction are equipped with preinstalled particle filters, and hence have low particle emissions. This particle filter effect on particle emissions needs to be taken into account in the calculations, since the baseline emission factors for TSP more aligns with EU emission legislation limits, and these emission limits do not necessarily require particulate filters in order to be met.

The particle reduction factor, F_{dpf}, for any given machinery type, engine size and engine age in year X, depends on the share of engines with preinstalled particle filters, in the different size classes and emission levels:

$$F_{dpf,i,j,k}(X) = \frac{(1-S_{y,z}) \cdot EF_{y,z} + S_{y,z} \cdot EF_{dpf,y,z}}{EF_{y,z}} \tag{23}$$

Where F_{dpf}, = particle reduction factor, S = Share of engines with preinstalled filters, i = machinery type, j = engine size, and k = engine age. This emission reduction factor only relates to particle emissions from Stage IIIB and IV diesel engines with preinstalled filters[19]. The emissions from all other non road machines are not affected by this adjustment.

The final calculation of fuel consumption and emissions in year X for a given machinery type, engine size and engine age, is the product of the expressions 19-23:

$$E(X)_{i,j,k} = E_{Basis}(X)_{i,j,k} \cdot TF(X)_{i,j,k} \cdot (1 + DF(X)_{i,j,k}) \cdot F_{dpf,i,j,k}(X)) \tag{24}$$

The evaporative hydrocarbon emissions from fuelling are calculated as:

$$E_{Evap,\,fueling,i} = FC_i \cdot EF_{Evap,\,fueling} \tag{25}$$

Where $E_{Evap,fueling}$, = hydrocarbon emissions from fuelling, i = machinery type, FC = fuel consumption in kg, $EF_{Evap,fueling}$ = emission factor in g NMVOC pr kg fuel.

For tank evaporation, the hydrocarbon emissions are found from:

$$E_{Evap,\tan k,i} = N_i \cdot EF_{Evap,\tan k,i} \tag{26}$$

Where $E_{Evap,tank,i}$ = hydrocarbon emissions from tank evaporation, N = number of engines, i = machinery type and $EF_{Evap,fueling}$ = emission factor in g NMVOC pr year.

National navigation and international navigation

The fuel consumption and emissions in year X, for domestic ferries are calculated as:

$$E(X) = \sum_i N_i \cdot T_i \cdot S_{i,j} \cdot P_i \cdot LF_j \cdot LAF_j \cdot EF_{k,l,y} \tag{27}$$

Where E = fuel consumption/emissions, N = number of round trips, T = sailing time pr round trip in hours, S = ferry share of ferry service round trips, P = engine size in kW, LF = engine load factor, LAF = engine load adjustment factor, EF = fuel consumption/emission factor in g pr kWh, i = ferry service, j = ferry, k = fuel type, l = engine type, y = engine year.

[19] The particle emission adjustment relating to Stage IIIB and IV engines equipped with particle filters also significantly affects BC emissions, since particle filters very efficiently reduce BC from the exhaust.

For the remaining navigation categories, other national sea transport and international navigation, the emissions are calculated using a simplified approach:

$$E(X) = \sum_i EC_{i,k} EF_{k,l,y} \tag{28}$$

Where E = fuel consumption/emissions, EC = energy consumption, EF = fuel consumption/emission factor in g per kg fuel, i = category (other national sea transport, international navigation), k = fuel type, l = engine type, y = average engine year.

The emission factor inserted in (28) is found as an average of the emission factors representing the engine ages which are comprised by the average lifetime in a given calculation year, X:

$$EF_{k,l,y} = \frac{\sum_{year=X}^{year=X-LT} EF_{k,l}}{LT_{k,l}} \tag{29}$$

National fishing

For fishing vessels, the fuel consumption and emissions in year X, are calculated as:

$$E(X) = \sum_i T_i \cdot P_j \cdot LF_j \cdot LAF_j \cdot EF_{k,l,y} \tag{30}$$

Where E = fuel consumption/emissions, T = sailing time pr fishing trip in hours, P = engine size in kW, LF = engine load factor, LAF = engine load adjustment factor, EF = fuel consumption/emission factor in g pr kWh, i = fishing trip no., j = fishing vessel registration no., k = fuel type, l = engine type, y = engine year.

Railways

The fuel consumption and emissions in year X, for private railway lines are calculated as:

$$E(X) = \sum_i EF_{i,j,k} \times S_{i,j} \times M_i \tag{31}$$

Here E = fuel consumption/emission, EF = fuel consumption/emission factor in g per km, S = Litra type share of total train set km, M = total train set km, i = railway line, j = Litra type and k = fuel type.

The fuel consumption for Danish State Railways are found as the difference between total fuel consumption from DEA (2022a) and the fuel consumption for private railway lines calculated in (x).

The emissions in year X, for Danish State Railways are calculated as:

$$E(X) = FC(X) \times EF(X) \tag{32}$$

Where E = fuel consumption/emissions, FC = fuel consumption, EF = emission factor in g per kg fuel.

Military

For military, the emissions are estimated with the simple method using fuel-related emission factors and fuel consumption from the DEA:

$$E(X) = FC(X) \times EF(X) \quad (33)$$

where E = emission, FC = fuel consumption and EF = emission factor.

The calculated emissions for other mobile sources are shown in CollectER format in Annex 3.B.16 for the years 1990 and 2021 and as time series 1990-2021 in Annex 3.B.15 (CRF format).

Energy balance between inventory and sales

Following convention rules, the DEA statistical fuel sales figures are the basis for the full Danish inventory. However, in some cases for mobile sources the DEA statistical sectors do not fully match the inventory sectors.

In the following, the transferal of fuel consumption data from DEA statistics into inventory relevant categories is explained for national navigation and national fishing, non-road mobile machinery and recreational craft, and road transport. A full list of all fuel consumption data, DEA figures as well as intermediate fuel consumption data, and final inventory input figures is shown in Annex 3.B.14.

National navigation

Fuel used for the remaining part of the traffic between two Danish ports, other national sea transport, is taken as the difference between 1) DEA national fuel sales for national sea transport minus fuel consumption at Danish off shore installations (off shore reduced fuel sales[20]) and 2) the bottom-up calculated fuel consumption for Danish ferries in DEMOS-Navigation.

For years when the fuel estimates for ferries (not including the ferry to the Faroe Islands) are higher than the “off shore reduced” fuel sold for national sea transport, fuel is taken from fisheries in the case of marine diesel (1985-1999). For heavy fuel oil, the missing fuel amount is taken from stationary sources (1985-1986, 1988, 1994-1996) and international sea transport (2015 onwards).

National fishing

For fisheries, the calculation methodology is activity based with a fuel balance, and input fuel data is in principle the diesel fuel sold for fisheries reported by DEA.

For years when diesel fuel calculated for national navigation are higher than the “Off shore reduced” fuel sold for national navigation, diesel is transferred from fisheries to national navigation in the inventories.

[20] According to the Danish Energy Authority, the latter diesel fuel sales are reported as sold for national navigation by the fuel sales reporting oil companies.

Incorrectly reported gasoline and heavy fuel oil for fisheries is transferred to recreational craft (reported under "Other") and national navigation, respectively.

According to the DEA, in some cases inaccurate costumer specifications are made by the oil suppliers, which result in sector misallocation in the sales statistics between national navigation and fisheries for diesel oil and between national navigation and industry for heavy fuel oil (Peter Dal, DEA, personal communication, 2007). Further, fuel sold for vessels sailing between Denmark and Greenland/Faroe Islands are reported as international in the DEA statistics, and this fuel categorisation is different from the IPCC guideline definitions (see following paragraph "Bunkers").

Inaccurate fuel sale specifications is also the reason for heavy fuel oil being reported for fisheries in the DEA statistics. No engines installed in fishing vessels use heavy fuel oil, even though a certain amount of heavy fuel oil is listed in the DEA numbers for some statistical years (H. Amdissen, Danish Fishermen's Association, personal communication, 2006).

Non-road mobile machinery and recreational craft

For diesel and LPG, the non-road fuel consumption estimated DEMOS-NRMM is partly covered by the fuel consumption amounts in the following DEA sectors: agriculture and forestry, market gardening, and building and construction. The remaining quantity of non-road diesel and LPG is taken from the DEA industry sector.

For gasoline, the DEA residential sector, together with the DEA sectors mentioned for diesel and LPG, contribute to the non-road fuel consumption total. In addition, a certain amount of fuel is transferred from DEA road transport in order to outbalance the bottom up fuel consumption calculated in DEMOS-NRMM.

The amount of diesel and LPG in DEA industry not being used by non-road mobile machinery is included in the sectors, "Combustion in manufacturing industry" (0301) and "Non-industrial combustion plants" (0203) in the Danish emission inventory.

For recreational craft, the calculated fuel consumption totals for diesel and gasoline in DEMOS-NRMM are subsequently subtracted from the DEA fishery sector. For gasoline, the DEA reported fuel consumption for fisheries is far too small to outbalance the bottom up fuel consumption for recreational craft, and hence the missing fuel amount is taken from the DEA road transport sector in order to fill the fuel gap.

Road transport

The bottom up diesel estimate for recreational craft is subtracted from road transport and grouped in the "Other" inventory category together with military activities.

For LPG, the difference between fuel reported in DEA statistics and bottom-up estimates for road transport is outbalanced with fuel totals from "non-industrial combustion plants" (020200) in order to obtain a fuel balance.

Classification of domestic and international aviation and navigation for Denmark

The distinction between domestic and international fuel consumption and emissions from aviation and navigation for Denmark are in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. For the national emission inventory, this, in principle, means that fuel sold (and associated emissions) for flights/sea transportation starting from a seaport/airport in the Kingdom of Denmark, with destinations inside or outside the Kingdom of Denmark, are regarded as domestic or international, respectively.

Aviation

As prescribed by the IPCC guidelines, for aviation, the fuel consumption and emissions associated with flights inside the Kingdom of Denmark are counted as domestic.

This report includes flights from airports in Denmark and associated jet fuel sales. Hence, the flights between airports in Denmark and flights from Denmark to Greenland and the Faroe Islands are classified as domestic and flights from Danish airports with destinations outside the Kingdom of Denmark are classified as international flights.

In Greenland and in the Faroe Islands, the jet fuel sold is treated as domestic. This decision becomes reasonable when considering that almost no fuel is bunkered in Greenland/the Faroe Islands by flights other than those going to Denmark.

Navigation

In DEA statistics, the domestic fuel total consists of fuel sold to Danish ferries and other ships sailing between two Danish ports. The DEA international fuel total consists of the fuel sold in Denmark to international ferries, international warships, other ships with foreign destinations, transport to Greenland and the Faroe Islands, tank vessels and foreign fishing boats.

In order to follow the IPCC guidelines the bottom-up fuel estimates for the ferry routes between Denmark and the Faroe Islands, and fuel sold in Denmark to vessels engaged in freight transportation between Denmark and Greenland/Faroe Islands are being subtracted from the fuel sales figures for international sea transport prior to inventory fuel input.

In Greenland, all marine fuel sales are treated as domestic. In the Faroe Islands, fuel sold in Faroese ports for Faroese fishing vessels and other Faroese ships is treated as domestic. The fuel sold to Faroese ships bunkering outside Faroese waters and the fuel sold to foreign ships in Faroese ports or outside Faroese waters is classified as international (Lastein and Winther, 2003).

Conclusively, the domestic/international fuel split (and associated emissions) for navigation is not determined with the same precision as for aviation. It is considered, however, that the potential of incorrectly allocated fuel quantities is only a small part of the total fuel sold for navigational purposes in the Kingdom of Denmark.

3.3.5 Uncertainties and time series consistency

Tier 1 uncertainty estimates for greenhouse gases, are made for road transport and other mobile sources using the guidelines formulated in the 2006 IPCC

Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). For road transport, railways and fisheries, these guidelines provide uncertainty factors for activity data that are used in the Danish situation. For other sectors, the factors reflect specific national knowledge (Winther et al., 2006 and Winther, 2008). These sectors are (SNAP categories): Inland Waterways (a part of 1A3d: Navigation), Agriculture and Forestry (parts of 1A4c: Agriculture-/forestry/fisheries), Industry (mobile part of (1A2f: Industry-other), Residential (1A4b) and National sea transport (a part of 1A3d: Navigation).

The activity data uncertainty factor for civil aviation is based on expert judgement.

The calculations for Tier 1 are shown in Annex 3.B.17 for all emission components.

Table 3.3.20 Tier 1 Uncertainties for activity data, emission factors and total emissions in 2021 and as a trend.

Category	Activity data	CO_2	CH_4	N_2O
		%		
Road transport	2	5	40	50
Military	2	5	100	1000
Railways	2	5	100	1000
Navigation (small boats)	41	5	100	1000
Navigation (large vessels)	11	5	100	1000
Fisheries	2	5	100	1000
Agriculture	24	5	100	1000
Forestry	30	5	100	1000
Industry (mobile)	41	5	100	1000
Residential	35	5	100	1000
Commercial/Institutional	35	5	100	1000
Civil aviation	10	5	100	1000
Overall uncertainty in 2021		4.8	29.7	97.2
Trend uncertainty		4.3	2.0	49.8

As regards time series consistency, background flight data cannot be made available on a city-pair level prior to 2000. However, aided by LTO/aircraft statistics for these years and the use of proper assumptions, a good level of consistency is in any case, obtained for this part of the transport inventory.

The time series of emissions for mobile machinery in the agriculture, forestry, industry, household and gardening (residential) and inland waterways (part of navigation) sectors are less certain than time series for other sectors, since DEA statistical figures do not explicitly provide fuel consumption information for working equipment and machinery.

3.3.6 Quality assurance/quality control (QA/QC)

The intention is to publish every second year a sector report for road transport and other mobile sources. The last sector report prepared concerned the 2020 inventory (Winther, 2022a).

The QA/QC descriptions of the Danish emission inventories for transport follow the general QA/QC description for DCE in Section 1.6, based on the prescriptions given in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000). A general

QA/QC plan for the Danish greenhouse gas inventory has been elaborated by Nielsen et al. (2012).

An overview diagram of the Danish emission inventory system is presented in Figure 1.2 (Data storage and processing levels), and the exact definitions of Critical Control Points (CCP) and Points of Measurements (PM) are given in Section 1.6. The status for the PMs relevant for the mobile sector are given in the following text and the result of this investigation indicates a need for future QA/QC activities in order to fulfil the QA/QC requirements from the IPCC GPG.

Data storage level 1

Data Storage level 1	3.Completeness	DS.1.3.1	Documentation showing that all possible national data sources are included by setting down the reasoning behind the selection of datasets.

The following external data sources are used in the mobile part of the Danish emission inventories for activity data and supplementary information:

- Danish Energy Agency: Official Danish energy statistics.
- National sea transport (Royal Arctic Line, Eim Skip): Annual fuel consumption data.
- DTU Transport: Road traffic vehicle fleet and mileage data.
- Danish Civil Aviation and Railway Authority: Flight statistics.
- Danish Civil Aviation and Railway Authority: Train km statistics for private railways.
- Non-road mobile machinery: Information from statistical sources, research organisations, different professional organisations and machinery manufacturers.
- Ferries (Statistics Denmark): Data for annual return trips for Danish ferry routes.
- Ferries (Danish Ferry Historical Society): Detailed technical and operational data for specific ferries.
- Ferries (Mols Linjen, Bornholmstrafikken, Langelandstrafikken, Færgeselskabet Læsø, Samsø Rederi, Ærøfærgerne A/S, Smyril Line): Detailed technical and operational data for specific ferries.
- Danish Meteorological Institute (DMI): Temperature data.
- The National Motorcycle Association: 2-wheeler data.

The emission factors come from various sources:

- Danish Energy Agency: CO_2 emission factors (all fuel types, except diesel, CNG and LPG) and lower heating values (all fuel types, except CNG, LNG, bio gas).
- COPERT 5: Road transport (all exhaust components, except CO_2, SO_2).
- Handbook of Emission Factors (fuel consumption factors for vans, fuel consumption factors for plug-in passenger cars).
- Danish State Railways: Diesel locomotives (NO_X, VOC, CO and TSP).
- IPCC: CO_2 emission factors for diesel.
- Energinet.dk: CO_2 emission factors for CNG, LNG, bio gas.
- EMEP/EEA guidebook: Civil aviation and supplementary.
- ICAO: Civil aviation auxiliary power units.
- Non-road mobile machinery: References given in NIR report and NERI reports.

- National navigation and fisheries: TEMA2015 (NO_X, VOC, CO and TSP), IMO (TSP), MAN Energy Solutions (sfc, NO_X), specific data from Mols Linjen (NO_x, CO, NMVOC, TSP) and LNG emission factors (NO_x, CO, NMVOC, TSP) from Bengtsson et al. (2011).

Table 3.3.21 to follow contains Id, File/Directory/Report name, Description, Reference and Contacts. As regards File/Directory/Report name, this field refers to a file name for Id when all external data (time series for the existing inventory) are stored in one file. In other cases, a computer directory name is given when the external data used are stored in several files, e.g. each file contains one inventory year's external data or each file contains time series of external data for sub-categories of machinery. A third situation occurs when the external data are published in publicly available reports; here the aim is to obtain electronic copies for internal archiving.

Table 3.3.21 Overview table of external data and contact persons for transport.

Id no	File/-Directory/-Report name	Description	Activity data or emission factor	Reference	Contacts	Data agreement
T1	Transport energy[1]	Dataset for all transport energy use	Activity data	The Danish Energy Agency (DEA)	Jane Rusbjerg	Yes
T2	Fleet and mileage data[2]	Road transport fleet and mileage data	Activity data	DTU Transport	Thomas Jensen	Yes
T3	Flight statistics[2]	Data records for all flights	Activity data	Danish Civil Aviation and Railway Authority	Helle Rosted	Yes
T4	Non-road machinery[2]	Stock and operational data for non-road machinery	Activity data	Non-road Documentation report		No
T5	Emissions from ships[3]	Data for ferry traffic	Activity data	Statistics Denmark	Heidi Sørensen	No
T6	Emissions from ships[3]	Technical and operational data for Danish ferries	Activity data	Navigation emission documentation report	Hans Otto Kristensen	No
T7	Temperature data[3]	Monthly average of daily max/min temperatures	Other data	Danish Meteorological Institute	Danish Meteorological Institute	No
T8	Fleet and mileage data[1]	Stock data for mopeds and motorcycles	Activity data	The National Motorcycle Association	Henrik Markamp	No
T9	CO_2 emission factors[1]	DEA CO_2 emission factors (all fuel types)	Emission factor	The Danish Energy Agency (DEA)	Jane Rusbjerg	No
T10	COPERT 5 emission factors[2]	Road transport emission factors	Emission factor	Laboratory of applied thermodynamics Aristotle University Thessaloniki	Leonidas Ntziachristos	No
T11	Railways emission factors[1]	Emission factors for diesel locomotives	Emission factor	Danish State Railways	Jesper Mølgård	Yes
T12	EMEP/EEA guidebook[3]	Emission factors for navigation, civil aviation and supplementary	Emission factor	European Environment Agency	European Environment Agency	No
T13	Non-road emission factors[3]	Emission factors for agriculture, forestry, industry and household/gardening	Emission factor	Non-road Documentation report		No
T14	Emissions from ships[3]	Emission factors for national sea transport and fisheries	Emission factor	Navigation emission documentation report		No
T15	Fishery activity statistics	Electronic trip-level data for fishing vessels	Activity data	Aarhus University	Nikolaj Andersen	No
T16	Railway statistics	Train km for private railways	Activity data	Danish Civil Aviation and Railway Authority	Tina Schelde	Yes

1) File name;

2) Directory in the DCE data library structure; 3) Reports available on the internet.

Danish Energy Agency (energy statistics)

The official Danish energy statistics are provided by the Danish Energy Agency (DEA) and are regarded as complete on a national level. For most transport sectors, the DEA subsector classifications fit the SNAP classifications used by DCE.

For non-road mobile machinery, this is however not the case, since DEA do not distinguish between mobile and stationary fuel consumption in the subsectors relevant for non-road mobile fuel consumption.

In this case, DCE calculates a bottom-up non-road fuel consumption estimate and for diesel (land-based machinery only) and LPG, the residual fuel quantities are allocated to stationary consumption. For gasoline (land-based machinery) the relevant fuel consumption quantities for the DEA are smaller than the DCE estimates, and the amount of fuel consumption missing is subtracted from the DEA road transport total to account for all fuel sold. For recreational craft, no specific DEA category exists and, in this case, the gasoline and diesel fuel consumption is taken from road transport.

For years when the fuel estimates for national navigation are higher than DEA reported fuel sold for national navigation, fuel is taken from fisheries in the case of marine diesel (1985-1999). For heavy fuel oil, the missing fuel amount is taken from stationary sources (1985-1986, 1988, 1994-1996) and international navigation (2015 onwards).

In order to maintain the national energy balance, the changes in the fuel consumption time series for national navigation lead, in turn, to changes in the fuel activity data for fisheries (diesel oil), industry and international navigation (heavy fuel oil).

The DCE fuel modifications, thus, give DEA-SNAP differences for road transport, national navigation and fisheries.

A special note must be made for the DEA civil aviation statistical figures. The domestic/international fuel consumption division derives from bottom-up fuel consumption calculations made by DCE.

DTU Transport

Figures for fleet numbers and mileage data are provided by DTU Transport on behalf of the Danish Ministry of Transport. Following the data deliverance contract between DCE and the Danish Ministry of Transport, it is a basic task for DTU Transport to possess comprehensive information on Danish road traffic. The fleet figures are based on data from the Danish vehicle register, kept by Statistics Denmark and are, therefore, regarded as very precise. Annual mileage information is obtained by DTU Transport from the Danish Vehicle Inspection and Maintenance Program.

Danish Civil Aviation and Railway Authority
(Former: Civil Aviation Agency of Denmark)

The Danish Civil Aviation and Railway Authority monitors all aircraft movements in Danish airspace and, in this connection, possesses data records for all take-offs and landings at Danish airports. The dataset from 2001 onwards, among others consisting of aircraft type and origin and destination airports for all flights leaving major Danish airports, are, therefore, regarded as very complete. For inventory years before 2001, the most accurate data contain

Transport Authority total movements from major Danish airports and detailed aircraft type distributions for aircraft using Copenhagen Airport, provided by the airport itself.

The Danish Civil Aviation and Railway Authority monitors all train traffic made by private railway lines in Denmark. The dataset is therefore regarded as very complete.

Aarhus University (fishing activity data)
The Danish Fisheries Agency gather data electronic log data for all fishing travels made by Danish fishing vessels, and is regarded as very complete. The data consist of vessel engine size and brutto tonnes, vessel build year, vessel type and the time duration of the fishing travel. This data is forwarded to Aarhus University as a part of a data agreement.

Non-road machinery (stock and operational data)
A great deal of stock and operational data for non-road machinery was obtained in a research project carried out by Winther et al. (2006) for the 2004 inventory. In 2016, a comprehensive data update were made for the most important building and construction machinery concerning engine load factors, equipment size - engine size relations, equipment scrapping curves and annual working hours as a function of engine age. In 2017, a comprehensive data update were made for the most important household and gardening machinery types concerning new sales data, equipment size - engine size relations, equipment scrapping curves and annual working hours as a function of machinery age, with sales figures validated through discussions with KVL.

In 2021, several comprehensive data updates were made. For tractors, stock data was updated based on data from the Danish vehicle register kept by Statistics Denmark.

For fork lifts, a revision of the stock data was made by including WITS (World Industrial Truck Sales) and FEM (Federation European Material) fork lift sales figures for Denmark in 2000-2020 provided by Toyota Material Handling, to adjust sales data provided by the Association of Producers and Distributors of Fork Lifts in Denmark for 1976-2019.

For forestry non road machinery, a revision of the number of forestry machines, engine size, annual working hours and average life times was made based on data provided by the Danish Forest Association.

The source for the stock of harvesters is Statistics Denmark. Sales figures for harvesters and construction machinery, together with operational data and supplementary information, are obtained from The Association of Danish Agricultural Machinery Dealers and key experts from the most important engine manufacturers.

Stock information disaggregated into vessel types for recreational craft was obtained from the Danish Sailing Association. A certain part of the operational data comes from previous Danish non-road research projects (Dansk Teknologisk Institut, 1992 and 1993; Bak et al., 2003).

Except for tractors, no statistical register exists for non-road machinery types and this affects the accuracy of stock and operational data.

For harvesters, Statistics Denmark provide total stock data based on information from questionnaires and the registers of crop subsidy applications kept by the Ministry of Environment and Food of Denmark. In combination with new sales figures per engine size from The Association of Danish Agricultural Machinery Dealers, the best available stock data are obtained.

In addition, using the data sources for construction machinery, forestry equipment, gasoline fuelled gardening machinery and fork lift sale figures are regarded as the only realistic approach for consolidated stock information for these machinery types.

Total stock estimates and engine lifetime assumptions are used to disaggregate the stock into layers in the case of machinery types (rare types of diesel and gasoline non-road equipment, recreational craft) where data is even scarcer.

To support the 2022 inventory, new 2021 stock data for tractors, forestry equipment, construction machinery, fork lifts and gasoline fuelled garden equipment was obtained from the sources listed in the present report. For non-road machinery in general, it is, however, uncertain if data in such a level can be provided annually in the future.

Ferries (Statistics Denmark)

Statistics Denmark provides information of annual return trips for all Danish ferry routes from 1990 onwards. The data are based on monthly reports from passenger and ferry shipping companies in terms of transported vehicles passengers and goods. Thus, the data from Statistics Denmark are regarded as complete. Most likely, the data can be provided annually in the future.

Ferries (Danish Ferry Historical Society, DFS)

No central registration of technical and operational data for Danish ferries and ferry routes is available from official statistics. However, one valuable reference to obtain data and facts about construction and operation of Danish ferries, especially in the recent 20 - 30 years is the archives of Danish Ferry Historical Society. Pure technical data has not only been obtained from this society´s archives, but some of the knowledge has been obtained through the personal insight about ferries from some of the members of the society, which have been directly involved in the ferry business for example consultants, naval architects, marine engineers, captains and superintendents. However, until recently no documentation of the detailed DFS knowledge was established in terms of written reports or a central database system.

To make use of all the ferry specific data for the Danish inventories, DSF made a data documentation for the years 1990-2005 as a specific task of the research project carried out by Winther (2008).

Ferries (Mols Linjen, Bornholmstrafikken, Langelandstrafikken, Færgeselskabet Læsø, Samsø Rederi, Ærøfærgerne A/S, Smyril Line)

For the years 2006+, the major Danish ferry companies are contacted each year in order to obtain ferry technical data, relating to specific ferries in service, annual share of total round trips and other technical information. The relevant annual information is given as personal communication, a method, which can be repeated in the future.

National navigation (Royal Arctic Line, Eim Skip)

For the years 2006+, the major shipping companies with frequent sailing activities between Denmark and Greenland/Faroe Islands are contacted each year in order to obtain data for fuel sold in Denmark used for these vessel activities. The relevant annual information is given as personal communication, a method, which can be repeated in the future.

Danish Meteorological Institute

The monthly average max/min temperature for Denmark comes from DMI. This source is self-explanatory in terms of meteorological data. Data are publicly available for each year on the internet.

The National Motorcycle Association

Road transport: 2-wheeler stock information (The National Motorcycle Association). Given that no consistent national data are available for mopeds in terms of fleet numbers and distributions according to engine principle, The National Motorcycle Association is considered the professional organisation, where most expert knowledge is available. The relevant annual information is given as personal communication, a method, which can be repeated in the future.

Danish Energy Agency (CO_2 emission factors and lower heating values)

The CO_2 emission factors and net calorific values (NCV) are fuel-specific constants. The country-specific values from the DEA are used for all inventory years.

COPERT 5

COPERT 5 provides factors for fuel consumption and for all exhaust emission components, which are included in the national inventory. For several reasons, COPERT 5 is regarded as the most appropriate source of road traffic fuel consumption and emission factors. First of all, very few Danish emission measurements exist, so data are too scarce to support emission calculations on a national level. Secondly, most of the fuel consumption and emission information behind the COPERT model are derived from different large European research activities, and the formulation of fuel consumption and emission factors for all single vehicle categories has been made by a group of road traffic emission experts. A large degree of internal consistency is, therefore, achieved. Finally, the COPERT model is regularly updated with new experimental findings from European research programs and, apart from updated fuel consumption and emission factors, the use of COPERT 5 by many European countries ensures a large degree of cross-national consistency in reported emission results.

The Handbook of Emission Factors

The Handbook of Emission Factors is a comprehensive road transport emission model developed by a consortium of research institutes in Germany, Austria, Switzerland, France, Sweden and Norway. A large corporation exist and data exchange activities takes place between Handbook, COPERT 5 and other European emission modellers, with the aims of sharing basis emission and fuel consumption measurement data as basis input for the different emission models. The most recent version of the Handbook is in a few cases more updated in terms of vehicle size-technology splits compared to COPERT 5. This is the case for light commercial vehicles, in which case the Handbook provides the necessary fuel consumption data split into the three vehicle size classes for all relevant fuel types and Euro levels. For plugin passenger cars, fuel consumption data from the Handbook is also used.

Danish State Railways

Aggregated emission factors of NO_x, VOC, CO and TSP for diesel locomotives are provided annually by the Danish State Railways. Taking into account available time resources for subsector emission calculations, the use of data from Danish State Railways is sensible. This operator accounts for around 90 % of all diesel fuel consumed by railway locomotives in Denmark and the remaining diesel fuel is used by various private railways companies. Setting up contacts with the private transport operators is considered a rather time consuming experience taking time away from inventory work in areas of greater emission importance.

EMEP/EEA guidebook

Fuel consumption and emission data from the EMEP/EEA guidebook is the prime and basic source for the aviation and navigation part of the Danish emission inventories. For aviation, the guidebook contains the most comprehensive list of representative aircraft types available for city-pair fuel consumption and emission calculations. The data have been provided by Eurocontrol (the European aviation safety organization) specifically for detailed national inventory use and was evaluated by the transport expert panel in the TFEIP (Task Force for Emission Inventories and Projections) under UNECE CLRTAP.

In addition, the EMEP/EEA guidebook is the source of non-exhaust TSP, PM_{10}, $PM_{2.5}$ and BC emission factors for road transport, and the primary source of emission factors for some emission components – typically N_2O, NH_3 and PAH – for other mobile sources.

Non-road machinery (fuel consumption and emission factors)

The references for non-road machinery fuel consumption and emission factors are listed in Winther (2022a) and in the present report. The fuel consumption and emission data is regarded as one of the most comprehensive data collections on a European level, having been thoroughly evaluated by German emission measurement and non-road experts in German non-road inventory projects.

National navigation and fisheries

Emission factors for NO_X, VOC and CO are taken from the TEMA2015 model developed for the Ministry of Transport. To a large extent, the emission factors originate from the exhaust emission measurement programme carried out by Lloyd's (1995). For TSP, IMO (2015) is the source for the emission factors. For NO_X, additional information of emission factors for engine manufacturing years going back to 1949, as well as NO_X, VOC and CO emission factors for engines built after 2010, was provided by the engine manufacturer MAN Energy Solutions. PM_{10} and $PM_{2.5}$ fractions of total TSP were also provided by the latter source.

Specifically for the ferries used by Mols Linjen, new NO_x, VOC and CO emission factors are provided by Kristensen (2008), originating from measurement results by Hansen et al. (2004), Wismann (1999) and PHP (1996). Kristensen (2013, 2019) has provided complimentary emission factor data for new ferries.

The experimental work by Lloyd's is still regarded as the most comprehensive measurement campaign with results publicly available. The additional NO_X and $PM_{10}/PM_{2.5}$ information comes from the world's largest ship engine manufacturer and data from this source is consistent with data from Lloyd's. Consequently, the data used in the Danish inventories for national sea transport is regarded as the best available for emission calculations.

Data Storage level 1	1. Accuracy	DS.1.1.1	General level of uncertainty for every dataset, including the reasoning for the specific values

The uncertainty involved in the DEA fuel consumption information (except civil aviation) and the Danish Transport and Construction Agency flight statistics is negligible, as such, and this is also true for DMI temperature data. For civil aviation, some uncertainty prevails, since the domestic fuel consumption figures originate from a division of total jet-fuel sales figures into domestic and international fuel quantities, derived from bottom-up calculations. A part of the fuel consumption uncertainties for non-road machines is due to the varying levels of stock and operational data uncertainties, as explained in DS 1.3.1.

As regards emission factors, the CO_2 factors (and NCVs) from the DEA are considered very precise, since they relate only to fuel. For the remaining emission factor sources, the SO_2 (based on fuel sulphur content), NO_X, NMVOC, CH_4, CO, TSP, PM_{10} and $PM_{2.5}$ emission factors are less accurate. Though many measurements have been made, the experimental data rely on the individual measurement and combustion conditions. The uncertainties for N_2O and NH_3 emission factors are even higher due to the small number of measurements available. For heavy metals and PAH, experimental data are so scarce that uncertainty becomes very high.

A special note, however, must be made for energy. The uncertainties due to the subsequent treatment of DEA data for road transport, national sea transport, fisheries and the non-road relevant sectors, explained in DS 1.3.1, trigger some uncertainties in the fuel consumption figures for these sectors. This point is, though, more relevant for QA/QC description for data processing, Level 1.

Data Storage level 1	2.Comparability	DS.1.2.1	Comparability of the emission factors/calculation parameters with data from international guidelines, and evaluation of major discrepancies.

Work has been carried out to compare Danish figures with corresponding data from other countries in order to evaluate discrepancies. The comparisons have been made on a CRF level, mostly for implied emission factors (Fauser et al., 2007, 2013).

Data Storage level 1	4.Consistency	DS.1.4.1	The origin of external data has to be archived with proper reference.

It is ensured that the original files from external data sources are archived internally at DCE. Subsequent raw data processing is carried out either in the DCE database models or in spreadsheets (data processing level 1).

Data Storage level 1	6.Robustness	DS.1.6.1	Explicit agreements between the external institution holding the data and DCE about the condition of delivery

For transport, DCE has made formal agreements with regard to external data deliverance with (Table 3.3.21 external data source Id's in brackets): DEA (T1), the Danish Civil Aviation and Railway Authority (T3), Danish State Railways (T9) and DTU Transport (T2).

Data Storage level 1	7. Transparency	DS.1.7.1	Listing of all archived datasets and external contacts

The listing of all archived datasets and external contact persons are given in Table 3.3.21.

Data Processing Level 1

Data Processing level 1	1. Accuracy	DP.1.1.1	Uncertainty assessment for every data source not part of DS.1.1.1 as input to Data Storage level 2 in relation to type and scale of variability.

The general uncertainties of the DEA fuel consumption information, DMI temperature data, road transport stock totals and the Danish Aviation and Railway Authority flight and train km statistics are zero. For domestic aviation fuel consumption, the uncertainty is based on own judgement. For road transport, military and railways the fuel consumption uncertainties are taken from the IPCC Good Practice Guidance manual. It is noted that for road transport, it is not possible to quantify in-depth the uncertainties (1) of stock distribution into COPERT 5 relevant vehicle subsectors and (2) of the national mileage figures, as such.

In the mobile part of the Danish emission inventories, uncertainty assessments are made at Data Processing Level 1 for non-road mobile machinery, recreational craft and national sea transport. For these types of mobile machinery, the stock and operational data variations are assumed to be normally distributed (Winther et al., 2006; Winther, 2008). Tier 1 uncertainty calculations produce final fuel consumption uncertainties ready for Data Storage Level 2 (SNAP level 2: Inland waterways, agriculture, forestry, industry and household-gardening). The sizes of the variation intervals are given for activity data and emission factors in the present report.

For non-road mobile machinery stock and operational data, the uncertainty figures are given in Winther et al. (2006). For navigation, the uncertainty figures are given in Winther (2008).

For emission factors, the uncertainties for mobile sources are determined as suggested in the IPCC and UNECE guidelines. The uncertainty figures are listed in Paragraph 1.1.5 for greenhouse gases, and in Winther et al. (2006) and Winther (2008, 2022a) for the remaining emission components.

Data Processing level 1	1. Accuracy	DP.1.2.1	The methodologies have to follow the international guidelines suggested by UNFCCC and IPCC.

An evaluation of the methodological inventory approach has been made, which proves that the emission inventories for transport are made according to the IPCC guidelines (IPCC, 2006). Further, the Danish inventories are reviewed annually by the UNFCCC.

Data Processing level 1	1. Accuracy	DP.1.1.4	Verification of calculation results using guideline values

It has been checked that the greenhouse gas emission factors used in the Danish inventory are within margin of the IPCC guideline values.

Data Processing level 1	3.Completeness	DP.1.3.1	Identification of data gaps with regard to data sources that could improve quantitative knowledge.

No important areas can be identified.

Data Processing level 1	4.Consistency	DP.1.4.1	Documentation and reasoning of methodological changes during the time series and the qualitative assessment of the impact on time series consistency.

See DP 1.7.5.

Data Processing level 1	5.Correctness	DP.1.5.2	Verification of calculation results using time series

Data Processing level 1	5.Correctness	DP.1.5.3	Verification of calculation results using other measures

For road transport, aviation, navigation and non-road machinery, whether all external data are correctly put into DCE's DEMOS model system is checked. This is facilitated by the use of sum queries, which sum up stock data (and mileages for road transport) to input aggregation levels. However, spreadsheet or database manipulations of external data are, in some cases, included in a step prior to this check.

This is carried out in order to produce homogenous input tables for the DEMOS sub-models (Road, Railways, Aviation, Navigation, NRMM). The subroutines perform operations, such as the aggregation/disaggregation of data into first sales year (Examples: Fleet numbers and mileage for road transport, stock numbers for tractors, harvesters and fork lifts) or simple lists of total stock per year (per machinery type for e.g. household equipment and for recreational craft). For civil aviation, additional databases control the allocation of representative aircraft to real aircraft types and the flown distance between airports. A more formal description of the sub-routines will be made.

Regarding fuel data, it is checked for road transport and civil aviation that DEA totals (modified for road) match the input values in the DEMOS submodels. For the transport modes military, the DEA fuel consumption figures go directly into Data Storage Level 2. This is also the case in general, for the emission factors, which are kept constant over the years.

The DEMOS model simulations of fuel consumption and emission factors for road transport, railways, civil aviation, navigation, fishing and non-road mobile machinery refer to Data Processing Level 1.

When DEMOS model changes are made relating to fuel consumption, it is checked that the calculated fuel consumption sums correspond to the expected fuel consumption levels in the time series. The fuel consumption check also includes a time series comparison with fuel consumption totals calculated in the previous model version. The checks are performed on a SNAP level and, if appropriate, detailed checks are made for vehicle/-machinery technology splits.

As regards model changes in relation to derived emission factors (and calculated emissions), the time series of emission factors (and emissions) are compared to previous model figures. A part of this evaluation includes an assessment, if the development corresponds to the underlying assumptions given by detailed input parameters. Among other things, the latter parameters depend on emission legislation, new technology phase-in, deterioration factors, engine operational conditions/driving modes, gasoline evaporation (hydrocarbons) and cold starts. For methodological issues, please refer to Section 3.3.2.

Data Processing level 1	7.Transparency	DP.1.7.1	The calculation principle, the equations used and the assumptions made must be described

The DEMOS model calculation principles and basic equations are thoroughly described in the present report, together with the theoretical model reasoning and assumptions. Documentation is also given e.g. in Winther (2001a, 2001b, 2008, 2022) and Winther et al. (2006). Further formal descriptions of DEMOS model sub routines are given in internal notes, and flow maps show the interrelations between tables and calculation queries in the models.

During model development, it has been checked that all mathematical model relations give exactly the same results as independent calculations.

Data Processing level 1	7.Transparency	DP.1.7.2	Clear reference to dataset at Data Storage level 1

In the different documentation reports for transport in the Danish emission inventories, there are explicit references for the different external data used.

Data Processing level 1	7.Transparency	DP.1.7.3	A manual log to collect information about recalculations

Recalculation changes in the emission inventories are described in the NIR and IIR reports as a standard. These descriptions take into account changes in emission factors, activity data and calculation methods.

Data Storage Level 2

Data Storage level 2	5.Correctness	DS.2.5.1	Check if a correct data import to level 2 has been made

At present, a DCE software program imports data from prepared input data tables (SNAP fuel consumption figures and emission factors) into the CollectER database.

Tables for CollectER fuel consumption and emission results are prepared in a special DCE database (NERIrep.mdb). The results relevant for mobile sources are copied into a database containing all the official inventory results for mobile sources (Data2021 NIR-UNECE.mdb). By the use of database queries, the results from this latter database are aggregated into the same formats as being used by the relevant DCE transport models in their results calculation part. The final comparison between CollectER and DEMOS transport model results are set up in a spreadsheet.

Data Storage Level 4

Data Storage level 4	4.Consistency	DS.4.4.3	The IEFs from the CRF are checked regarding both level and trend. The level is compared to relevant emission factors to ensure correctness. Large dips/jumps in the time series are explained

A spreadsheet "Check CRF 2021.xls" has been set up to check that the fuel consumption and emission totals from CollectER imported in Data2021 NIR-UNECE.mdb are identical to the fuel consumption and emission totals from the CRF.

3.3.7 Recalculations and improvements

Road transport

For road transport the following changes have been made.

- More precise fleet information on the number of diesel passenger cars and vans retrofitted with particulate filters, and reclassifications of some of the diesel passenger cars and vans from Euro 5 to Euro 4 in fleet data.
- Diesel fuel consumption for road transport has slightly decreased due to a subtraction of the diesel fuel used by recreational craft. In the previous inventory submissions this fuel was subtracted from the fishery sector in the energy statistics. However, according to the Ministry of Taxation the diesel fuel for recreational craft is purchased at road transport fuel stations, and must therefore be subtracted from road transport instead in the energy statistics.
- Gasoline fuel consumption for road transport has slightly decreased due to more annual working hours for residential gasoline machinery, and hence larger calculated amounts of gasoline for these machinery types in the inventories. This gasoline fuel consumption change has an impact on the gasoline fuel balance made across sectors to account for total gasoline fuel sales.

The percentage emission change interval and year of largest absolute percentage differences (low %; high %, year) for the different emission components are: CO_2 (-0.7 %, -0.3 %, 2013), CH_4 (-3.2 %; 0.4%, 2010) and N_2O (-1.0 %; 0.04 %, 2013).

Navigation

For navigation the following changes have been made.

- An error in diesel fuel input data has been corrected for the years 2015-2018.
- An error in the VOC/CH_4 split for marine diesel has been corrected, and is now in line with the original data from EMEP/EEA (2019).
- A few changes in sailing time, main engine size and engine load factors has been made for some of the small island ferries.
- The fuel type Gas-to-liquid (GTL) has been used by some small ferries since 2018, and is introduced in the inventories for the years 2018-2021.

The following largest percentage differences (in brackets) for navigation are noted for CO_2 and N_2O in 2015 (-21 %), 2016 (-19 %), 2017 (-18 %) and 2018 (-19 %). For CH_4 the largest percentage differences become -33 % for the years before 2015.

Fisheries

For fisheries the following changes have been made.

- An error in the VOC/CH_4 split for marine diesel has been corrected, and is now in line with the original data from EMEP/EEA (2019).
- Diesel fuel consumption for fisheries has slightly increased. In the previous inventory submissions the diesel fuel used by recreational craft was subtracted from the fishery sector. However, according to the Ministry of Taxation the diesel fuel for recreational craft is purchased at road transport fuel stations, and this fuel must therefore be subtracted from road transport instead of fisheries in the overall energy input data.

The following largest percentage differences (in brackets) for fisheries are noted in 2020 for CO_2 (28 %) and N_2O (28 %). For CH_4 the percentage differences gradually decrease from -31 % in 1985 to -15 % in 2020.

Agriculture/forestry

For agriculture/forestry the following changes have been made.

- Engine load factors for agricultural tractors and harvesters are substantially reduced based on telemetri data gathered in the emission inventory for the UK.
- Updated stock and utility data for small gasoline machinery types (e.g. sweepers, bedding machines, fodder trucks) are provided by agricultural key experts, and used as input for updated inventory calculations for the years 1990-2020.
- Small adjustments are made in the total stock for forestry machinery due to errors discovered for the years 2005-2020.

For CO_2 and N_2O the percentage differences for the years 1995-2003 are approximately -31 %, and then gradually reduce to -21 % in 2020. For CH_4 the largest percentage difference is -17 % in 2020.

Industry

For industry the following changes have been made.

- Engine load factors for tractors used in industry (building and construction, manufacturing industries) and commercial/institutional non road

sectors has been substantially lowered based on telemetri data gathered in the emission inventory for the UK.
- Updated stock information of diesel fueled Stage IIIB and IV non road machinery for building and construction machinery equipped with diesel particulate filters.
- Updated PM emission factors for Stage IIIB, IV and V diesel machinery based on new emission measurement data gathered by ICCT (2016).
- Proxy data development in the 1985-2021 periods are used to adjust stock numbers for small sources machinery types, e.g. pumps, compressors and personal lifts.
- Updated number of refrigeration units on board Danish long distance and local distribution trucks based on data from Danish Technological Institute.

The following largest percentage differences (in brackets) for industry are noted for CO_2 (12 %), CH_4 (44 %) and N_2O (11 %).

Commercial and institutional

For commercial and institutional the following changes have been made.

- Engine load factors for tractors used in industry (building and construction, manufacturing industries) and commercial/institutional non road sectors has been substantially reduced based on telemetri data gathered in the emission inventory for the UK.

The following largest percentage differences (in brackets) for commercial and institutional are noted for CO_2 (-12 %), CH_4 (-1 %) and N_2O (-14 %).

Residential

For residential the following changes have been made.

- The calculated gasoline fuel consumption for residential gasoline machinery has slightly increased due to more annual working hours expected for these machinery types.

The following largest percentage differences (in brackets) for residential are noted for CO_2 (38 %), CH_4 (38 %) and N_2O (67 %).

Railways

A major inventory revision has been made for railways. A new model has been developed which include Tier 3 estimates for fuel consumption and emissions for train traffic carried out by private railways.

- The fuel type Gas-to-liquid (GTL) has been used by some private railway companies since 2018, and is introduced in the railways emission inventories for the years 2018-2021.

The following largest percentage differences (in brackets) for railways are noted for CO_2 (0 %), CH_4 (-5 %) and N_2O (0 %).

Civil aviation

No changes have been made.

Other (Military and recreational craft)

Updated emission factors derived from the road transport model in the case of military equipment for all years have caused small emission changes from 1985-2020.

The following largest percentage differences (in brackets) for the Other sector are noted for CO_2 (-2.6 %), CH_4 (-0.2 %) and N_2O (0.5 %).

3.3.8 Response to the review process

The table below contains the recommendations of the most recent UNFCCC review of the Danish greenhouse gas inventory. The table details the status of implementation of the recommendations as well as references to where improvements have been implemented in this report. A review of the Danish 2021 submission took place in September 2021. At the time of preparing this report, Denmark had not yet received a draft review report. Therefore, the table below represents the latest available report.

Table 3.3.22 Response to the review process.

Para.	CRF	ERT Comment	Denmark's response	Reference
2018 submission (Review report: https://unfccc.int/sites/default/files/resource/dnk_0.pdf)				
E.2	1.A.3.a Domestic aviation – gasoline – CH_4 (E.7, 2020) Transparency	Revise the incorrect reference to the source of the EFs for CH_4 emissions from piston engine aircraft using aviation gasoline.	The reference is corrected in the 2022 submission.	
E.3	1.A.3.d Domestic navigation – liquid and gaseous fuels – CO_2 and CH_4 (E.4, 2020) (E.4, 2018) Comparability	Reallocate emissions from LNG used in ferries from natural gas liquid to gaseous fuels in CRF table 1.A(a).	The reallocation is made in the 2022 submission.	
E.7	1.A.3 Transport – all fuels – CO_2, CH_4, N_2O	The Party reported in NIR table 3.3.3 (p.173) fuel consumption (in PJ) for domestic transport for 2019. The data listed in the table appear to differ from those used to develop road transport results in NIR figure 3.3.4 (p.175) and from the reporting for mobile sources in CRF tables 1.A(a)s2, 1.A(a)s3 and 1.A(a)s4. For example, NIR figure 3.3.4 indicates energy use for two-wheelers as 0 PJ over time, while NIR table 3.3.3 reports fuel consumption for road transport: mopeds and motorcycles as 53.0 PJ for 2019. During the review, the Party clarified that it encountered a copy/paste issue while entering the NIR chapter data in table 3.3.3. The Party clarified that the data in the CRF table are correct. The ERT recommends that the Party correct the fuel consumption values (in PJ) listed for 2019 in NIR table 3.3.3, as appropriate, to ensure consistency with the values reported for road transport in NIR figure 3.3.4 (p.175) and the reporting for mobile sources in CRF tables 1.A(a)s2, 1.A(a)s3 and 1.A(a)s4.	The error in the NIR report is corrected in the present NIR report.	

3.3.9 Planned improvements

No planned improvements are envisaged to be made.

QA/QC
Future improvements regarding this issue are dealt with in Section 3.1.4.

3.3.10 References for Chapter 3.3

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3.4 Additional information, CRF sector 1A Fuel combustion

3.4.1 Reference approach, feedstocks and non-energy use of fuels

In addition to the sector specific CO_2 emission inventories (the sectoral approach - SA), the CO_2 emission is also estimated using the reference approach (RA) described in the IPCC Guidelines (IPCC, 2006). The reference approach is based on data for fuel production, import, export and stock change. The CO_2 emission inventory based on the reference approach is reported to the Climate Convention and used for verification of the sectoral approach.

Methodology and data input

Data for import, export and stock change used in the reference approach originate from the annual "basic data" table prepared by the Danish Energy Agency (DEA) and published on their home page (DEA, 2022a). The fraction of carbon oxidised has been assumed 1.00.

The applied carbon emission factors are equal to the emission factors also applied in the sectoral approach and thus include nationally referenced emission factors. This is in agreement with the 2006 IPCC Guidelines.

The Climate Convention reporting tables include a comparison of the sectoral approach and the reference approach estimates.

The consumption for non-energy purposes is subtracted in the reference approach, because non-energy use of fuels is included in other sectors (2D Non-energy products from fuels and solvent use) in the Danish sectoral approach. Three fuels are used for non-energy purposes: lubricants, bitumen and white spirit. The total consumption for non-energy purposes is relatively low, in 2021 the consumption was 9.5 PJ.

The CO_2 emission from oxidation of lube oil during use was 31.7 kt in 2021 and this emission is reported in the sector Non-energy products from fuels and solvent use (sector 2D). The reported emission corresponds to 20 % of the CO_2 emission from lube oil consumption assuming full oxidation. This is in agreement with the methodology for lube oil emissions in the 2006 IPCC Guidelines (IPCC, 2006). Methodology and emission data for lube oil are shown in NIR Chapter 4.5.3.

For white spirit, the CO_2 emission is indirect as the emissions occur as NMVOC emissions from the use of white spirit as a solvent. The indirect CO_2 emission from solvent use was 70.4 kt in 2021. The methodology and emission data for white spirit are included in NIR Chapter 4.5.4.

The CO_2 emission from bitumen is included in sector 2.D.3, Road paving with asphalt and Asphalt roofing. The total CO_2 emissions for these sectors are 0.86 kt in 2021. Methodology and emission data for non-energy use of bitumen are shown in NIR Chapter 4.5.6.

Results

The sectoral approach and the reference approach have been compared and the differences between the two approaches are shown in Table 3.4.1 below.

Table 3.4.1 Difference between sectoral approach and reference approach.

Year	Difference Energy consumption [%]	Difference CO_2 emission [%]
1990	0.28	-0.36
1991	-0.55	-0.99
1992	-0.02	-0.67
1993	-0.40	-1.04
1994	-0.31	-0.92
1995	-0.56	-0.97
1996	-0.48	-0.79
1997	-0.03	-0.16
1998	1.50	1.30
1999	-0.58	-0.92
2000	0.27	0.02
2001	0.75	0.60
2002	0.05	-0.16
2003	0.10	-0.10
2004	0.00	-0.20
2005	-0.88	-0.95
2006	-0.69	-0.92
2007	-0.96	-1.09
2008	-0.21	-0.39
2009	-1.67	-1.81
2010	0.12	-0.26
2011	-0.99	-1.16
2012	-1.54	-1.97
2013	-0.79	-1.20
2014	-1.41	-1.72
2015	-1.49	-1.88
2016	-2.77	-3.41
2017	-0.66	-0.94
2018	-1.31	-1.63
2019	-0.89	-1.44
2020	-0.90	-1.96
2021	-1.89	-2.99

The comparison of the sectoral approach and the reference approach is illustrated in Figure 3.4.1. In 2021, the fuel consumption rates in the two approaches differ by 1.89 % and the CO_2 emission differs by 2.99 %. Both the fuel consumption and the CO_2 emission differ by less than 2 % for all years except 2016 and 2021. The high difference for CO_2 emission in 2021 is mainly related to solid and liquid fuels.

The fluctuations in Figure 3.4.1 follow the fluctuations of the statistical difference in the Danish energy statistics shown in Figure 3.4.2. The large differences in certain years, e.g. in 1998, 2016 and 2021 are due to high statistical differences in the Danish energy statistics in these years.

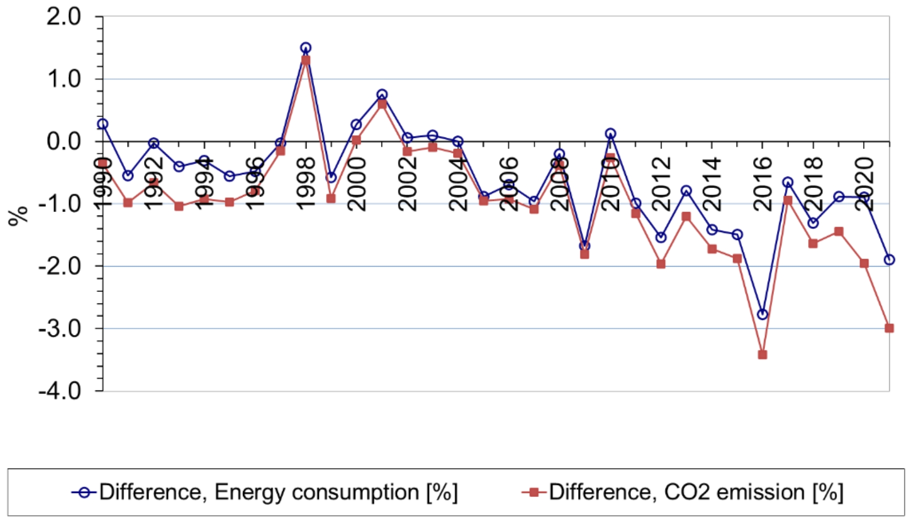

Figure 3.4.1 Comparison of the reference approach and the sectoral approach.

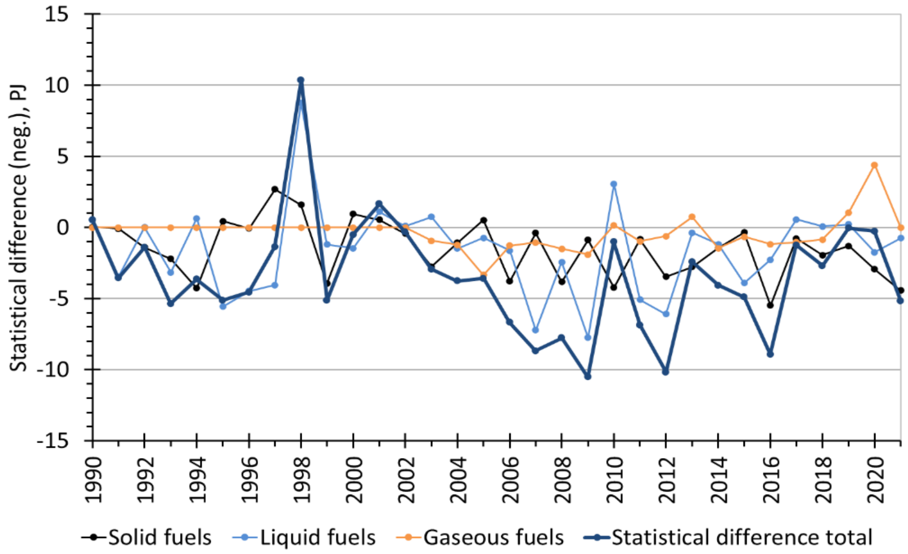

Figure 3.4.2 Statistical difference in the Danish energy statistics (DEA, 2021a).

The difference between SA and RA for CO_2-emission is above 2 % for 2016 and 2021. The reason for this has been further analysed.

The large differences between RA and SA in 2016 and 2021 are mainly related to fuel consumption data. The fuel consumption applied in the SA was higher than in the RA for all fuel categories for 2016 and 2021.

Analysis of the differences between the sectoral approach and the reference approach

The difference between the sectoral approach and the reference approach is above 2 % for 2016 and 2021. The sources causing the differences for 2016 and 2021 have been analysed for each of the fossil fuel categories.

Solid fuels

The difference for solid fuels in 2016 is 6.2 % or 5.5 PJ. The statistical difference for solid fuels in the Danish energy statistics is 5.5 PJ for 2016. This difference mainly relates to coal (5.5 PJ). Thus, the difference between approaches is a result of the statistical difference in the energy statistics.

For 2021, the difference for solid fuels is 10.1% or 4.5 PJ. The statistical difference for solid fuels in the Danish energy statistics is 4.4 PJ for 2021. This difference mainly relates to coal (4.4 PJ). Thus, the difference between approaches is a result of the statistical difference in the energy statistics.

A time series for the difference of solid fuel consumption is shown in Figure 3.4.3.

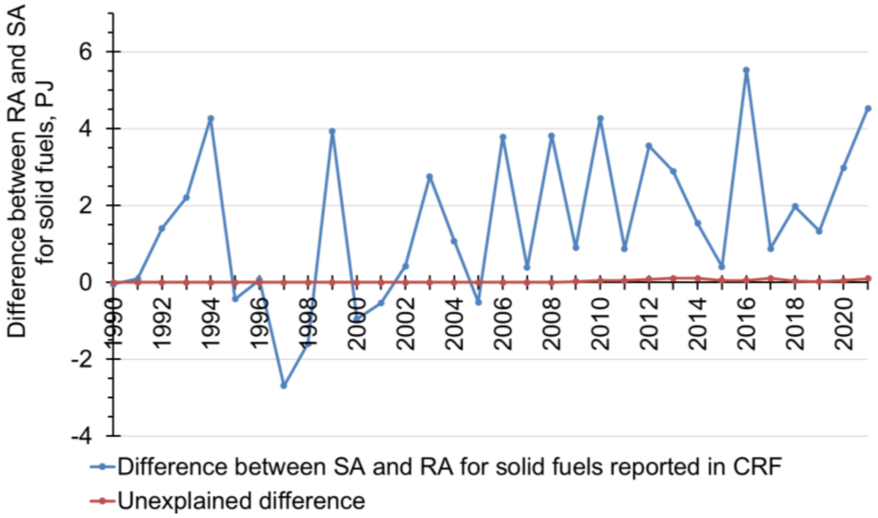

Figure 3.4.3 Difference between RA and SA for solid fuels reported in CRF and the difference not explained by statistical difference of the Danish energy statistics.

Liquid fuels

The difference for <u>liquid fuels</u> in 2016 is 1.8 % or 4.4 PJ. This difference has been further analysed and several sources identified.

- The statistical difference for liquid fuels in the Danish energy statistics is 2.3 PJ for 2016. This difference mainly relates to crude oil (3.7 PJ), motor gasoline (-0.9 PJ) and gas-/diesel oil (-0.8 PJ).
- The Danish energy statistics includes data for net input of blends. In 2016, the net input was 0.2 PJ.
- In the Danish energy statistics, the fuel input to refineries is not equal to the fuel output added to fuel consumption. In 2016, the difference was 2.7 PJ.
- For refinery gas, the fuel consumption applied in the SA is based on EU ETS data rather than the energy statistics (see NIR Chapter 3.2.5). For 2016, the fuel consumption in EU ETS that are applied in SA is 0.7 TJ lower than the data from the energy statistics.

The explained differences for liquid fuels in 2016 add up to 5.4 PJ. Thus, only the remaining 1.0 PJ is not explained.

For 2021, the difference for liquid fuels is 0.7 % or 1.7 PJ.

- The statistical difference is 0.8 PJ. This difference mainly relates to crude oil (2.2 PJ), motor gasoline (0.6 PJ) and gas-/diesel oil (-2.2 PJ).
- The Danish energy statistics includes data for net input of blends. In 2021, the net input was 0.9 PJ.
- In the Danish energy statistics, the fuel input to refineries is not equal to the fuel output added to fuel consumption. In 2021, the difference was 0.9 PJ.

- For refinery gas, the fuel consumption applied in the SA is based on EU ETS data rather than the energy statistics (see NIR Chapter 3.2.5). For 2021, the fuel consumption in EU ETS that are applied in SA is 0.3 TJ lower than the data from the energy statistics.

The explained differences for liquid fuels in 2021 add up to 1.0 PJ. Thus, only the remaining 0.7 PJ is not explained.

The time series for reported difference for liquid fuels between SA and RA for 1990-2021 is shown in Figure 3.4.4 below. In the figure, the estimated difference taking into account the four known sources explained above is also shown.

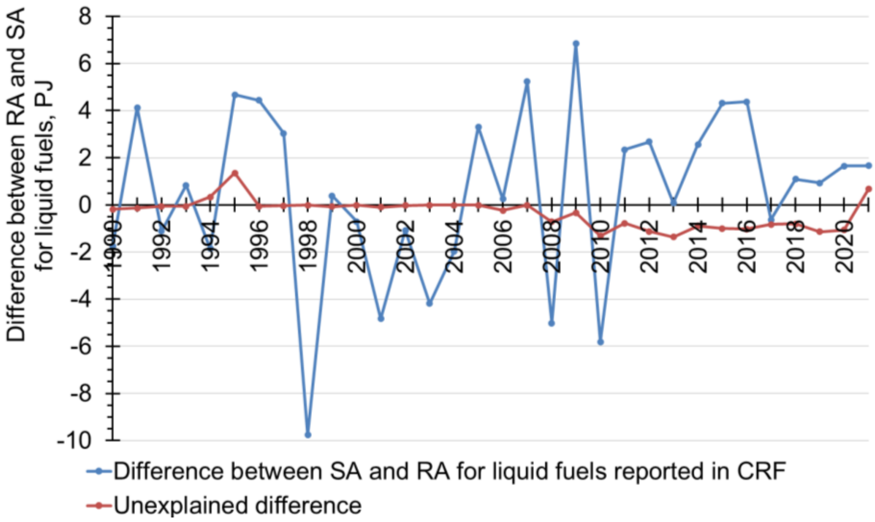

Figure 3.4.4 Difference between RA and SA for liquid fuels reported in CRF and the difference not explained by four known sources.

Gaseous fuels

For 2016, the difference for gaseous fuels is 1.7 % or 2.1 PJ. The statistical difference for gaseous fuels in the Danish energy statistics is 1.2 PJ for 2016. For offshore gas turbines the fuel consumption applied in the sectoral approach is based on EU ETS data rather than the energy statistics (see NIR Chapter 3.2.5). For 2016, the consumption in EU ETS that are applied in SA was 1.2 PJ higher than the data from the energy statistics. The difference between SA and RA for gaseous fuels is shown in Figure 3.4.5 below. The remarkable difference for 2020 is related to a large statistical difference for gaseous fuels in 2020.

DEA has further improved data collection for natural gas consumption, and this has caused lower statistical differences for 2021 onwards.

A time series for the difference of gaseous fuels consumption is shown in Figure 3.4.5.

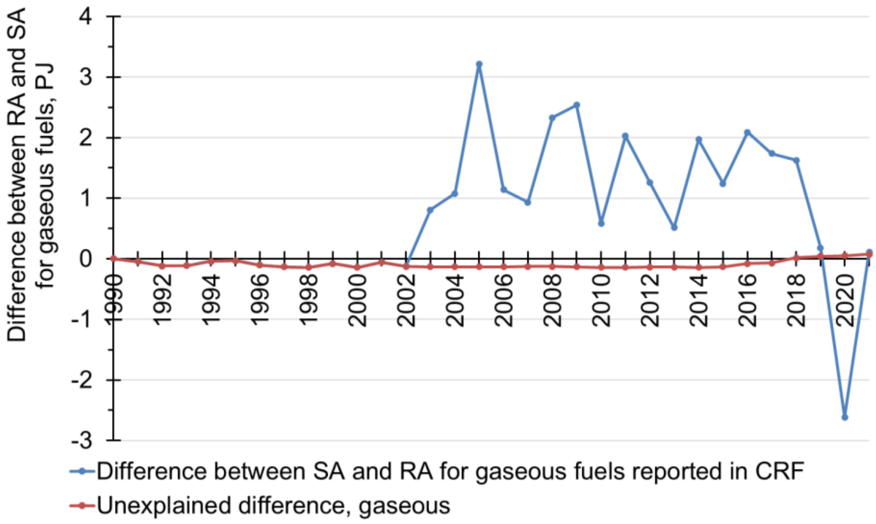

Figure 3.4.5 Difference between RA and SA for gaseous fuels reported in CRF and the difference not explained by three known sources.

Other fossil fuels

For 2016, the difference for <u>other fossil fuels</u> (fossil waste) is 5.7 % or 1.1 PJ.

The statistical difference for fossil waste in the Danish energy statistics is 0.0 PJ for 2016. The fossil part of waste applied in the Danish cement production plant is higher than for other waste applied in Danish incineration plants. The higher fossil part of the energy content of waste applied in the cement production plant have been implemented in the SA but not in the RA. For 2016, this corresponds to a 0.5 PJ difference. In addition, the combustion of waste in individual plants implemented in the SA for 2016 added up to a higher total than included in the energy statistics. This difference corresponds to a difference of 0.2 PJ fossil waste. Finally, the fossil part of biodiesel reported in SA sector 1A3 is included in the fuel category other fossil fuels. This fuel consumption is included in biomass in RA. In 2016, the fossil part of biodiesel added up to 0.4 PJ.

The higher waste consumption based on the plant specific data than included the energy statistics is related to the applied fuel group for some specific biomass waste fractions. The recent implementation of EU ETS data as a data source for the industrial subsectors has improved transparency and the agreement between the two data sets.

For 2021, the difference for other fossil fuels (fossil waste) is 4.7 % or 0.9 PJ. The statistical difference for fossil waste in the Danish energy statistics is 0.0 PJ for 2021. The fossil part of waste applied in the Danish cement production plant is higher than for other waste applied in Danish incineration plants. The higher fossil part of the energy content of waste applied in the cement production plant have been implemented in the SA but not in the RA. For 2021, this corresponds to a 0.5 PJ difference. Finally, the fossil part of biodiesel reported in SA sector 1A3 is included in the fuel category other fossil fuels. This fuel consumption is included in biomass in RA. In 2021, the fossil part of biodiesel added up to 0.4 PJ.

A time series for the fuels consumption difference for other fossil fuels (fossil waste) is shown in Figure 3.4.6.

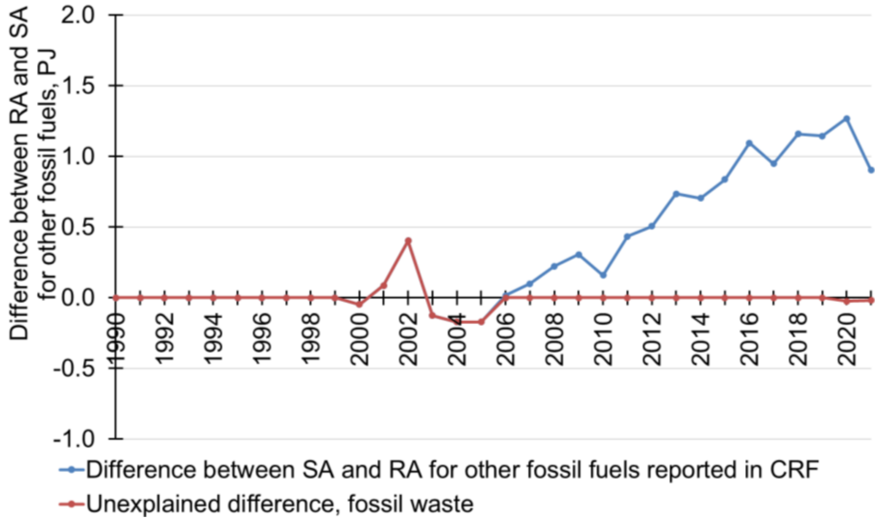

Figure 3.4.6 Difference between RA and SA for other fossil fuels reported in CRF and the difference not explained by four known sources.

Recalculations and improvements

Data for both reference approach and national approach have been updated according to the latest energy statistics.

Response to the review process

One issue is from the review process is relevant for the reference approach. The issue shown below refer to the *Report on the individual review of the annual submission of Denmark submitted in 2021*.

The issue has been resolved in the 2023 reporting.

Regarding implementation of data for international bunkers in the Reference Approach for Faroe Islands, see NIR Annex 7. Consistency between CRF tables 1.D and 1.A(b) are now checked for both CRF reportings: Denmark (DNM), and Denmark, Greenland and Faroe Islands (DNK).

Table 3.4.2 Response to the review process.

E.1	International bunkers and multilateral operations – liquid fuels – CO2 (E.6, 2020) (E.7, 2018) Convention reporting adherence	Ensure consistent reporting between CRF tables 1.D and 1.A(b) for jet kerosene consumed in international aviation bunkers (1990–2000) and for residual fuel oil consumed in international navigation bunkers.	Not resolved. The Party continued to report inconsistent values in CRF tables 1.D and 1.A(b) since the Faroe Islands reporting used only the sectoral approach and not the reference approach. During the review, the Party clarified that efforts to improve the Faroese inventory are ongoing and that it plans to include the reference approach data in the 2022 submission. In response to the draft review report, Denmark informed the ERT that the reference approach will not be fully implemented for the Faroe Islands before the 2023 submission.

Planned improvements

The differences mentioned above are part of the ongoing dialogue with the Danish Energy Agency.

3.4.2 References for Chapter 3.4

Danish Energy Agency (DEA), 2022a: The Danish energy statistics, Available at: https://ens.dk/sites/ens.dk/files/Statistik/grunddata2021_-_basicdata2021.xlsx (2023-01-26).

IPCC, 2006: Revised 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at:
http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (2023-01-26).

3.5 Fugitive emissions (CRF sector 1B)

3.5.1 Overview of sector

Fugitive emissions from fuels include emissions from production, storage, refining, transport, venting and flaring of oil and natural gas. Denmark has no production of solid fuels, and accordingly greenhouse gas emissions from solid fuels are not occurring. The fugitive sector consists of the following CRF categories:

- 1B2a Oil
- 1B2b Natural gas
- 1B2c Venting and flaring

Most fugitive emission sources are of minor importance compared to the total Danish emissions. Fugitive and national total emissions are given in Table 3.5.1. Note that the data presented in Chapter 3 relate to Denmark only, whereas information for Greenland is included in Chapter 16 and for the Faroe Islands in Annex 7.

Table 3.5.1 National and fugitive emissions of CO_2, CH_4 N_2O and GHG in 2021, and the fugitive emissions share of national total emissions.

	National emission	Fugitive emission	Fugitive/national emission
	kt CO_2 eqv.	kt CO_2 eqv.	%
CO_2	29 608	111	0.4
CH_4	8 591	61	0.7
N_2O	5 116	0.05	<0.01
GHG	43 606	172	0.4

Table 3.5.2 list the results from the key category analysis for approach 1 and approach 2 for fugitive emission sources.

Table 3.5.2 Key categories in the fugitive emission sector.

CRF table	Pollutant	Key category identification	
		Approach 1	Approach 2
1.B.2.a.1 Exploration, oil	CO_2	-	-
1.B.2.a.2 Production, oil	CO_2	-	-
1.B.2.a.4 Refining/storage	CO_2	-	-
1.B.2.b.1 Exploration, gas	CO_2	-	-
1.B.2.b.2 Production, gas	CO_2	-	-
1.B.2.b.4 Transmission and storage, gas	CO_2	-	-
1.B.2.b.5 Distribution, gas	CO_2	-	-
1.B.2.c.1.ii Venting, gas	CO_2	-	-
1.B.2.c.2.i Flaring, oil	CO_2	-	-
1.B.2.c.2.ii Flaring, gas	CO_2	-	-
1.B.2.c.2.iii Flaring, combined	CO_2	Level (1990)	-
1.B.2.a.1 Exploration, oil	CH_4	-	-
1.B.2.a.2 Production, oil	CH_4	-	-
1.B.2.a.3 Transport, oil	CH_4	-	-
1.B.2.a.4 Refining/storage	CH_4	-	-
1.B.2.b.1 Exploration, gas	CH_4	-	-
1.B.2.b.2 Production, gas	CH_4	-	-
1.B.2.b.4 Transmission and storage, gas	CH_4	-	-
1.B.2.b.5 Distribution, gas	CH_4	-	-
1.B.2.c.1.ii Venting, gas	CH_4	-	-
1.B.2.c.2.i Flaring, oil	CH_4	-	-
1.B.2.c.2.ii Flaring, gas	CH_4	-	-
1.B.2.c.2.iii Flaring, combined	CH_4	-	-
1.B.2.a.1 Exploration, oil	N_2O	-	-
1.B.2.c.2.i Flaring, oil	N_2O	-	-
1.B.2.c.2.ii Flaring, gas	N_2O	-	-
1.B.2.c.2.iii Flaring, combined	N_2O	-	-

Calculations of fugitive emissions are to the highest degree possible, based on Tier 2 and Tier 3 methodologies. The methodological Tiers and the level of detail for the applied emission factors in are listed in (Table 3.5.3).

Table 3.5.3 Applied methodology for fugitive emission sources.

CRF	Source	Pollutant	Method	Emission factor
1 B 2 a i	Exploration of oil	CO_2	Tier 3	PS
		CH_4	Tier 3	CS
		N_2O	Tier 3	D1
1 B 2 a ii	Production of oil	CO_2	Tier 1	D1
		CH_4	Tier 1	D1
1 B 2 a iii	Transport	CH_4	Tier 2	PS, CS, D2
1 B 2 a iv	Refining/storage	CO_2	Tier 3	CS(1990-2005), PS(2006 onwards)
		CH_4	Tier 3	PS, CS
1 B 2 b i	Exploration of gas	CO_2	Tier 3	PS
		CH_4	Tier 3	CS
		N_2O	Tier 3	D1
1 B 2 b ii	Production of gas, Offshore activities	CO_2	Tier 1	D1
		CH_4	Tier 1	D1
1 B 2 b iv	Transmissions and storage	CO_2	Tier 2	CS
		CH_4	Tier 2	CS
1 B 2 b v	Distribution	CO_2	Tier 2	CS
		CH_4	Tier 2	CS
1 B 2 c 1 ii	Venting in gas storage	CO_2	Tier 3	CS(1990-1994), PS(1995 onwards)
		CH_4	Tier 3	CS(1990-1994), PS(1995 onwards)
1 B 2 c 2 i	Flaring in oil refinery	CO_2	Tier 3	CS(1990-2006), PS(2007 onwards)
		CH_4	Tier 3	CS
		N_2O	Tier 3	OTH (Olf, 1993)
1 B 2 c 2 ii	Flaring in gas storage, transmission and distribution	CO_2	Tier 3	CS(1990-2006), PS(2007 onwards)
		CH_4	Tier 3	CS
		N_2O	Tier 3	D1
1 B 2 c 2 iii	Flaring in oil and gas extraction	CO_2	Tier 3	CS(1990-2007), PS(2008 onwards)
		CH_4	Tier 3	CS
		N_2O	Tier 3	D1

Note: PS: plant specific. CS: country specific, D: default (D1: IPCC, 2006; D2: IPCC, 2019), OTH: other.

3.5.2 Source category description

According to the IPCC sector definitions the category *fugitive emissions from fuels* is a sub-category under the main-category Energy (Sector 1). The category *fugitive emissions from fuels* (Sector 1B) is segmented into sub-categories covering emissions from solid fuels *(coal mining and handling (1B1a), solid fuel transformation (1B1b) and other (1B1c))*, oil *(oil (1B2a)*, natural gas *(1B2b)*, venting and flaring *(1B2c)* and other *(1B2d)*. The sub-categories relevant for the Danish emission inventory are shortly described below according to Danish conditions:

- 1B1a: Fugitive emission from solid fuels: Coal mining and solid fuel transformation are not occurring in Denmark. Accordingly, greenhouse gas emissions from solid fuels are not occurring in Denmark.
- 1B2a: Fugitive emissions from oil include emissions from exploration, production, storage, and transmission of crude oil, distribution of oil products and fugitive emissions from refining.
- 1B2b: Fugitive emissions from natural gas include emissions from exploration, production, transmission of natural gas and distribution of natural gas and town gas. Fuel consumption in the Danish gas treatment plant used for gas heating and drying is included under category 1A1cii (Oil and gas extraction).
- 1B2c: Venting and flaring include activities onshore and offshore. Flaring occur both offshore in upstream oil and gas production, and onshore in gas treatment and storage facilities, in refineries and in natural gas transmission and distribution. Venting occurs in gas treatment and storage facilities. Venting of gas is assumed negligible in oil and gas production and in refineries, as controlled venting enters the gas flare system.

Table 3.5.4 summarizes the Danish fugitive greenhouse gas emissions in 2021. Information on other pollutants are included in the Informative Inventory Reports (IIR) reported annually to UNECE CLRTAP (Nielsen et al., 2023).

Table 3.5.4 Summary of the Danish fugitive emissions 2021. P refers to point source and A to area source.

PCC code	Source	Type*	Pollutant	Emission	Unit	Share of total fugitive
LB2a1	Exploration of oil	A	004	0	t	0%
LB2a1	Exploration of oil	A	006	0	kt	0%
LB2a1	Exploration of oil	A	007	0	t	0%
LB2a2	Production of oil	A	004	2.253	t	0.10%
LB2a2	Production of oil	A	006	<0.001	kt	<0.01%
LB2a3	Offshore loading of oil	A	004	30.107	t	1.38%
LB2a3	Onshore loading of oil	A	004	2.425	t	0.11%
LB2a4	Other**	P	006	0.059	kt	0.05%
LB2a4	Petroleum products processing	P	004	526.200	t	24.10%
LB2a4	Storage of crude oil	A	004	179.961	t	8.24%
LB2a4	Storage of crude oil	A	006	0.001	kt	<0.01%
LB2b1	Exploration of gas	A	004	0	t	0%
LB2b1	Exploration of gas	A	006	0	kt	0%
LB2b1	Exploration of gas	A	007	0	t	0%
LB2b2	Production of gas	A	004	502.360	t	23.01%
LB2b2	Production of gas	A	006	0.019	kt	0.02%
LB2b4	Natural gas transmission	A	004	277.318	t	12.70%
LB2b4	Natural gas transmission	A	006	0.003	kt	<0.01%
LB2b5	Natural gas distribution	A	004	146.437	t	6.71%
LB2b5	Natural gas distribution	A	006	0.001	kt	<0.01%
LB2b5	Town gas distribution	A	004	63.727	t	2.92%
LB2b5	Town gas distribution	A	006	<0.001	kt	<0.01%
LB2c1ii	Venting in gas storage	P	004	34.462	t	1.58%
LB2c1ii	Venting in gas storage	P	006	0.113	kt	0.10%
LB2c2i	Flaring in oil refinery	P	004	3.928	t	0.18%
LB2c2i	Flaring in oil refinery	P	006	12.777	kt	11.49%
LB2c2i	Flaring in oil refinery	P	007	0.102	t	56.35%
LB2c2ii	Flaring in gas storage	P	004	0.460	t	0.02%
LB2c2ii	Flaring in gas storage	P	006	1.227	kt	1.10%
LB2c2ii	Flaring in gas storage	P	007	<0.001	t	0.41%
LB2c2ii	Flaring in gas transmission and distribution	A	004	0.254	t	0.01%
LB2c2ii	Flaring in gas transmission and distribution	A	006	0.055	kt	0.05%
LB2c2ii	Flaring in gas transmission and distribution	A	007	<0.001	t	0.02%
LB2c2iii	Flaring in gas and oil extraction	A	004	413.807	t	18.95%
LB2c2iii	Flaring in gas and oil extraction	A	006	96.986	kt	87.18%
LB2c2iii	Flaring in gas and oil extraction	A	007	0.078	t	43.22%

* A: area source, P: point source.

**Regeneration of catalysts.

3.5.3 Use of EU ETS data

Reporting to the European Union Emission Trading Scheme (EU ETS) are available in the annual EU ETS reports for refineries, upstream oil and gas extraction facilities and the natural gas treatment plant, concerning fugitive emissions. EU ETS data are only included in the national emission inventory if higher tier methodologies are applied, which is the case for the EU ETS reports regarding fugitive emission sources. The EU ETS data used are fully in line with the requirements in the IPCC Guidelines and are considered the best data source on CO_2 emission factors due to the legal obligation for the relevant companies to make the accounting following the specified EU decisions. The EU ETS data are thereby a source of consistent data with low uncertainties. For further information on EU ETS, please refer to the section "*Use of EU Emission Trading Scheme data*" in Chapter 1. Unfortunately, corresponding data do not exist before the commencement of EU ETS in 2006 and therefore it is not possible to set up time series based on EU ETS. In these cases, appropriate methods from the IPCC Guidelines have been selected to ensure time series consistency. This is described in the specific sections.

EU ETS reports for refineries

Activity data are measured with flow meters and rates are reported with high accuracy using the Tier 4 methodology (uncertainty ±1.5 %) for large sources and Tier 3 (uncertainty ±2.5 %) or Tier 2 (uncertainty ±5 %) for small sources. The oxidation factor is set to 1, corresponding the Tier 1 methodology. CO_2 emission factors are calculated according to the relevant Tier given in the EU Commission Implementing Regulation of 19 December 2018 (EU Commission, 2018). The Tier 2b methodology based on yearly density and calorific values is applied, while the activity specific Tier 3 methodology is applied for diesel. CO_2 emissions factors for flaring are calculated using the Tier 3 methodology based on the measured carbon contents.

EU ETS reports for offshore installations

Activity data are measured with flow meters and rates are reported with high accuracy. For combustion, the Tier 4 methodology (uncertainty ±1.5 %) is used for large sources and Tier 3 (uncertainty ±2.5 %) or Tier 2 (uncertainty ±5 %) for small sources. For flaring, mainly the Tier 3 or the Tier 2 methodology is used (uncertainty ±7.5 % or ±12.5 %) is used. The oxidation factor is set to 1, corresponding the Tier 1 methodology. CO_2 emission factors are calculated according to the relevant Tier given in the EU Commission Implementing Regulation of 19 December 2018 (EU Commission, 2018). For combustion of fuel gas the Tier 3 methodology, which is activity specific, is applied, while the country specific Tier 3 methodology is applied for diesel. CO_2 emissions factors for flaring are calculated using the Tier 2b methodology.

3.5.4 Activity data, emission factors and emissions for fugitive sources

The following paragraphs describe the methodology for emission calculation for fugitive sources, including activity data, emission factors and annual emissions. The order follow the IPCC structure (1B2a Oil, 1B2b Natural gas, 1B2c Venting and flaring), with the exception that exploration and production of gas are include in the paragraphs for exploration and production of oil, due to similar methodologies and data providers.

Fugitive emissions from oil (1B2a)

The emissions from oil derive from exploration, production, onshore and offshore loading of ships, onshore oil tanks, service stations and refineries. Exploration and production of both oil and gas are described in this paragraph.

Exploration (1B2a1, 1B2b1)

Activity data

Activity data for oil and gas exploration are provided annually by the Danish Energy Agency (Erichsen, 2022). Data for exploration of oil and gas are given separately for each exploration drilling, and fluctuate significantly over the time series. The largest oil rates are seen for 1990, 2002 and 2005, while relatively large gas rates are seen for more years of the time series. There was no exploration activity in 2021. Explored rates are shown in Figure 3.5.1.

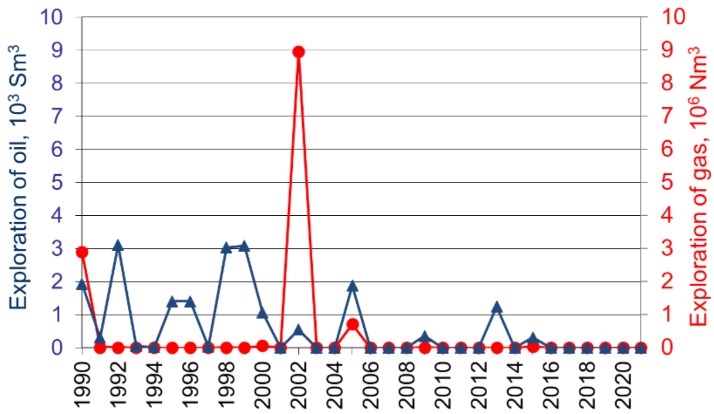

Figure 3.5.1 Exploration of oil and gas.

Emission factors

Annual CO_2 emission factors are based on composition data, calorific values and densities for explored oil and gas provided by the Danish Energy Agency. Composition data are available for the exploration and appraisal wells (E/A wells) separately, except for a few E/A wells, for which the compositions for the previous E/A well are used for emission calculation. As calorific values and densities are not available per drilling, data from a gas test in 1992 are used. CO_2 emission factors are listed in Table 3.5.5. The emission factors used to calculate emissions from offshore flaring in upstream oil and gas production are applied for the remaining pollutants (refer to the Section *Fugitive emissions from venting and flaring (1B2c)* below).

Table 3.5.5 Annual CO_2 emission factors for years with exploration of oil and gas.

	1990	1991	1992	1993	1994	1995	1996	1997
EF(CO_2), exploration of oil, kg/Sm3	2433	2437	2441	2441	2437	2449	2449	2449
EF(CO_2), exploration of gas, kg/Nm3	2.85	2.81	2.84	2.93	2.81	2.94	2.94	2.94
continued	1998	1999	2000	2002	2005	2009	2013	2015
EF(CO_2), exploration of oil, kg/Sm3	2445	2449	2449	2442	2444	2449	2449	2449
EF(CO_2), exploration of gas, kg/Nm3	2.93	2.94	2.94	2.92	2.89	2.82	2.82	2.82

Emissions

Calculated CH_4 emissions for exploration of oil and gas are shown in Figure 3.5.2. There is no correlation between emissions from oil and gas, as the individual exploration drillings have different ratios between oil and gas rates.

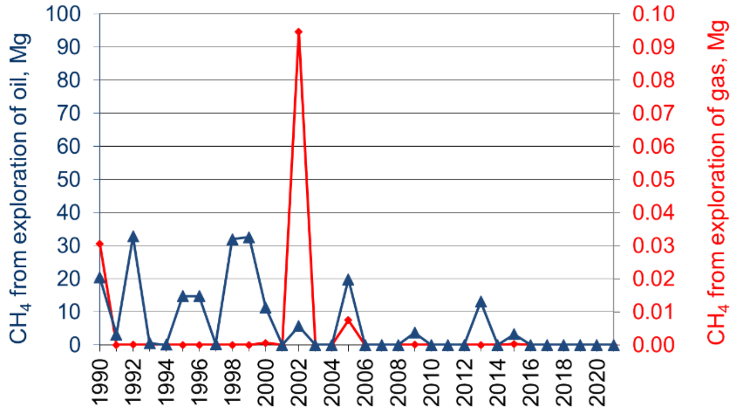

Figure 3.5.2 CH_4 emissions from exploration of oil and gas.

Production (1B2a2, 1B2b2)

Activity data

Activity data used for oil and gas production are provided by the Danish Energy Agency (DEA 2022a). As seen in Figure 3.5.3 the production of oil and gas in the North Sea has generally increased in the years 1990-2004, and since 2004 the production has decreased. Five major platforms were completed in 1997-1999, which is the main reason for the great increase in the oil production in the years 1998-2000.

The Tyra platforms are closed in the period between September 2019 and the winter season 2023/2024 due to redevelopment. The Tyra platforms have for 30 years been processing the majority of the Danish natural gas production, and the redevelopment ensures continued production from Denmark's largest producing gas field.

The gas produced in the North Sea and transported by pipeline to the treatment gas plant Nybro is dry and with low H_2S content. Following, the gas does not need any processing, which causes fugitive emissions, before going into the transmission network. The environmental approval from 2009 for Nybro states that gas processing equipment are in place, but as some parts have never been used, is has been mothballed or phased out. As follow up to the 2022 UNFCCC review, it has been verified by the senior operations supporter at Nybro that these conditions are still applicable and therefore emissions from gas processing are reported as not applicable (NA) for the entire time series.

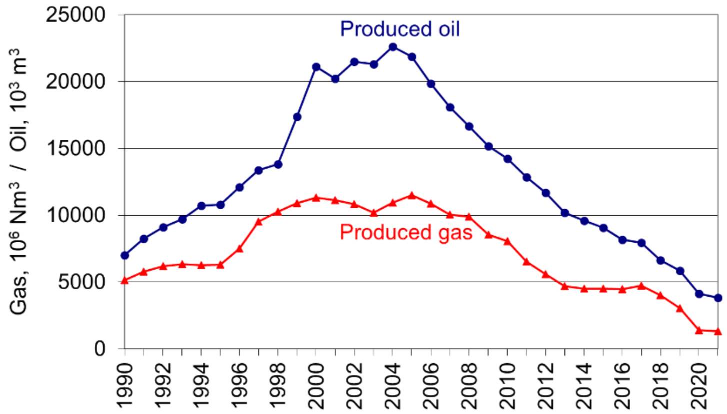

Figure 3.5.3 Production of oil and gas.

Emission factors

Standard emission factors from the 2006 IPCC Guidelines (IPCC, 2006) are used to calculate emissions from production of oil (see Table 3.5.6).

Table 3.5.6 Emission factors for production of oil and gas.

	CO_2	CH_4	N_2O	Reference
Production of oil, kt/1000m^3	4.30E-08	5.90E-07	NA	IPCC 2006
Production of gas, kt/Mm3	1.40E-05	3.80E-04	NA	IPCC 2006

Emissions

Calculated CH_4 emissions from oil and gas production are shown in Figure 3.5.4. The annual variations follow the production rates.

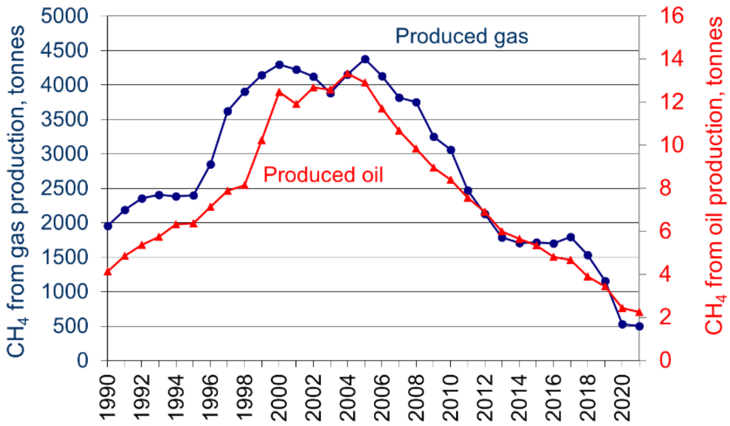

Figure 3.5.4 CH_4 emissions from production of oil and gas.

Transport (1B2a3)

Activity data

Fugitive emissions of oil transport include loading of ships from storage tanks or directly from the wells. Activity data for loading offshore and onshore are provided by the Danish Energy Agency (DEA 2022a) and from the annual self-regulating reports and supplementing data from Danish Oil Pipe A/S (Boesen, 2022), respectively.

The rates of oil loaded on ships roughly follow the trend of the oil production (see Figure 3.5.5). Offshore loading of ships was introduced in 1999. In earlier years, the produced oil was transported to land via pipeline.

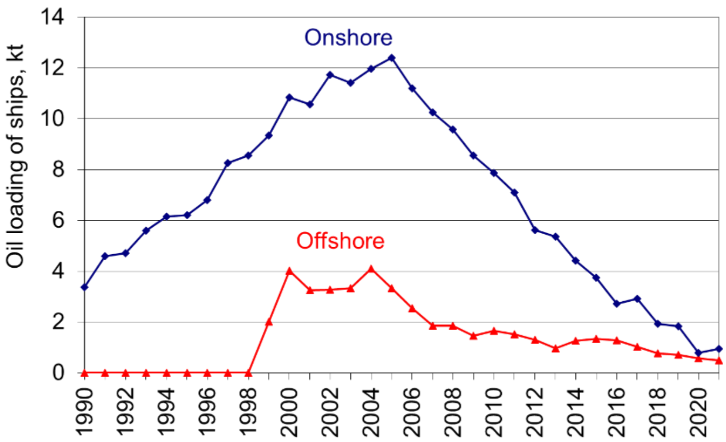

Figure 3.5.5 Onshore and offshore loading of ships.

Emission factors

Emissions from storage tanks at the Oil terminal are provided annually by Danish Oil Pipe A/S. During 2009 new emission reducing technologies (degassing unit) were installed at the crude oil terminal, leading to a significant decrease of the emissions as shown in Figure 3.5.6.

Emissions from offshore loading are based on the default emission factors for offshore loading of ships from the 2019 IPCC Refinement (IPCC, 2019). A 50/50 split between loading with/without VRU is assumed in the emission calculations.

Emission factors for onshore loading is based on annual reports from the Crossbridge Harbour Terminal for the years 2012 onwards (A/S Dansk Shell - Havneterminalen, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021; Crossbridge – Havneterminalen 2022), which include loaded amounts, standard NMVOC emission factors and emissions of NMVOC (2013-2017) or VOC (2019-2020). Estimation of CH_4 emission factors are based on the assumption that NMVOC make up 80% of VOC in accordance with the annual reports for the harbour terminal.

The emission factor for 2012 is applied for the earlier years in the time series. The emission factors show a significant decrease from 2016 due to installation of a new vapour recovery unit (VRU2) during 2017. No emissions were reported for 2018, but have been estimated according to the environmental approval for VRU2 (Danish EPA, 2017) which include a requirement of 85 % emission reduction of the VRU2. Emission factors for loading of ships offshore and onshore are listed in Table 3.5.7.

Table 3.5.7 Emission factors for the oil terminal and for onshore and offshore loading of ships.

Source	Pollutant	Unit	Emission factor
Oil terminal	CO_2	kg/Mg crude oil	0.001
Offshore loading of ships	CH_4	Mg/1000 m3 oil loaded	0.0525
Ships onshore, -2012	CH_4	g/ton	146
Ships onshore, 2013	CH_4	g/ton	147
Ships onshore, 2014-2016	CH_4	g/ton	146
Ships onshore, 2017	CH_4	g/ton	84
Ships onshore, 2018	CH_4	g/ton	22
Ships onshore, 2019	CH_4	g/ton	1.8
Ships onshore, 2020	CH_4	g/ton	2.1
Ships onshore, 2021	CH4	g/ton	2.6

Emissions

CH_4 emissions from transport of oil are shown in Figure 3.5.6.

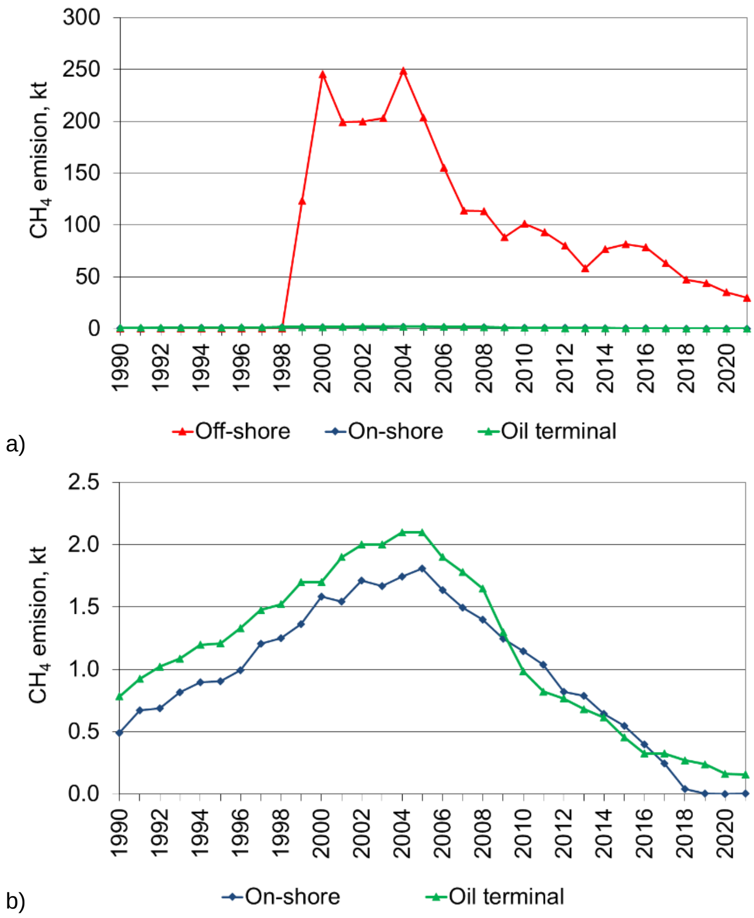

Figure 3.5.6 a) CH_4 emissions from storage at the raw oil terminal and from onshore and offshore loading of ships. b) Emissions from offshore loading are excluded from figure b.

Refining/storage (1B2a4)

Activity data

Refining/storage include emissions from storage and handling at the oil terminal and emissions from oil refinery processes, including non-combustion emissions from handling and storage of feedstock (raw oil), from the petroleum product processing, from handling and storage of products, and from regeneration of catalysts. Emissions from flaring in refineries are included in the Section *Fugitive emissions from venting and flaring (1B2c)*. Emissions related to process furnaces in refineries are included in stationary combustion.

Annual emissions from storage and handling at the oil terminal is provided in the annual self-regulating reports and supplementing data from Danish Oil Pipe A/S (Boesen, 2022).

Rates of crude oil processed in the two Danish refineries are given in their annual environmental report (Crossbridge, 2022 and Kalundborg Refinery, 2022). Until 1996 a third refinery was in operation, leading to a decrease in the crude oil rate from 1996 to 1997. Activity data are shown in Figure 3.5.7.

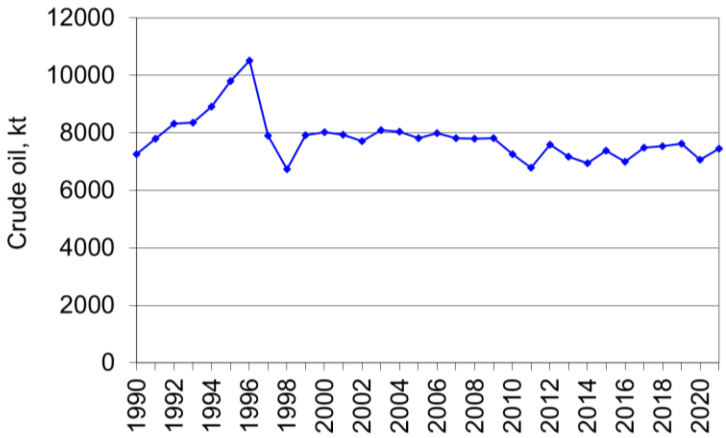

Figure 3.5.7 Crude oil processed in Danish refineries.

Emission factors

The standard CO_2 emission factor for oil transport from the 2006 IPCC Guidelines (IPCC, 2006) is used to calculate emissions from storage and handling at the oil terminal (Table 3.5.7).

VOC emissions are provided by the refineries. Only one of the two refineries has made a split between NMVOC and CH_4. For the other refinery, it is assumed that 10 % of the VOC emission is CH_4 (Hjerrild & Rasmussen, 2014).

Both the non-combustion processes including product processing and sulphur recovery plants emit SO_2. For descriptions regarding fugitive emissions of SO_2 and other pollutants from refining, please refer to the Danish Informative Inventory Report (Nielsen et al., 2023).

Emissions

CH_4 emissions from storage at the raw oil terminal is shown in Figure 3.5.6.

Annual plant specific CO_2 emission from regeneration of catalysts are available in the EU ETS reporting from 2006 onwards. For years prior to 2006, the CO_2 emissions from regeneration of catalysts are based on 1) emissions given in the annual environmental reports, 2) the average emission factor for years with both activity data and emission in the EU ETS reporting (2.515 t CO2 / t coke) for years where activity data, or 3) the average emission for the first five years with data.

Figure 3.5.8 shows CH_4 emissions from the Danish refineries for selected years in the time series. The increase from 2005 to 2006 owes a new measurement campaign at one refinery, which showed larger emissions than the previous. According to the environmental department at the refinery, fugitive emissions from oil processing in refineries are not correlated to any measured parameters, but are expected to follow a more random pattern. The refinery has chosen to report the latest measured emission for the years between measurement campaigns, and as no better methodology are available, the same approach is used in the national emission inventories.

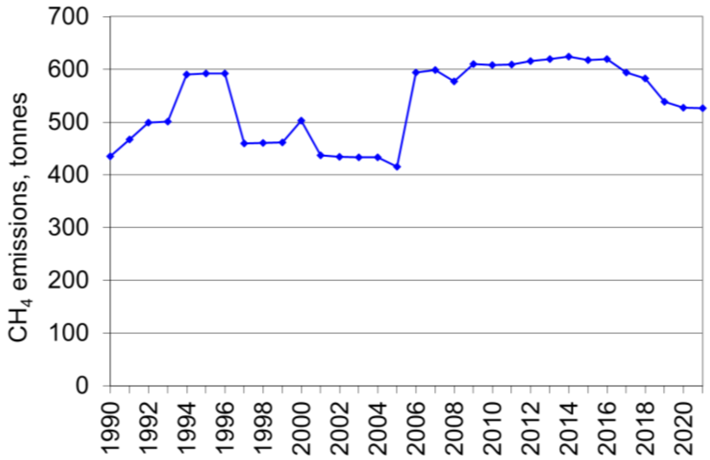

Figure 3.5.8 CH_4 emissions from crude oil processing in Danish refineries.

Service stations (1B2a5)

Fugitive emissions from service stations cover only NMVOC. For a description on methodology and data basis, please refer to the Danish Informative Inventory Report (Nielsen et al., 2023).

Fugitive emissions from natural gas (1B2b)

The emissions from natural gas derive from exploration, transmission, storage and distribution. Descriptions of exploration and production of natural gas are included in the sections covering exploration and production of oil *Exploration (1B2a1, 1B2b1)* and *Production (1B2a2, 1B2b2)*.

Exploration (1B2b1)

See Section *Exploration (1B2a1, 1B2b1)*.

Production (1B2b2)

See Section *Production (1B2a2, 1B2b2)*.

Transmission and storage (1B2b4)

Activity data

The fugitive emissions from transmission and storage of natural gas are based on information from the gas transmission companies, which provide data on transported rate, pipeline losses, and length and material of the pipeline systems. The length of the transmission pipelines is approximately 900 km.

The activity data used in the calculation of the emissions from transmission of natural gas are shown in Figure 3.5.9. Transmission rates for 1990-1998 refer to annual environmental reports of DONG Energy. In 1999-2006, transmission rates refer to the Danish Gas Technology Centre (Karll 2002, Karll 2003, Karll 2004, Karll 2005, Oertenblad 2006, Oertenblad 2007). From 2008 onwards, transmission rates refer to Energinet.dk (2022b). Transmission losses for 1991-1999 are based on annual environmental report of DONG Energy. The average for 1991-1995 is applied for 1990. From 2005 onwards, transmission losses are given by Energinet.dk. The average for 2005-2010 is applied for the years 2000-2004.

The variation over the time series owes mainly to variations in the winter temperature and to the variation of import/export of electricity from Norway and Sweden. The transmission rate is less than the production rate, as part of the produced natural gas is exported through the NOGAT pipeline system.

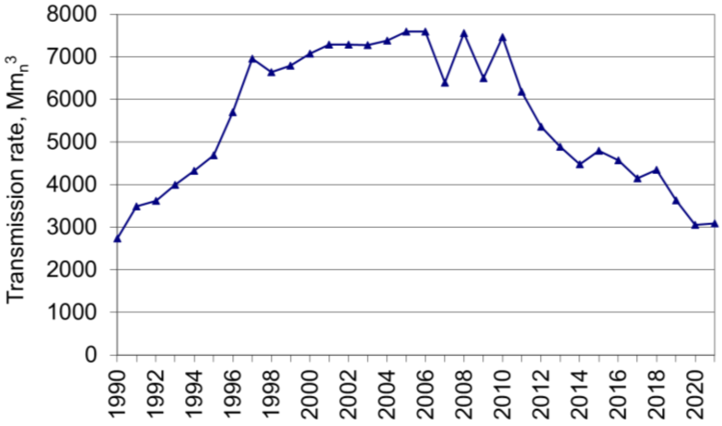

Figure 3.5.9 Rates for transmission of natural gas.

Emission factors

The fugitive emissions from transmission and storage of natural gas are based on data on gas losses from the companies and on the average annual natural gas composition given by Energinet.dk (2022c) (Table 3.5.8).

Table 3.5.8 Annual gas composition, lower heating value and density for Danish natural gas.

		Unit	1990	2000	2005	2010	2015	2019	2020	2021
Methane	CH_4	molar-%	90.92	86.97	88.97	89.95	88.80	91.2	95.9	96.16
Ethane	C_2H_6	molar-%	5.08	6.88	6.14	5.71	6.08	5.01	3.05	2.9
Propane	C_3H_8	molar-%	1.89	3.17	2.50	2.19	2.47	1.75	0.18	0.12
i-Butane	i-C_4H_{10}	molar-%	0.36	0.43	0.40	0.37	0.39	0.31	0.05	0.04
n-Butane	n-C_4H_{10}	molar-%	0.50	0.61	0.55	0.54	0.59	0.46	0.03	0.02
i-Petane	i-C_5H_{12}	molar-%	0.14	0.11	0.11	0.13	0.13	0.11	0.01	0.01
n-Petane	n-C_5H_{12}	molar-%	0.10	0.08	0.08	0.08	0.10	0.07	0.01	0
n-Hexane and heavier hydrocarbons	C^{6+}	molar-%	0.09	0.06	0.05	0.06	0.05	0.05	0.02	0.02
Nitrogen	N_2	molar-%	0.31	0.34	0.29	0.31	0.32	0.29	0.31	0.3
Carbon dioxide	CO_2	molar-%	0.60	1.35	0.90	0.66	1.07	0.76	0.44	0.41
Lower heating value	H_n	MJ/m^3_n	39.176	40.154	39.671	39.461	39.635	38.812	36.700	36.620
Density	ρ	kg/m^3_n	0.808	0.846	0.825	0.816	0.828	0.803	0.749	0.746

Emissions

The gas transmission company reports emissions of CH_4 for the years 1999 and onwards, based on registered loss in the transmission grid and the emission from the natural gas consumption in the pressure regulating stations. For the years 1991-1998, the CH_4 emissions for transmission are estimated based on the registered loss provided by the transmission company and the annual composition of Danish natural gas given by Energinet.dk. Transmission loss is not available for 1990, why the average for 1991-1995 is applied.

As the pipelines in Denmark are relatively new and made of plastic, most emissions are due to leaks during construction and maintenance. This leads to large annual fluctuations in emissions, which are not correlated to the transmission rates. E.g. the large emission in 1995 owe to a large construction work covering four different locations. The increase in 2011 owe to venting for drainage of the pipes in preparation for construction work on a new compressor station, and the increase in 2014 owe to the construction of a new major railway line. The increase in 2021 owe to increased focus from the transmission company on improvement of the data foundation. Further, there have been more construction work than in the previous years, e.g. activities related to two biogas systems and the Baltic pipe.

Emissions of CH_4 from transmission of natural gas are shown in Figure 3.5.10. Emissions of CO_2 from transmission and storage are very limited and not included in the figure. For information on emissions of NMVOC, please refer to Chapter 3.4 in the Danish Informative Inventory Report (Nielsen et al., 2023).

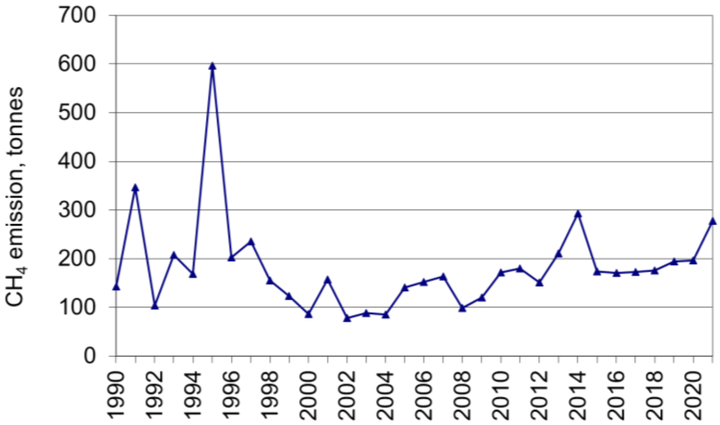

Figure 3.5.10 CH_4 emissions from transmission of natural gas.

Distribution (1B2b5)

Activity data

Distribution rates for 1990-1998 are estimated from the Danish energy statistics. Distribution rates are assumed to equal total Danish consumption rate minus the consumption rates of sectors that receive the gas at high pressure. The following consumers are assumed to receive high-pressure gas: town gas production companies, production platforms and power plants. In 1999-2006, distribution rates refer to DONG Energy/Danish Gas Technology Centre/Danish gas distribution companies (Karll, 2002; Karll, 2003; Karll, 2004; Karll, 2005; Oertenblad, 2006; Oertenblad, 2007). Since 2007, the distribution rates are given by the companies. The fugitive losses from distribution of natural gas are only given for some companies. The average of the available "loss/distribution"-ratios is used for the remaining companies too.

Activity data for distribution of town gas are rather scarce, and calculations are based on the available data from the town gas distribution companies on gas losses from the pipelines. At present, there are two areas with town gas distribution and correspondingly two distribution companies. Two other companies in other areas were closed in 2004 and 2006, and it have not been possible to collect data for all years in the time series. The emissions have been calculated for the years with available data and the distribution loss for the first year with data has been applied for the previous years in the time series. Data is missing for the later years (1996-2003) for one of the distribution companies. The distribution rate is assumed to decrease linearly to cero over these years, and the share ("distribution loss/distribution rate") is assumed equal to the value for 1995.

Data on the distribution network are given by Energinet.dk, DGC and the distribution companies concerning length and material. The length of the distribution network is around 20.000 km. Because the distribution network in Denmark is relatively new, most of the pipelines are made of plastic (approximately 90 %). For this reason, the fugitive emission is negligible under normal operating conditions as the distribution system is basically tight with no fugitive losses. However, the plastic pipes are vulnerable and therefore most of the fugitive emissions from the pipes are caused by losses due to excavation damages, and construction and maintenance activities performed by the gas companies. These losses are either measured or estimated by calculation in each case by the gas companies. About 5 % of the distribution network is used for town gas. This part of the network is older and the fugitive losses are larger. The fugitive losses from this network are associated with more uncertainty as it is estimated as a percentage (15 %) of the meter differential. This assumption is based on expert judgement from one of the town gas companies (Jensen, 2008). Distribution rates are shown in Figure 3.5.11.

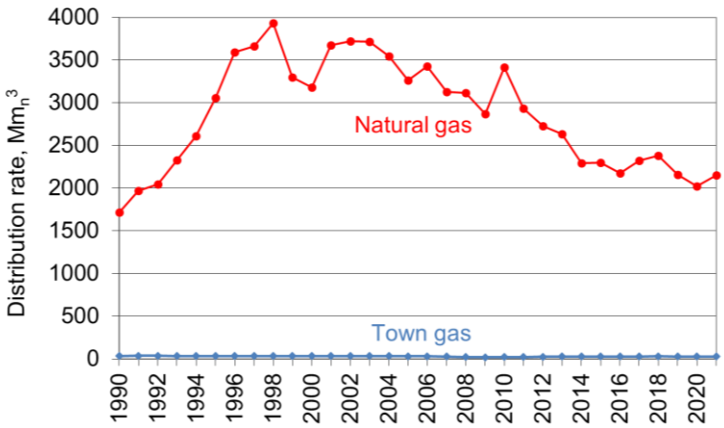

Figure 3.5.11 Distribution rates of natural gas and town gas.

Emission factors

Emissions from natural gas distribution are calculated from the fugitive losses from pipelines and the gas quality measured by Energinet.dk (see Table 3.5.8). The same approach is used for town gas, which is natural gas admixed ~ 50 % ambient air. From 2014, one town gas distribution company has started to admix biogas. In 2014, the share of biogas is 10.1 %, which is expected to increase in the coming years. The admixed biogas has not been upgraded as tests of different appliances have shown that up to 40 % non-upgraded biogas can be added to the town gas without causing problems with the appliances' combustion. The composition of biogas is given in Table 3.5.9.

Table 3.5.9 Composition of biogas admixed to town gas (Jeppesen, 2014; Ea Energianalyse, 2014).

Methane	CH_4	molar-%	60.98
Nitrogen	N_2	molar-%	0.001
Carbon dioxide	CO_2	molar-%	39.02
Lower heating value	H_n	MJ/m^3_n	21.53
Density	ρ	kg/m^3_n	0.808

The distribution companies provide emissions of CH_4 for 1997 and onwards. For the years 1995-1996, CH_4 emissions are calculated from the registered loss from distribution and the annual composition of Danish natural gas given by Energinet.dk. As distribution losses are not available for the years 1990-1994, the percentage loss for 1995 is used.

Emissions

Emissions of CH_4 from distribution of natural gas and town gas are shown in Figure 3.5.12. Emissions of CO_2 are very limited and not included in the figure. For information on emissions of NMVOC, please refer to Chapter 3.4 in the Danish Informative Inventory Report (Nielsen et al., 2023).

Emissions from the natural gas network are variable and are associated with renovation to the network and excavation damages.

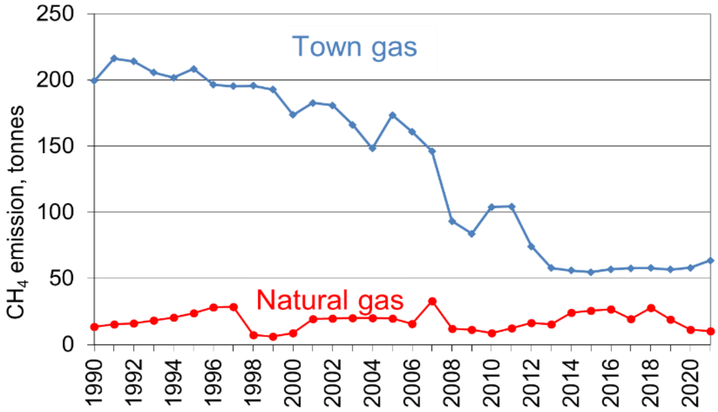

Figure 3.5.12 CH_4 emissions from distribution of natural gas.

Fugitive emissions from venting and flaring (1B2c)

Venting occur in the two Danish natural gas storage facilities and from measurement equipment at the natural gas treatment plant. Flaring occurs in oil and gas production, in gas treatment and storage facilities, in refineries, and in gas transmission and distribution.

Venting

Activity data

The natural gas storage facilities are obligated to make environmental reports on an annual basis, including data on venting. Venting from measurement equipment at the gas treatment facility is provided in Nygaard (2020) based on information from the gas treatment plant. Venting of gas is assumed to be not occurring in extraction and in refineries, as controlled venting enters the gas flare system. Venting rates in gas storage and treatment facilities are shown in Figure 3.4.13. Data are not available for the years 1990-1994 for the one gas storage facility that was in operation over the entire time series, and the average for 1995-1998 is applied. The second gas storage facility was opened in 1994, leading to increasing venting rates.

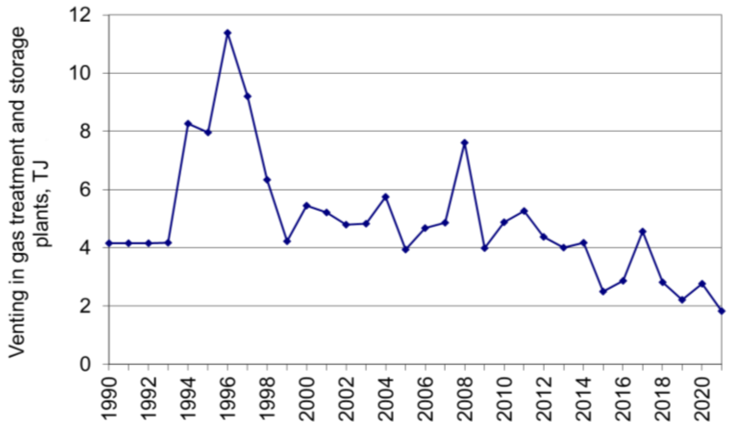

Figure 3.5.13 Venting rates in gas storage and treatment facilities.

Emission factors

Emissions of CH_4 and NMVOC from venting are given in the environmental reports for the gas storage facilities (Energinet.dk, 2022a). CO_2 emissions from venting and CH_4 and NMVOC emissions from the gas treatment facility are calculated from country specific emission factors based on annual natural gas composition published by Energinet.dk.

Emissions

Venting is limited to the gas storage and treatment facilities and the emissions are of minor importance to the total fugitive emissions. Venting emissions are included in Figure 3.5.14.

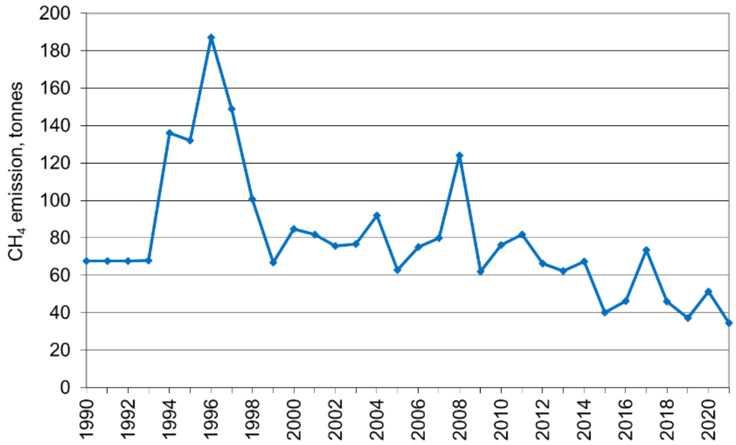

Figure 3.5.14 CH_4 emissions from venting.

Flaring

Flaring in refineries

Activity data

Flaring rates for the two Danish refineries are given in their environmental reports and in additional data provided by the refineries directly to DCE. From 2006, flaring rates are given in the EU ETS reporting. Data are not available for the years 1990-1993, why the flaring rate for 1994 has been adopted for the previous years. Flaring rates are shown in Figure 3.5.15.

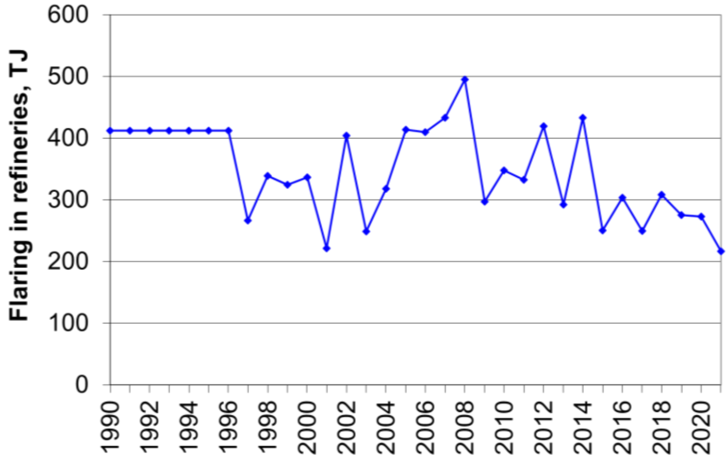

Figure 3.5.15 Flaring rates in refineries.

Emission factors

The composition of refinery gas is given for 2008 by one of the two refineries. As the composition for refinery gas is very different from the composition of natural gas, the 2008 refinery gas composition is used in calculations for both

Danish refineries. The CH_4 and NMVOC emission factors based on the 2008 refinery gas composition are applied for both refineries for the entire time series. The CO_2 emission factor is based on the refineries reporting to the EU ETS from the years 2006 and onwards. Before 2006, corresponding data are not available, and the average of CO_2 emission factors for 2007-2011 for each refinery is applied. The emission factor applied for N_2O is based on OLF (1993) for flaring in oil and gas extraction, as no value are given for flaring in refineries. The emission factors are listed in Table 3.5.10. For information on emissions of other pollutants, please refer to Chapter 3.4 in the Danish Informative Inventory Report (Nielsen et al., 2023).

Table 3.5.10 Emission factors for flaring in refineries for 2021.

Pollutant	Emission factor	Unit
CH_4	18.1	g per GJ
CO_2 *	58.08 / 60.44	kg per GJ
N_2O	0.47	g per GJ

** The CO_2 emission factors are based on the refineries reports for EU ETS and are plant specific.

Emissions

Emissions of CH_4 and CO_2 are shown in Figure 3.5.16. The variation over the time series follow the flaring rates, with small variations for CO_2 from 2006 onwards, when annual plant specific CO_2 emission factors became available in EU ETS reporting.

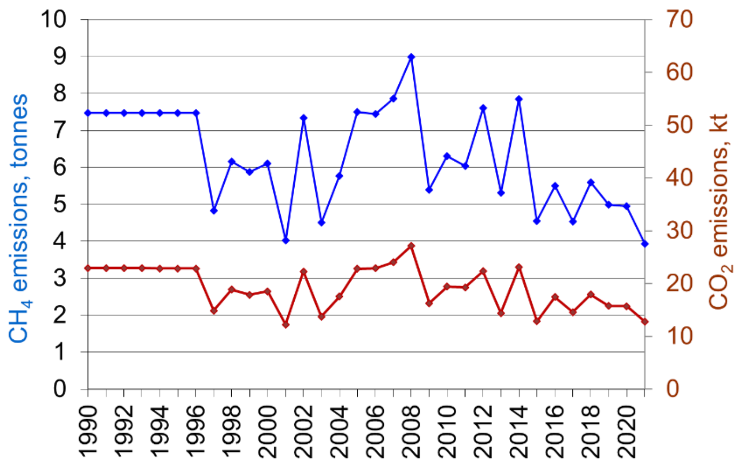

Figure 3.5.16 CH_4 and CO_2 emissions from flaring in refineries.

Flaring in upstream oil and gas production

Activity data

From 2006, data on flaring in upstream oil and gas production is given in the reports submitted under the EU ETS and thereby emission calculation can be made for the individual production units. Before 2006 only the total flared amount is available in the annual report Denmark's oil and gas production (Danish Energy Agency, 2022a). Flaring rates (and CO_2 emissions) are shown in Figure 3.5.17. Flaring rates in upstream oil and gas production have been decreasing over the last 10 years period in accordance with the decrease in production as seen in Figure 3.5.3. Further, there is focus on reducing the amount being flared for environmental reasons.

The Tyra platforms are closed in the period between September 2019 and the winter season 2023/2024 due to redevelopment. The Tyra platforms have for 30 years been processing the majority of the Danish natural gas production, and the redevelopment ensures continued production from Denmark's largest producing gas field.

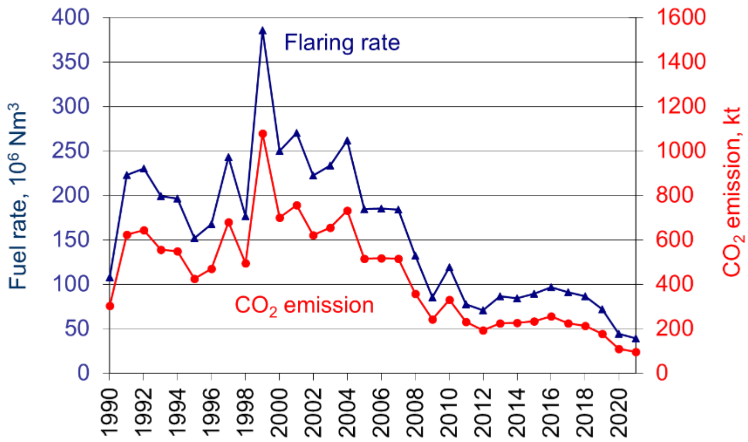

Figure 3.5.17 Fuel rate and CO_2 emission from flaring in upstream oil and gas production.

Emission factors

The emission factors for flaring in upstream oil and gas production are shown in Table 3.5.11. Since 2006, the CO_2 emission factor is calculated according to the reporting for EU ETS. As corresponding data are not available for earlier years, the average CO_2 EF for the years 2008-2012 is applied for the years 1990-2007. The emission factor for CH_4 is estimated from flare gas quality data for one offshore production platform, assuming a flare efficiency of 98 % in agreement with IPCC (2006) and API (2009). Emission factors for N_2O are based on IPCC (2006). For information on emissions of other pollutants, please refer to Chapter 3.4 in the Danish Informative Inventory Report (Nielsen et al., 2023).

Table 3.5.11 Emission factors for flaring in upstream oil and gas production for 2021.

Pollutant	Emission factor	Unit
CH_4	10.56	g/Nm^3
CO_2	2.48	kg/Nm^3
N_2O	0.002	g/Nm^3

Emissions

The time series for the emission of CO_2 from flaring in upstream oil and gas production fluctuates due to the fluctuations in the fuel rate and to a minor degree due to the CO_2 emission factor. As shown in Figure 3.5.18, there was a marked increase in the rate of flaring in upstream oil and gas production in 1997 and especially in 1999. The increase in 1997 was due to the new Dan field and the completion of the Harald field. The increase in 1999 was due to the opening of the three new fields Halfdan, Siri and Syd Arne. The CH_4 and N_2O emissions from flaring in upstream oil and gas production are estimated from the same emission factors for all years and the variations reflect only the variations in the flared amounts. Emissions of CH_4 from flaring are shown in Figure 3.5.18.

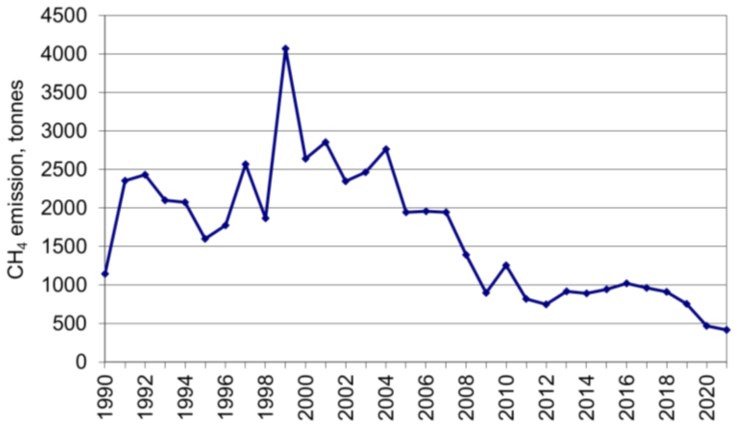

Figure 3.5.18 CH_4 emissions from flaring in upstream oil and gas production.

Flaring in gas treatment and storage facilities

Activity data

Activity data for flaring at the gas treatment facility are given in environmental reports (1994-2005) and in the EU-ETS reports (2006 onwards) and for gas storage facilities in environmental reports (Energinet.dk, 2022a). Flaring rates in gas treatment and gas storage facilities are not available before 1994. The mean value for 1994-1998 has been adopted as basis for the emission calculation for the years 1990-1993 (Figure 3.5.19). Note that one of the two gas storage facilities was not opened before 1994. The large amount of gas flared in 2007 owe to a larger maintenance work at the gas treatment plant.

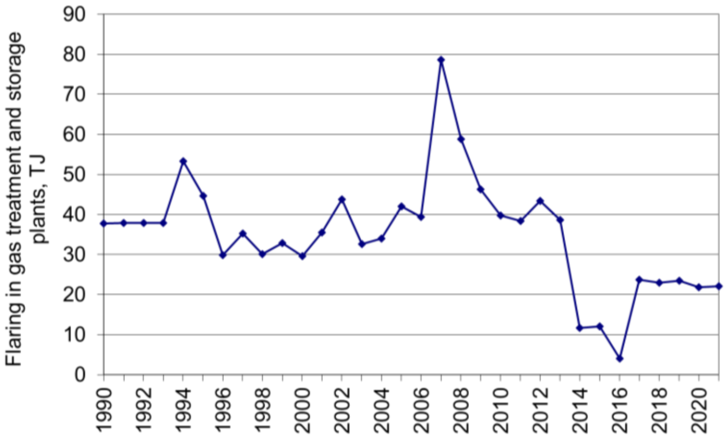

Figure 3.5.19 Flaring in gas treatment and storage facilities.

Emission factors

Emissions from flaring in gas treatment and storage facilities are calculated from the same emission factors, which are used for flaring in upstream oil and gas production, except for CO_2. The natural gas flared in the treatment and storage facilities are natural gas with the same composition as natural gas distributed in Denmark, and the CO_2 emission factors are based on the gas composition given by Energinet.dk.

Emissions

Emissions from flaring in gas treatment and storage facilities are of minor importance to the total fugitive emissions. Emissions from gas treatment and storage facilities have decreased from 2009 to 2010 due to a change from continuous to regulating power operation of the power producing gas turbine at the gas storage plant. CH_4 emissions are included in Figure 3.5.20. The increase in 2017 owe to increased flaring amount at the gas treatment plant.

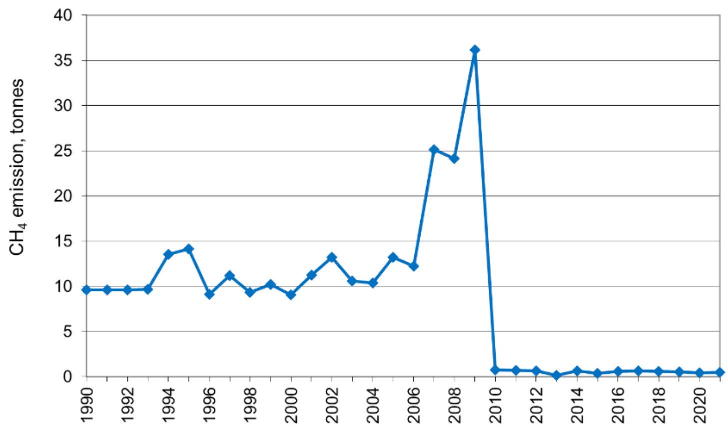

Figure 3.5.20 CH_4 emissions from flaring in gas treatment and storage facilities.

Flaring in gas transmission and distribution

Activity data

Flaring in gas transmission occur in the years 2011-2013 and 2021. Flaring rates are provided by the gas transmission company Energinet.dk.

Flaring in gas distribution was introduced in 2011 and the relevant gas distribution company has provided activity data for the years 2011-2016. Data are not available for the years 2017-2021 due to more rounds of consolidations of the distribution companies, ending up with one single gas distribution company (Evida) since October 2019.

Emission factors

The same emission factors are used for flaring in gas transmission and distribution as for flaring in gas treatment and storage facilities, and the description can be found in the relevant section above.

Emissions

Only minor emissions occur from flaring in gas transmission and distribution and only since 2011. CH_4 emissions are included in Figure 3.5.21.

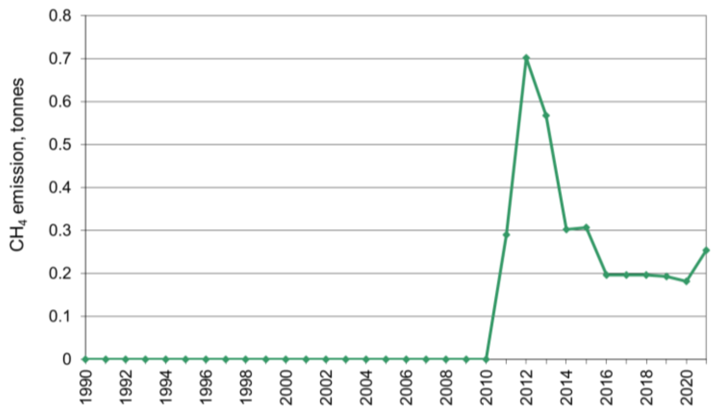

Figure 3.5.21 CH_4 emissions from flaring in gas transmission and distribution.

3.5.5 Uncertainties and time series consistency

Until 2016, two sets of uncertainty estimates were made for the Danish emission inventory for greenhouse gases based on Approach 1 and Approach 2, respectively. The uncertainty models follow the methodology in the 2006 IPCC Guidelines (IPCC, 2006). Approach 1 is based on the simplified uncertainty analysis (error propagation method) and Approach 2 is based on Monte

Carlo simulations. From the 2017 submission, the Approach 2 uncertainty estimation has not been carried out due to a lack of resources.

Uncertainty estimates are made for total emissions in the latest inventory year and for the emission trend for the corresponding time series. Uncertainty estimates are made for the CO_2, CH_4 and N_2O separately and summarized.

Input data

The Approach 1 uncertainty model is based on emission data, uncertainty levels for activity data and uncertainty levels for emission factors for base year and latest inventory year. Emission data, activity data and emission factors are described in Section *3.5.4 Activity data, emission factors and emissions for fugitive sources*.

The uncertainty levels used in the uncertainty models are based on different sources, e.g. the 2006 IPCC Guidelines, EMEP/EEA Guidebook and reports under the EU ETS. Further, a number of the uncertainty levels are given as DCE assumptions. DCE assumptions are based on source and/or plant specific uncertainty levels for part of the SNAP category and assumptions for the remaining sources and/or plants in the category.

Input data are aggregated on SNAP level. Estimates are made for the greenhouse gases CO_2, CH_4 and N_2O, both separately and summarized (GHG). Uncertainty levels for activity data and emission factors are listed in Table 3.5.12. Uncertainty levels are given in percentage related.

Table 3.5.12 Uncertainty levels for activity rates and emission factors.

Pollutant	CRF category	Source	Activity data uncertainty level, %	Emission factor uncertainty level, %
CO_2	1.B.2.a.1	Exploration	2 A	10 A
CO_2	1.B.2.a.2	Production	2 A	100 I
CO_2	1.B.2.a.4	Refining/storage	2 A	40 S
CO_2	1.B.2.b.1	Exploration	2 A	10 A
CO_2	1.B.2.b.2	Production	2 A	50 R
CO_2	1.B.2.b.4	Transmission and storage	15 G	2 Q
CO_2	1.B.2.b.5	Distribution	25 G, A	10 Q, A
CO_2	1.B.2.c.1.ii	Venting	15 G, A	2 Q
CO_2	1.B.2.c.2.i	Flaring, oil	11 E	2 E
CO_2	1.B.2.c.2.ii	Flaring, gas	7.5 E	2 E
CO_2	1.B.2.c.2.iii	Flaring, combined	7.5 E	2 E
CH_4	1.B.2.a.1	Exploration	2 A	125 A
CH_4	1.B.2.a.2	Production	2 A	100 I
CH_4	1.B.2.a.3	Transport	2 A	50 R
CH_4	1.B.2.a.4	Refining/storage	1 E, A	200 A
CH_4	1.B.2.b.1	Exploration	2 A	125 A
CH_4	1.B.2.b.2	Production	2 A	100 I
CH_4	1.B.2.b.4	Transmission and storage	15 G	2 Q
CH_4	1.B.2.b.5	Distribution	25 G, A	10 Q, A
CH_4	1.B.2.c.1.ii	Venting	15 G, A	2 Q
CH_4	1.B.2.c.2.i	Flaring, oil	11 E	15 H, A
CH_4	1.B.2.c.2.ii	Flaring, gas	7.5 E	2 A
CH_4	1.B.2.c.2.iii	Flaring, combined	7.5 E	125 I
N_2O	1.B.2.a.1	Exploration, oil	2 A	1000 A
N_2O	1.B.2.c.2.i	Flaring, oil	11 E	1000 I
N_2O	1.B.2.c.2.ii	Flaring, gas	7.5 E	1000 I
N_2O	1.B.2.c.2.iii	Flaring, combined	7.5 E	1000 I

A: DCE assumption.
E: EU Emission Trading Scheme (EU ETS).
G: EMEP/EEA Guidebook, 2009.
H: Holst, 2009 and Statoil A/S, 2010b
I: IPCC Good Practice Guidance (default value).
Q: Annual gas quality, Energinet.dk
R: 2019 IPCC Refinement
S: Statistisk Sentralbyrå, Statistics Norway, 2008.

The CO_2 emission factors for flaring in upstream oil and gas production and in refineries and the CO_2 and CH_4 emission factors for natural gas transmission, distribution and venting, are the most accurate as they are calculated on basis of gas composition measurements. Emissions factors for flare gas are available in the EU ETS reporting while emissions factors for natural gas are published by Energinet.dk.

The calculation of CO_2 emissions from exploration of oil and gas is based on information on oil and gas quality for most drillings. As the uncertainty levels of the measurements are not available, the double of the uncertainty for flaring in oil and gas extraction (before EU ETS standards) has been used.

The CO_2 emission factor for production of oil and gas is based on standard emission factors from IPCC (2006) and the corresponding uncertainties of 100 % are applied in the uncertainty analysis.

The uncertainty level for the emission factor for fugitive CH_4 emissions from refineries is dominated by a large uncertainty for one refinery. Further, measurements of fugitive emissions from the refineries are only available for one and two years, respectively, and these measurements indicate larger emissions than earlier estimates. As more measurements become available, the uncertainty level is expected to decrease.

The emission factors for onshore loading of ships are based on data for the Danish harbour terminal and the uncertainty is expected to be relatively low, as it is based on results from measurement campaigns. The uncertainty for the CH_4 emission factors for offshore loading of ships in the 2019 IPCC Refinement (IPCC, 2019) is ±50 %. Following, an uncertainty level of 50% are used for CRF 1B2a3 Oil transport.

For onshore activities, the emission factor uncertainty corresponds to the uncertainty for onshore loading by Statistics Norway (2008), and the same uncertainty level is assumed for the CH_4 emission factor for onshore activities.

According to IPCC (2006) the emission factor for N_2O is the least reliable, and the uncertainty interval for the N_2O emission factors given for flaring in oil and gas production is -10 % to +1 000 %. An uncertainty level of 1 000 % is adopted in the Danish uncertainty model for all fugitive sources in the Danish inventory (exploration and flaring of oil and gas).

Results

The results of the Approach 1 uncertainty model for 2021 are shown in Table 3.5.13. N_2O has the largest uncertainty for both the total emission and the trend followed by CH_4 and CO_2. The estimated uncertainty for the total GHG emission is 27 % and the GHG emission trend is -66 % ±4 %-point.

Table 3.5.13 Uncertainty estimates for total emissions and emission trends from the Approach 1 uncertainty model.

	1990 emission,	2021 emission,	Uncertainty,	Trend 1990-2020,	Uncertainty,
	kt CO_2 eqv	kt CO_2 eqv	% lower and upper (±)	%	% lower and upper (±)
CO_2	341	111	7	-67	3
CH_4	149	61	73	-59	10
N_2O	0.11	0.05	710	-57	57
GHG	490	172	26	-65	4

3.5.6 Source specific QA/QC and verification

The elaboration of a formal QA/QC plan started in 2004 and was updated in 2013 (Nielsen et al., 2013) and latest in 2020 (Nielsen et al., 2020). The plan describes the concepts of quality work and definitions of sufficient quality, Critical Control Points (CCP) and a list of Points of Measuring (PM) (Figure 3.5.22). Please refer to the general Section *1.6 Information on QA/QC plan including verification and treatment of confidential issues where relevant* for further information.

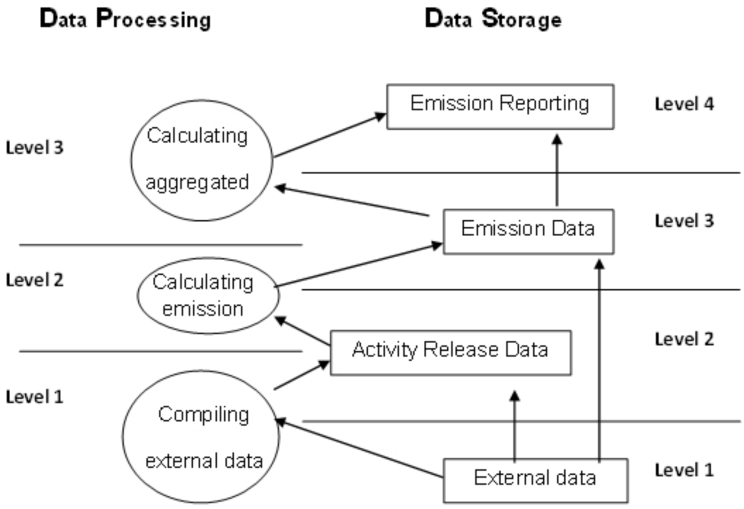

Figure 3.5.22 The general data structure for the Danish emission inventory (Nielsen et al., 2020).

Data storage level 1

Data storage level 1 refers to the data collected by DCE before any processing or preparing. Table 3.5.14 lists the external data deliveries used for the inventory of fugitive emissions. Further, the table holds information on the contacts at the data delivery companies.

Table 3.5.14 List of external data sources.

Category	Data description	Activity data, emission factors or emissions	Reference	Contact(s)	Data agreement /comment
Exploration of oil and gas	Dataset for exploration of oil and gas, including rates and composition.	Activity data	The Danish Energy Agency	Kirsten Lundt Erichsen	Data agreement
Production of oil and gas	Gas and oil production. Dataset, including rates of offshore loading of ships.	Activity data	The Danish Energy Agency	Kirsten Lundt Erichsen	Not necessary due to obligation by law
Offshore flaring	Flaring in upstream oil and gas production (EU ETS data)	Activity data	The Danish Energy Agency	Dorte Maimann	Data agreement
Service stations	Data on gasoline sales from the Danish energy statistics.	Activity data	The Danish Energy Agency	Jane Rusbjerg	Data agreement
Gas transmission	Natural gas transmission rates from the transmission company, sales and losses.	Activity data	Energinet.dk	Frederikke Byrial Zilstorff	Not necessary due to obligation by law
Onshore activities	Rates of oil transport in pipeline and onshore loading to ships. Emissions from storage of raw oil in the terminal.	Activity data and emission data	Ørsted	Søren Boesen	No formal data agreement.
Gas distribution	Natural gas and town gas distribution rates from the distribution company, sales and losses (meter differences)	Activity data	Evida	Susanne Kirkegaard	No formal data agreement.
Emissions from refinery	Fuel consumption and emission data.	Activity data and emission data	Kalundborg Refinery, Crossbridge	Anette Holst, Trine Bjerre Kristiansen	No formal data agreement.
Treatment and storage of gas	Environmental reports and supplemental data from plants defined as large point sources (Lille Torup, Stenlille, Nybro)	Activity data and emission data	Energinet.dk Ørsted	Christian Guldager Corydon Per Korshøj	No formal data agreement.
Onshore loading	Annual report for the harbour terminal.	Activity data and emission data	Crossbridge	Trine Bjerre Kristiansen	No formal data agreement.
CO_2 emission factors for different sources	Reports according to the CO_2 emission trading scheme (EU ETS)	Activity data	Various plants		Not necessary due to obligation by law
Emission factors	Emission factors origin from a large number of sources	Emission factors	See Section *3.5.4 Activity data, emission factors and emissions for fugitive sources* regarding emission factors		

The following lists the CCPs and the PMs in the Danish QA/QC plan, relevant for the emission inventory for the fugitive sector.

Level	CCP	PM	Description
Data Storage level 1	1. Accuracy	DS.1.1.1	General level of uncertainty for every dataset including the reasoning for the specific values.

The uncertainty for every dataset included in the inventory of fugitive emissions are evaluated and included in the Tier 1 uncertainty calculations with short descriptions of the reasoning behind the specific values. The general levels of uncertainty are relatively low. The largest uncertainties are expected for emissions from refineries and distribution of town gas, the latter being of minor importance to the total fugitive emissions. For further comments regarding uncertainties, see Section *3.5.5 Uncertainties and time series consistency*.

Level	CCP	PM	Description
Data Storage level 1	2.Comparability	DS.1.2.1	Comparability of the emission factors/calculation parameters with data from international

			guidelines, and evaluation of major discrepancies.

Systematic inter-country comparison has only been made on Data Storage Level 4. Refer to DS.4.3.2 in Section *1.6 Information on QA/QC plan including verification and treatment of confidential issues where relevant*.

Level	CCP	PM	Description
Data Storage level 1	3.Completeness	DS.1.3.1	Ensuring that the best possible national data for all sources are included, by setting down the reasoning behind the selection of datasets.

External data include energy statistics from the Danish Energy Agency, EU ETS reports and annual environmental reports from a number of plants and companies. Further, supplementary information are gathered annually from some companies. Only one national data set is found for most fugitive sources, and all data sets are expected to be complete and include all activities/emissions form the sources. Data on flaring in upstream oil and gas production, in refineries and in gas treatment and storage facilities are available both in annual environmental reports and in EU ETS reports. Data are compared and if any differences occur, this is checked with the data suppliers. Minor differences may owe to the allocation of fuels, e.g. if pilot gas are included in the flare gas or the fuel gas rate.

Energy statistics

The Danish Energy Agency reports fuel consumption statistics on the SNAP level based on a correspondence table developed in co-operation with DCE. Both traded and non-traded fuels are included in the Danish energy statistics. Data on production and flaring in upstream oil and gas production, and gasoline sales are used for estimation of fugitive emissions.

Environmental reports

A large number of plants are obligated by law to publish an environmental report annually with information on e.g. fuel consumption and emissions. DCE compares data with those from previous years, discrepancies are checked, and large fluctuations are verified.

Annual reports

The gas distribution companies and the raw oil terminal are not obligated to publish environmental reports. Instead, the self-regulation reports, annual reports and/or additional information are used. All information is compared with data for previous years.

Reports for the European Union Greenhouse Gas Emission Trading System (EU ETS)

CO_2 emission factors for offshore in upstream oil and gas production and in refineries are taken from the EU ETS reports since 2006, when the EU ETS reports became available. EU ETS reports are available individually for the Danish oil/gas production fields and refineries.

Emission factors from a wide range of sources

For specific references, see Section *3.5.4 Activity data, emission factors and emissions for fugitive sources*.

Level	CCP	PM	Description
Data Storage level 1	4.Consistency	DS.1.4.1	The original external data has to be archived with proper reference.

All external data are stored in the inventory file system and are accessible for all inventory staff members. Data processing is carried out in separate spread sheets to ensure that the external data are always available in the original form. Data sources are referenced in the spread sheets. Refer to Section *1.3. Brief description of the process of inventory preparation. Data collection and processing, data storage and Archiving*.

Level	CCP	PM	Description
Data Storage level 1	6.Robustness	DS.1.6.1	Explicit agreements between the external institution holding the data and DCE about the conditions of delivery

Formal agreements are made with the Danish Energy Agency. Annual environmental reports are available due to legal requirements. The remaining data are published or delivered by the companies on voluntary basis. See Table. 3.5.14.

Level	CCP	PM	Description
Data Storage level 1	7.Transparency	DS.1.7.1	Listing of all archived datasets and external contacts.

See DS 1.3.1 and Table 3.5.14.

Data Processing Level 1

Level	CCP	PM	Description
Data Processing level 1	1. Accuracy	DP.1.1.1	Uncertainty assessment for every data source not part of DS.1.1.1 as input to Data Storage level 2 in relation to type and scale of variability.

Refer to Section *1.7 General uncertainty evaluation, including data on the overall uncertainty for the inventory totals* in the Danish NIR and Section *3.5.6 Source specific QA/QC and verification*.

Level	CCP	PM	Description
Data Processing level 1	2.Comparability	DP.1.2.1	The methodologies have to follow the international guidelines suggested by UNFCCC and IPCC.

The methodologies in the inventory follow the principles in international guidelines by UNFCCC and IPCC.

Level	CCP	PM	Description
Data Processing level 1	3.Completeness	DP.1.3.1	Identification of data gaps with regard to data sources that could improve quantitative knowledge.

Data gaps are found for distribution of town gas, as more companies are closed before this source was included in the Danish inventory. Emissions, which account for only a limited part of the total fugitive emissions, are calculated on a scarce data foundation. Also further information regarding VOC emissions from refineries would be preferred, but are not available. DCE continue the collaboration with the refineries update the methodology and emission estimates if new information become available.

Level	CCP	PM	Description
Data Processing level 1	4.Consistency	DP.1.4.1	Documentation and reasoning of methodological changes during the time series and the qualitative assessment of the impact on time series consistency.

Since 2006, the EU ETS data have been available for a number of sources. In all cases, the new data replace use of data assumed to be less accurate. Therefore, the CO_2 emission factors have been updated for all years, and no methodological change occur in the time series.

A change in the calculating procedure would entail elaboration of an updated description in Section *3.5.4 Activity data, emission factors and emissions for fugitive sources*.

Level	CCP	PM	Description
Data Processing level 1	5.Correctness	DP.1.5.2	Verification of calculation results using time series

Time series for activity data, emission factors and/or emissions on SNAP level are used to identify possible errors in the calculation procedure.

Level	CCP	PM	Description
Data Processing level 1	5.Correctness	DP.1.5.3	Verification of calculation results using other measures

For fugitive sources, only one data set is available for calculation, and no verification using other measures are possible. For sources where activity data is available in more data sources (e.g. in both EU ETS and annual reports), data are compared and reasons for any differences are clarified.

Level	CCP	PM	Description
Data Processing level 1	7.Transparency	DP.1.7.1	The calculation principle, the equations used and the assumptions made must be described.

Descriptions are included in the NIR in Section *3.5.4 Activity data, emission factors and emissions for fugitive sources*.

Level	CCP	PM	Description
Data Processing level 1	7.Transparency	DP.1.7.2	Clear reference to dataset at Data Storage level 1

Notes on data sources are included in the calculation files for all input data.

Level	CCP	PM	Description
Data Processing level 1	7.Transparency	DP.1.7.3	A manual log to collect information about recalculations.

A log holding information on recalculations are included in the national inventory system. Further, a log is prepared annually holding information on status of the inventory work and recalculations for each source in the fugitive sector.

Data storage level 2

Level	CCP	PM	Description
Data Storage level 2	5.Correctness	DS.2.5.1	Check if a correct data import to level 2 has been made

To ensure a correct connection between data on level 2 to data on level 1, different controls are in place, e.g. control of sums and random tests.

Data storage level 4

Level	CCP	PM	Description
Data Storage level 4	4.Consistency	DS.4.4.3	The IEFs from the CRF are checked both regarding level and trend. The level is compared to relevant emission factors to ensure correctness. Large dips/jumps in the time series are explained.

Time series for IEFs are checked to identify large fluctuations, which are afterwards investigated and explained. The level of the IEFs are compared to other relevant EFs, e.g. in standard EFs in guidebooks and guidelines.

Other QC procedures

A list of QA/QC tasks are performed directly in relation to the fugitive emission part of the Danish emission inventories. The following procedures are carried out to ensure the data quality:

- The emission from the large point sources (refineries, gas treatment and gas storage facilities) is compared with the emission reported the previous year.
- Annual environmental reports are kept for subsequent control of plant-specific emission data.
- Checks of data transfer are incorporated in the fugitive emission models, e.g. sum checks.
- Verification of activity data from external data when data are available through more data sources (production and flaring rates in upstream oil and gas production).
- Data sources are incorporated in the fugitive emission models
- A manual log table in the emission databases is applied to collect information about recalculations.
- Comparison with the inventory of the previous year. Any major changes are verified.
- Total emission, when aggregated to reporting tables, is compared with totals based on SNAP source categories (control of data transfer).
- Checking of time series in the CRF and SNAP source categories. Significant dips and jumps are controlled and explained.

External review

A documentation report for the sector "The Danish emission inventory for fugitive emissions from fuels" was published in 2021. The report includes detailed information on the methodology used in the emission inventories for greenhouse gases and air pollution (Plejdrup et al., 2021). The report was reviewed by Jesper Werner Løhndorf Christensen from the Danish Energy Agency.

The previous versions of the documentation report from 2015 and 2009 was reviewed by Glen Thistlethwaite from Ricardo Energy & Environment, Oxfordshire, UK and by Anette Holst, Statoil A/S, The Refinery, Kalundborg, Denmark, respectively.

3.5.7 Recalculations

CO_2

The CO_2 IEF for oil exploration has been updated for the years 1992, 1998 and 2002, leading to only minor changes in emissions.

The NCV for natural gas used in calculations of implied emission factors have been updated. This recalculation influence emissions from oil and gas exploration, and offshore flaring in oil and gas production. The recalculation leads to minor changes in emissions.

Minor updates have been made in the emission calculation for onshore loading and oil storage at the crude oil terminal based on new information provided. The recalculation leads to minor changes.

A minor error for the oil density for the harbour terminal has been corrected, increasing the CO_2 emission in 2020 by 0.2 t.

The CO_2 IEFs for gas transmission and distribution have been updated and new data provided by the distribution company regarding annual distribution, gas loss and share of bio-natural gas for 2019-2020 have been implemented. The recalculation leads to minor changes.

Emissions from gas chromatographs at the Danish gas treatment plant has been included as a new source in the inventory. The annual amount of natural gas loss from measurement equipment of 14 000 Nm^3 has been estimated by the gas treatment plant and is included in the inventory of methane losses from the Danish distribution and transmission network (Nygaard, 2020). The recalculation leads to minor changes of the CO_2 emissions (largest change is an increase of 0.4 kt in 2000).

Activity data for offshore flaring is updated for 2006 according to statistics from the Danish Energy Agency. The recalculation increase the CO_2 emission by 12.47 kt, corresponding 2% of the total fugitive CO_2 emission.

The IEF for flaring in gas storage has been updated. The recalculation leads to minor changes.

The CO_2 IEF for flaring in gas transmission and distribution have been updated for the time series. This recalculation leads to minor changes (largest change in 2002 of 0.03 kt).

CH_4

The NCV for natural gas used in calculations of implied emission factors have been updated. This recalculation influence emissions from oil and gas exploration, and offshore flaring in oil and gas production. The recalculation leads to minor changes in emissions.

The CH_4 EF for offshore loading has been updated according to the 2019 Refinement. The recalculation increase the CH_4 emission by 0.01 kt - 0.04 kt, corresponding 0.2 % - 0.5 % of the total fugitive CH_4 emission.

The NCV for natural gas used in calculations of implied emission factors have been updated. This recalculation influence emissions from oil and gas exploration, and offshore flaring in oil and gas production. The recalculation leads to minor changes in emissions.

Minor updates have been made in the emission calculation for onshore loading and oil storage at the crude oil terminal based on new information provided. A minor error has been corrected for the harbour terminal. The recalculation leads to minor changes.

The CH_4 IEF for gas transmission and distribution have been updated and new data provided by the distribution company regarding annual distribution, gas loss and share of bio-natural gas for 2019-2020 have been implemented. The recalculation decrease the CH_4 emission by 0.02 kt - 0.1 kt, corresponding 0.3% - 1.1 % of the total fugitive CH_4 emission.

Emissions from gas chromatographs at the Danish gas treatment plant has been included as a new source in the inventory. The annual amount of natural gas loss from measurement equipment of 14 000 Nm^3 has been estimated by the gas treatment plant and is included in the inventory of methane losses from the Danish distribution and transmission network (Nygaard, 2020). The recalculation increase the CH_4 emission by 9 t per year, corresponding 0.1 % - 0.4 % of the total fugitive CH_4 emission.

Activity data for offshore flaring is updated for 2006 according to statistics from the Danish Energy Agency. The recalculation increase the CH_4 emission by 47 t, corresponding 0.4% of the sectoral total CH_4 emission.

The IEF for flaring in gas storage has been updated. The largest recalculation is an increase of 0.6 t CH_4 in 2003.

An error for the CH_4 IEF for flaring in gas transmission and distribution has been corrected. The recalculation increase the emission by 0.2 kt – 0.3 kt for the years 2011-2020.

N_2O

The NCV for natural gas used in calculations of implied emission factors have been updated. This recalculation influence emissions from oil and gas exploration, and offshore flaring in oil and gas production. The recalculation leads to minor changes in emissions.

An error have been corrected for the N_2O IEF used for oil and gas exploration and flaring in offshore flaring in oil and gas production. Also, activity data for offshore flaring is updated for 2006 according to statistics from the Danish

Energy Agency. The recalculation decrease the N_2O emission by 71 t – 616 t, the latter corresponding -2 % of the national total N_2O emission in 1999.

Small recalculations have been made for flaring in gas transmission and distribution, leading to minor changes.

3.5.8 Source specific implemented improvements

Venting from measurement equipment at the natural gas treatment plant has been implemented in the inventory. The methodology and data are described in Chapter 3.5.4.

3.5.9 Response to the review process

A review of the Danish 2022 submission took place from 29th September to 1st October 2022. At the time of preparing this report, Denmark had not yet received a draft review report. Therefore, the table below represents the latest available report.

Table 3.5.15 contains the recommendations of the most recent UNFCCC review of the Danish greenhouse gas inventory. The table details the status of implementation of the recommendations as well as references to where improvements have been implemented in this report.

Table 3.5.15 Response to the review process.

Para.	CRF	ERT Comment	Denmark's response	Reference
2021 submission (Review report: FCCC/ARR/2021/DNK (unfccc.int))				
No findings for CRF 1.B Fugitive emissions from fuels				

3.5.10 Source specific planned improvements

Gas transmission and distribution

A review of the inventory for fugitive emissions from gas transmission and distribution is planned within the next year. Depending on the findings during the review, potential changes are assumed included in the 2024 submission.

Offshore oil and gas production

A review of the inventory for fugitive emissions from offshore oil and gas production is ongoing and will continue in the coming years. It is expected that a new national methodology can be implemented in the 2024 or 2025 submission. The work is made in close cooperation with the Danish operators on the North Sea and the trade association for the Danish North Sea oil- and gas producers (Dansk Offshore). The aim is to develop a new methodology, which is to the extent possible based on company emission estimations and results from measurement campaigns for a number of offshore platforms. Only few measurements have been carried out to date, but the operators are planning on further measurement campaigns in 2023.

The first draft estimates based on few input data indicate that the emissions are significantly lower than estimates based on the default emission factors included in the 2019 IPCC Refinement. The Danish oil and gas production is subject to environmental and safety regulations which contribute to reduction of fugitive emissions. The new EU regulation on methane emissions reduction in the energy sector (EU, 2021) will entail focus on and initiatives regarding emissions reduction and quantification, and results and knowledge will be used in the development of a national methodology.

Changes in practise and equipment over the time series will be taken into account in cooperation with the operators. The methodology will be validated against methods and emission factors used by other countries or regions to the extent possible.

3.5.11 References

A/S Dansk Shell - Havneterminalen, 2013: Annual Report for the Harbour Terminal (in Danish).

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4 Industrial Processes and Product Use

4.1 Overview of the sector

The *Industrial Processes and Product Use* (IPPU) sector covers greenhouse gases (GHG) from industrial processes not related to generation of energy along with emissions from product use. The IPPU sector consists of the following CRF source categories:

- 2A Mineral Industry
- 2B Chemical Industry
- 2C Metal Industry
- 2D Non-Energy Products from Fuels and Solvent Use
- 2E Electronics Industry
- 2F Product Uses as Substitutes for Ozone Depleting Substances (ODS)
- 2G Other Product Manufacture and Use

The data presented in Chapter 4 relate to Denmark only, whereas information for Greenland is included in Chapter 16 and for the Faroe Islands in Annex 7.

For a more detailed description of the methods used and the verifications performed, please refer to the sectoral method report Hjelgaard & Nielsen (2018).

4.1.1 Methodology overview

Table 4.1.1 gives a brief overview over methodologies applied for the IPPU sector. Further description of the applied methodologies can be found in the following chapters.

Table 4.1.1 Overview of methodologies used for the 2019 data (or the latest active year for activities that have ceased).

IPCC code	Process	Substance	Tier	EF	Key category 1990/2021/ trend
2A1	Cement production*	CO_2	T3	PS	Yes/Yes/Yes
2A2	Lime production	CO_2	T2	PS/CS	No/No/No
2A3	Glass production	CO_2	T3	PS	No/No/No
2A4a	Ceramics	CO_2	T3	CS	No/No/No
2A4b	Other uses of soda ash	CO_2	T3	D	No/No/No
2A4d	Other process uses of carbonates	CO_2	CS/T3	D	No/No/No
2B2	Nitric acid production	N_2O	T2	PS	Yes/No/Yes
2B10	Catalyst production	CO_2	CS	PS	No/No/No
2C1	Iron and steel production*	CO_2	T1	CS, D	No/No/No
2C4	Magnesium production	SF_6	T2	D	No/No/No
2C5	Secondary lead production	CO_2	T1	D	No/No/No
2D1	Lubricant use	CO_2	T1	D	No/No/No
2D2	Paraffin wax use	CO_2, N_2O, CH_4	T2	OTH/D	No/No/No
2D3	Paint application	CO_2	CS/T2	CS	No/No/No
2D3	Degreasing, dry cleaning and electronics	CO_2	CS/T2	CS	No/No/No
2D3	Chemical products manufacturing or processing	CO_2	CS/T2	CS	No/No/No
2D3	Other use of solvents and related activities	CO_2	CS/T2	CS	No/No/No
2D3	Road paving with asphalt	CO_2, CH_4	T2	OTH	No/No/No
2D3	Asphalt roofing	CO_2	T2	OTH	No/No/No
2D3	Urea-based catalysts	CO_2	T3	D	No/No/No
2E5	Other electronics industry	HFCs, PCFs	T2	D	No/No/No
2F1	Refrigeration and air conditioning	HFCs, PFCs	T2	D/CS	No/Yes/Yes
2F2	Foam blowing agents	HFCs	T2	D	No/No/Yes
2F4	Aerosols	HFCs	T2	D	No/No/No
2F5	Solvents	PFCs	T2	D	No/No/No
2G1	Electrical equipment	SF_6	T3	D	No/No/No
2G2	SF_6 and PFCs from other product use	SF_6	T2	D	No/No/No
2G3a	Medical application	N_2O	T1	D	No/No/No
2G3b	Propellant for pressure and aerosol products	N_2O	T1	D	No/No/No
2G4	Other product uses	CO_2, CH_4, N_2O	T2	D/CS/OTH	No/No/No

* The methodology used for this category varies over the time series, see Table 4.1.2.

Table 4.1.2 Overview of implemented methodologies for categories where the methodology varies over the time series.

Process	Years	Available activity data	Available emission factors	Resulting methodology
2A1 Cement production	1990-1997	Production of white cement and production of three types of grey clinker.	Plant specific factors for the three individual grey clinker types and for white cement.	Tier 1/PS
	1998-2021	Consumption of raw materials.	Plant specific measured carbonate content of raw materials.	Tier 3/PS
2A4a Ceramics	1990-2005	Estimated $CaCO_3$ eq. data based on national statistics	Country specific	Tier 2/CS
	2006-2021	Plant specific data on carbonate consumption	Country specific	Tier 3/CS
2A4d Other process uses of carbonates	1990-2005	Estimated $CaCO_3$ data based on total produced flue gas cleaning residue	Default	Tier 2/D
	2006-2021	Plant specific data on carbonate consumption	Default	Tier 3/D
2C1 Iron and steel production	1990-1992, 2005	Extrapolation, interpolation, expert judgement	Expert judgement	Tier 1/CS,D
	1993-2001	Environmental reports	Environmental reports	Tier 2/CS,D

4.1.2 Key categories

A Key Category Analysis (KCA) for the years 1990 and 2021 as well as for the trend has been carried out. The result for the IPPU sector is shown in Table 4.1.3. A detailed KCA is presented in Chapter 1.5 and Annex 1. The calculations are based on national emissions including LULUCF but excluding Greenland and the Faroe Islands.

The analysis is carried out using both Approach 1 and Approach 2 methods. Four categories are identified as key categories in IPPU in this submission, three of which both for level and trend.

Table 4.1.3 Key Category Analysis for Industrial Processes and Product Use.

IPCC code	Process	Substance	Approach 1 1990	Approach 1 2021	Approach 1 1990-2021	Approach 2 1990	Approach 2 2021	Approach 2 1990-2021
2A1	Cement production	CO_2	Level	Level	Trend			
2B2	Nitric acid production	N_2O	Level		Trend	Level		Trend
2F1	Refrigeration and air conditioning	HFCs		Level	Trend		Level	Trend
2F2	Foam blowing agents	HFCs			Trend			Trend

Only source categories identified as key categories are presented in Table 4.1.3, for a full overview of the source categories included in this inventory please refer to Table 4.1.1.

4.1.3 Emission overview

An overview of the most significant sources in 2021 is presented in Table 4.1.4; these five source categories comprise more than 90 % of emissions in CO_2 equivalents (CO_2 eq.) from IPPU. The table below also gives an indication of the contribution to the total emission of greenhouse gases in 2021 in the IPPU sector.

Table 4.1.4 Overview of the largest sources to greenhouse gas emissions in the IPPU sector in 2021.

Process	IPCC Code	Substance	Emission kt CO_2 eq.	%*
Cement production	2A1	CO_2	1215	65.6
Refrigeration and air conditioning	2F1	HFCs, PFCs	264	14.3
Other process uses of carbonates[2]	2A4	CO_2	85	4.6
Other[1]	2D3	CO_2, CH_4	81	4.4
Paraffin wax use	2D2	CO_2, CH_4, N_2O	66	3.6
Total of five largest sources			1711	92.4

*of total CO_2 equivalent emissions from the IPPU sector.
[1] 2D3 consists of solvent use, road paving with asphalt, asphalt roofing and urea use in vehicle catalysts. [2] 2A4 consists of ceramics, other uses of soda ash, flue gas desulphurisation and stone wool production.

For 2021, the subsector Mineral Industry (2A) constitutes 73 % of the GHG emissions from the IPPU sector and Product Uses as Substitutes for ODS (2F) constitutes 15 %. Non-Energy Products from Fuels and Solvent Use (2D) and Other Product Manufacture and Use (2G) constitutes 10 and 2 % respectively, while Chemical Industry (2B) and Metal production (2C) together constitutes below 0.1 %. The total emission of greenhouse gases (excl. LULUCF) in Denmark in 2021 is estimated to 43.2 Mt CO_2 equivalents of which IPPU contribute with 1.9 Mt CO_2 equivalents (4.3 %). The emissions of GHG from IPPU from 1990-2021 are presented in Figure 4.1.1.

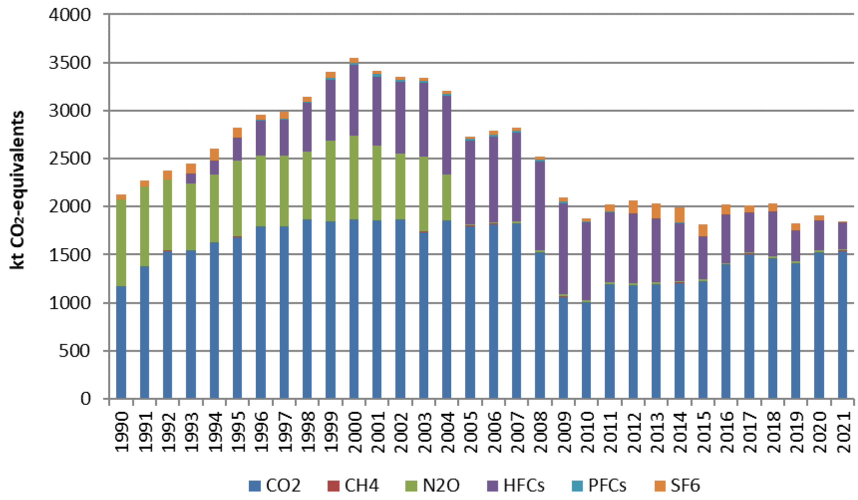

Figure 4.1.1 Emission of individual- and total greenhouse gases from IPPU (CRF Sector 2) from 1990-2021.

The majority of CO_2 emissions in the IPPU sector are emitted from the cement production, the small drop in CO_2 emissions in 2003 and the larger decrease in 2008-2010 are caused by a lower production of cement for these years. The production of nitric acid closed down during 2004 causing the N_2O emission to drop drastically; from 680-907 kt CO_2 equivalents in 1990-2003 to 14-20 kt CO_2 equivalents in 2005-2021. The use of HFCs in mainly refrigeration and air conditioning has increased significantly during the time series but is decreasing in recent years. HFC emissions peaked in 2009 with 951 kt CO_2 equivalents, but has decreased to 275 kt CO_2 equivalents in 2021.

4.1.4 EU-ETS (EU Emission Trading Scheme)

Guidelines for calculating company specific CO_2 emissions are developed by the EU (EU Commission, 2018). The guidelines present standard methods for minor companies and methods for developing individual plans for major companies. The standard methods include default emission factors similar to the default emission factors presented by IPCC (e.g. for limestone), whereas, the major companies have to use individual methods to determine the actual composition of raw materials (e.g. purity of limestone or Ca per tonne ratio in dolomite) or the actual CO_2 emission from the specific process. Where data from the EU-ETS are used more detail is provided on the specific methodologies used in the specific chapter. This is the case in the following categories:

- Cement production
- Lime production
- Glass production
- Ceramics
- Flue gas desulphurisation
- Stone wool production

4.2 Mineral Industry

4.2.1 Source category description

The sector *Mineral Industry* (CRF 2A) covers the following industries relevant for the Danish air emission inventory:

- 2A1 Cement production; see section 4.2.3.
- 2A2 Lime production; see section 4.2.4.
- 2A3 Glass production; see section 4.2.5.
- 2A4a Ceramics; see section 4.2.6.
- 2A4b Other uses of soda ash; see section 4.2.7.
- 2A4d Flue gas desulphurisation; see section 4.2.8.
- 2A4d Stone wool production; see section 4.2.9.

Cement production is identified as key category according to Approach 1 for level in 1990 and 2021 and for trend; see *Annex 1: Key Category Analyses*.

4.2.2 Emissions

Total greenhouse gas emissions from the Mineral Industry sector are available in the CRF Table 10. The emission time series for the source categories within *Mineral Industry* (2A) are presented in Figure 4.2.1 and individually in the subsections below (Sections 4.2.3 – 4.2.9). The following figure gives an overview of how much the individual source categories contribute throughout the time series.

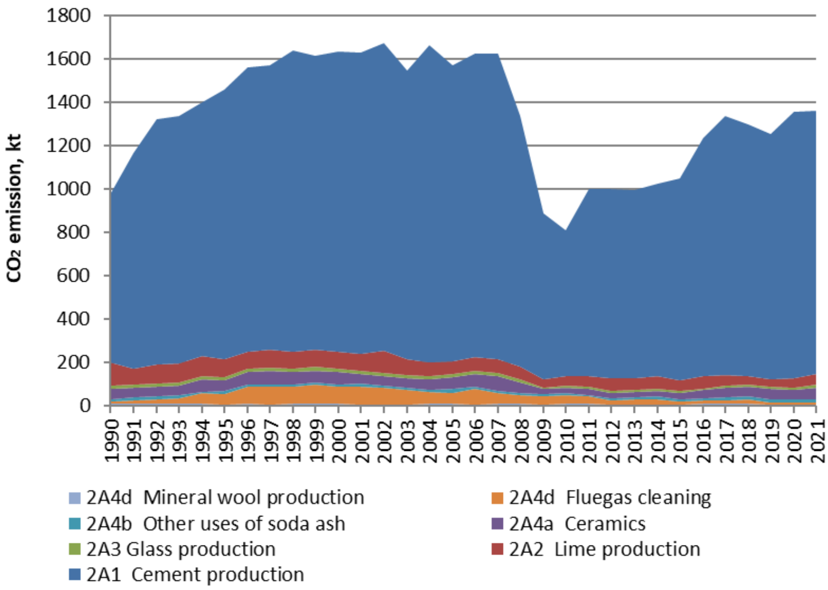

Figure 4.2.1 Emission of CO_2 from the individual source categories compiling *2A Mineral Industry*, kt.

Greenhouse gas emissions from *Mineral Industry* are made up mostly by CO_2 emissions from the production of cement; min. 80 % (1990) to max. 91 % (2020).

Emissions from *Mineral Industry* increased with 72 % from 1990 to the time series peak in 2002 (2002 emission: 1670 kt CO_2). The overall development in the CO_2 emission for 1990 to 2021 shows an increase from 973 kt CO_2 to 1359 kt CO_2, i.e. 40 %.

The increase from 1990 to 1997 can be explained by the increase in the annual cement production. The emission factor has only changed slightly as the distribution between types of cement especially grey/white cement has been almost constant from 1990-1997. The increase in emissions from 2010-2017 may be explained by an increase in the construction activity after the financial crisis in 2008-2010 and hence an increase in cement demand and production.

4.2.3 Cement production

The production of cement in Denmark is concentrated at one company: Aalborg Portland A/S situated in Aalborg. The following source is covered:

- Cement (decarbonising)

Emissions associated with fuel combustion in cement kilns are estimated and reported in the energy sector. Only emissions related to the calcination of non-fuel feedstock to cement kilns are reported under category 2A.

Methodology

Process emissions are released from the calcination of raw materials (primarily chalk and sand). The overall process for calcination is:

$$CaCO_3 \rightarrow CaO + CO_2$$

The primary raw materials are sand, chalk and water and the main products are grey cement, white cement and cement clinker for sale.

Aalborg Portland uses a semi-dry process. The first step is production of raw meal. The chalk slurry and the grounded sand are mixed as slurry that is injected into a drier crusher. The raw materials are converted into raw meal that releases carbon dioxide (CO_2) in the calciner.

In a rotary kiln, the material is burned to clinker that afterwards is grounded to cement in the cement mill. During the process, cement kiln dust is recirculated.

The emission of CO_2 depends on the ratio: white/grey cement and the ratio between the three types of clinker used for grey cement: GKL-clinker/FKH-clinker/SKL-RKL-clinker.

For 1990-1997, the ratio white/grey cement and the ratio GKL-clinker/FKH-clinker/SKL-RKL-clinker is known. The fraction of white cement in relation to total cement production peaked in 1990 (25 %) and decreased thereafter. The production of SKL/RKL-clinker peaks in 1991 (25 % of total grey clinker production) and decreases hereafter. FKH-clinker is introduced in 1992 and increases to a share of 35 % of total grey clinker production in 1997. The CO_2 emission is calculated according to the following equation:

$$M_{CO_2} = M_{grey} * \frac{M_{GLK} * EF_{GLK} + M_{FKH} * EF_{FKH} + M_{SKL/RKL} * EF_{SKL/RKL}}{M_{GLK} + M_{FKH} + M_{SKL/RKL}} + M_{white} * EF_{white}$$

M_{grey}	Grey cement	t
M_{white}	White cement	t
M_{GLK}	GKL clinker (rapid cement)	t
M_{FKH}	FKH clinker (basis cement)	t
$M_{SKL/RKL}$	SKL/RKL clinker (low alkali cement)	t
EF_{white}	CO_2 emission factor	t/t white cement
EF_{GLK}	CO_2 emission factor	t/t GLK clinker
EF_{FKH}	CO_2 emission factor	t/t FKH clinker
$EF_{SKL/RKL}$	CO_2 emission factor	t/t SKL/RKL clinker

The company has at the same time stated that data until 1997 cannot be improved as there are no further information available. Data for white cement is therefore used as an estimate for white clinker making the methodology used for the years 1990-1997 a Tier 1.

From 1998-2004 carbonate content of the raw materials has been determined by loss on ignition methodology. Determination of loss on ignition takes into account all the potential raw materials leading to release of CO_2 based on full oxidation and omits the Ca-sources leading to generation of CaO in cement clinker without CO_2 release. The applied methodology is in accordance with EU guidelines on calculation of CO_2 emissions (Aalborg Portland, 2008). Clinker data are available.

From the year 2006 the CO_2 emission determined by Aalborg Portland, independently verified and reported under the EU-ETS (EU Emission Trading Scheme) is used in the inventory (Aalborg Portland, 2022a). The reporting to EU-ETS also provides detailed information of alternative fuels used in the production of clinker and the amount of clinker produced.

EU-ETS data for cement production

Cement production applies the Tier 3 methodology for calculating the CO_2 emission for 1998-2021.

The implied CO_2 emission factor for Aalborg Portland is plant specific and based on the reporting to the EU-ETS. The EU-ETS data have been applied for the years 2006 – 2021.

The CO_2 emission for cement production is based on measurements of the consumption of calcium carbonate to the calcination process. These measurements fulfil a Tier 3 methodology (± 1.6 %) as defined in the EU decision (EU Commission, 2018). The emission factor is based on continuous measurements with flow meters, density meters, X-ray and CaO analysis. (Aalborg Portland, 2013b).

Activity data

Activity data for cement (measured in total cement equivalents (TCE)) and clinker production are presented in Table 4.2.1 and Annex 3C-1. Emissions are based on clinker production alone, cement production data are used for verification.

Table 4.2.1 Production statistics for cement and clinker production, kt (Aalborg Portland, 2008, 2013a, 2020, 2022a, b).

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
kt TCE	1620	2274	2613	2706	1454	1902	2360	2342	2444	2568
kt clinker[1]	1406	2353	2452	2521	1314	1715	2141	2146	2240	2202

[1] 1990-1997: Clinker production is estimated as grey clinker plus white cement (Aalborg Portland, 2008).

Cement data are generally higher than clinker data, with the exception of 1995 and 1996.

Emission factors

The calculated implied emission factors (IEF) for cement production are presented in Table 4.2.2 and Annex 3C-2.

Table 4.2.2 Implied emission factors for CO_2 for cement production.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
IEF t CO_2 per t TCE[1,2,3]	0.478	0.546	0.530	0.504	0.462	0.490	0.491	0.482	0.502	0.473
IEF t CO_2 per t clinker[3,4]	0.551	0.528	0.565	0.541	0.512	0.543	0.542	0.526	0.548	0.552

[1] 1990-1997: IEF based on information provided by Aalborg Portland (2005).

[2] 1998-2004: IEF based on information provided by Aalborg Portland (2008).

[3] 2005-2021: IEF based on emissions reported to EU-ETS (Aalborg Portland, 2022a).

[4] 1998-2021: IEF based on clinker production statistics provided by Aalborg Portland (2020, 2022b).

The IEF for CO_2 from the calcination process is expressed per tonne of cement or clinker and depends on the actual input of chalk/limestone in the process. The IEF will therefore vary as the allocation of different cement/clinker types produced varies. A higher share of white cement will lead to a higher implied emission factor, as white cement production has the highest emission factor; see Table 4.2.3. The share of white cement decreases through the early part of the 1990s causing the emission per clinker to decrease as well. In 1990, 25 % of all cement produced was white cement; in 1991-1997 that same share fluctuates around 22 % (20.1-24.8 %).

Table 4.2.3 Emission factors used for 1990-1997 (Aalborg Portland, 2008).

Product	Value	Unit
White cement	0.669	t CO_2/t white cement
GLK clinker	0.477	t CO_2/t GLK grey clinker
FKH clinker	0.459	t CO_2/t FKH grey clinker
SKL/RKL clinker	0.610	t CO_2/t SKL/RKL grey clinker

For the entire time series, the emission factor (carbon content) has been estimated from the loss on ignition determined for the different kinds of clinkers produced (1990-1997) or different raw materials used (1998-2021). Determination of loss on ignition means that there is no need to consider uncalcined cement kiln dust (CKD) not recycled to the kiln; further detail is given above under methodology.

The company reporting to the EU-ETS applies the following emission factors for the most important raw materials used in 2021, similar data are available back to 2006 (Aalborg Portland 2022a) and to a less detailed degree back to 1998 (Aalborg Portland, 2020).

Table 4.2.4 Emission factors for some of the raw materials used in 2021 (Aalborg Portland, 2022a).

Raw material	t CO_2 per t raw material
Limestone	0.44
Magnesium carbonate	0.52
Ferrous carbonate	0.38
Sand	0.01-0.03
Fly ash	0.08
Bottom ash from biomass	0.47
Oxiton	0.03

The emission factors for limestone and carbonates are in accordance with the stoichiometric factors and the emission factors for the remaining raw materials and CKD are determined by individual yearly analysis.

Emission trends

The emission trend for the CO_2 emission from cement production is available in Annex 3C-3 and is also presented in Figure 4.2.2 below.

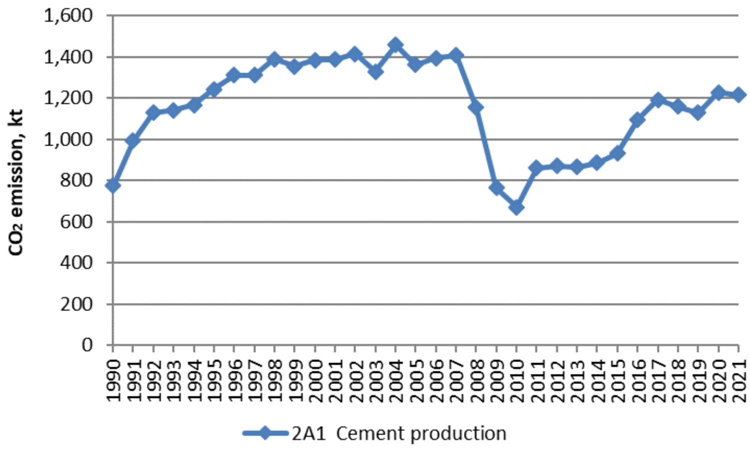

Figure 4.2.2 Emission of CO_2 from cement production.

The increase in CO_2 emission from the production of cement from 1990 to 1997 can be explained by the increase in the annual cement production. The most significant change to occur in the time series is the decline in emissions from 2007-2010, the decrease is due to reduced production resulting from the economic recession caused by the global financial crisis. The emissions increased 81 % in 2010-2021, but the emissions are still below the pre-recession levels. However, the overall development in the CO_2 emission from 1990 to 2021 is an increase from 775 to 1215 kt CO_2, i.e. by 57 %. The maximum emission occurred in 2004 and constituted 1 459 kt CO_2.

Time series consistency and completeness

Since Denmark only has one cement factory, all data collected from the production are plant specific data.

For 1990-1997, activity data for grey cement production fulfil the Tier 2 methodology while activity data for white cement (20-25 % of mass produced) only fulfil the Tier 1 methodology (IPCC, 2006). The company has informed that data until 1997 cannot be improved as there is no further information available. Since 1998, the determination of activity data for cement production has met the requirements of the Tier 3 methodology.

Emission factors have for the entire time series been determined by analysed loss on ignition which fulfil the requirements of the Tier 3 methodology.

Due to extensive verification, the methodology is believed to be consistent. For the various verifications performed, please refer to the IPPU sector report Hjelgaard & Nielsen (2018).

The inventory on cement production is considered complete in accordance with IPCC (2006) as the sole producer of cement in Denmark is fully included.

4.2.4 Lime production

The production of limestone ($CaCO_3$) and lime/burned lime/quicklime (CaO) is located at a few localities: Faxe Kalk (Lhoist group) situated in Faxe, Scandinavian Calcium Oxide ApS situated in Støvring, Dankalk A/S situated in Løgstør with limestone quarries/limeworks in Aggersund, Mjels, Poulstrup and Batum. In addition to the marketed lime production is the lime production related to production of sugar. Sugar production is concentrated at one company: Nordic Sugar (previously Danisco Sugar A/S) located in Assens (closed since 2007), Nakskov and Nykøbing Falster. The following source is covered:

- Lime (decarbonising)

Emissions associated with the fuel use are estimated and reported in the energy sector.

Methodology

Calculation of CO_2 emissions from oxidation of carbonates follows the general process:

$$CaCO_3 + heat \rightarrow CaO + CO_2$$

The emission of CO_2 results from heating of the carbonates in the lime-kiln. The lime-kilns can be located either at the location for limestone extraction or at the location for use of burned lime.

The CO_2 emission from the production of marketed burnt lime has been estimated from the annual production figures registered by Statistics Denmark, and emission factors. Since 2006, point source data for Faxe Kalk have been applied, but the total production always sums up to the national statistics. Plant specific activity data for marketed lime from Faxe Kalk are available from EU-ETS since 2006. Faxe Kalk constitutes 22-83% (55 % in average) of the Danish activity in 2006-2021. The plant specific activity data are available back to 1995 from the environmental reports but these are not applied as a point source. Different smaller productions account for the remaining production of marketed lime in Denmark.

Since 2006, process CO_2 emissions from Faxe Kalk have been calculated by the company and reported to EU-ETS and since 2008 Faxe Kalk has measured and included the content of tonnes CO_3 in the process emissions reported to EU-ETS. For the sake of consistency, the same method has been applied for the entire time series and for all producers, i.e. assuming the same $CaCO_3/MgCO_3$ ratio as the measured average from Faxe Kalk in 2008-2012 (Faxe Kalk, 2013b). By this, Denmark applies a country specific emission factor to estimation of emissions from lime production.

Limestone consumption data for production of sugar are available from the company's environmental reports (Nordic Sugar, 2022; Nordic Sugar Nykøbing, 2010; Nordic Sugar Nakskov, 2012; Danisco Sugar Assens, 2007) back to 1996 and sugar sales statistics are available from Statistics Denmark (2022) for the entire time series. Limestone consumption data are used when available and national sugar sales statistics are used as surrogate data for the remaining years (1990-1995). Raw material consumption data are for 1990-2006 only given in amount of limestone, these data and calculated into amount of burnt lime (CaO) equivalents using the stoichiometric relation between $CaCO_3/CaO$ and the 2007-2013 average measured $CaCO_3$ content in limestone of 11.62 % (Nordic Sugar Nakskov, 2012 and Nordic Sugar, 2022).

The applied emission factor is based on EU-ETS data (Tier 3) and thereby assumes 100% calcination. There is therefore no carbonate left to become lime kiln dust (LKD).

EU-ETS data for lime production

The applied methodology for Faxe Kalk is specified in the individual monitoring plan that is approved by Danish authorities (DEA) prior to the reporting of the emissions. Lime production applies the Tier 2 methodology for the activity data (uncertainty ± 1.0 %) and Tier 3 for the emission factor.

The implied CO_2 emission factor for Faxe Kalk is plant specific and based on the reporting to the EU Emission Trading Scheme (EU-ETS). The EU-ETS data have been applied for the years since 2006.

The CO_2 emission for lime production is based on sales (± 1.0 %) and measurements of the CaO and MgO contents in the product (annual averages of weekly measurements) (Faxe Kalk, 2013a).

Activity data

The production data for burnt lime are presented in Table 4.2.5 and Annex 3C-4.

Table 4.2.5 Production of burnt lime, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
From Faxe Kalk	-	-	-	-	25.6	30.1	29.3	15.9	11.7	32.0
From other producers	-	-	-	-	24.8	33.4	15.8	25.5	42.3	29.6
From sugar production	5.8	5.1	5.8	4.7	2.0	0.7	1.3	1.3	1.4	1.3
Total lime production	133.8	105.9	97.8	75.9	52.4	64.2	46.4	42.8	55.4	62.9

Emission factors

The country specific emission factor that is applied for calcination of both marketed and non-marketed calcium carbonate is based on measurements from Faxe Kalk in 2008-2012. The emission factor applied is 0.788 kg CO_2 per kg CaO (Faxe Kalk, 2022) and includes a small impurity of MgO. It is assumed that the degree of calcination is 100 % and that no lime kiln dust (LKD) emits from the process.

The actual reported emissions are used for Faxe Kalk in 2008-2021. This means that the implied emission factor for marketed lime production will vary as the measured emission factor for Faxe Kalk fluctuates, the implied emission factor is between 0.769 kg CO_2 per kg CaO (2021) and 0.793 kg CO_2 per kg CaO (2018). For all other producers and for Faxe Kalk 1990-2007, the country specific implied emission factor of 0.788 kg CO_2 per kg CaO is applied.

This method causes fluctuations in the implied emission factor for the years since 2008, but not for 1990-2007.

Table 4.2.6 Implied emission factors for Danish lime production

	1990-2007	2008-2021
Faxe Kalk	0.788	0.752-0.796
Other marketed lime	0.788	0.788
Un-marketed lime	0.788	0.788

Emission trends

The trend for the CO_2 emission from lime production, including sugar production; is available in Annex 3C-5 and Figure 4.2.3.

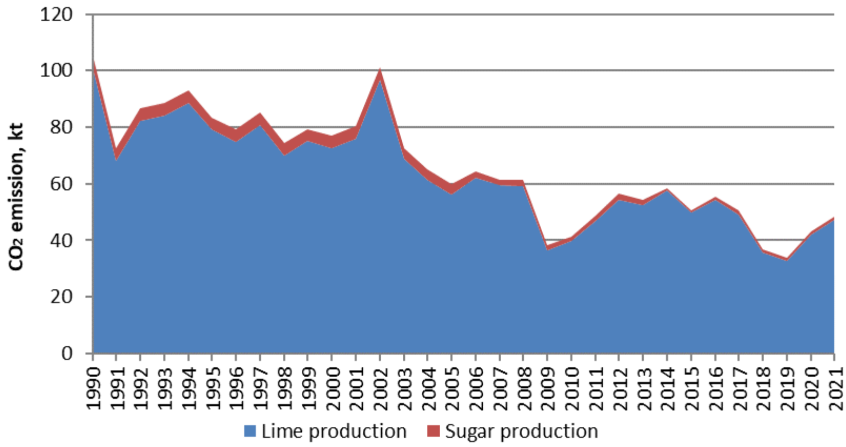

Figure 4.2.3 Emission of CO_2 from lime production.

The emission from sugar production only comprise 1 % (2015) to 6 % (1991) of the total CO_2 emission from lime production; 4 % in average over the time series.

The activity data are based on the official statistics from Statistics Denmark and there is no immediate explanation to the peak in 2002. There are very few producers in Denmark and therefore it will not be possible to obtain more detailed information from Statistics Denmark.

Time series consistency and completeness

The chosen methodology, activity data and emission factor for calculation of CO_2 emissions from marketed lime are consistent throughout the time series.

All though the activity data for non-marketed lime production at the sugar factories are based on actual carbonate consumption from 1996 onward and on estimated consumptions for 1990-1995, the methodology and applied emission factor are both considered to be consistent.

With regards to completeness concerning production of other lime products than burnt lime, dolomitic lime is not produced in Denmark and the production of hydrated lime (slaked lime) from burnt lime does not emit any greenhouse gasses. All burnt lime that is later slaked is included in the statistical data on which the calculations are based, and adding the production of slaked lime to the activity data would therefore result in double counting.

Other industries that typically use lime as an intermediate product are chemical-, metal-, production for emissions abatement etc., these industries have been investigated with respect to completing this source but nothing was found. Regarding industries producing lime as intermediate products only one was identified (i.e. Nordic Sugar). Denmark has virtually no chemical or metal industry, so the need for lime in the Danish industry is non-existing with the exception of the sources listed, and the sector must therefore be complete.

For verification, please refer to Hjelgaard & Nielsen (2018).

4.2.5 Glass production

Glass production in Denmark includes production of:

- Container glass
- Industrial art glass
- Glass wool

The production of container glass for packaging is concentrated at one company; Ardagh Glass Holmegaard A/S (previously Rexam Glass Holmegaard A/S), and the production of art industrial glass products is concentrated at Holmegaard A/S, both companies are situated in Fensmark, Næstved. Saint-Gobain Isover situated in Vamdrup is the only Danish producer of glass wool. The following source is covered:

- Glass (decarbonising)

Emissions associated with the fuel use are estimated and reported in the energy sector.

Methodology

For the production of both container glass, art glass and glass wool, the main raw materials are soda ash (Na_2CO_3), dolomite ($CaMg(CO_3)_2$), limestone ($CaCO_3$) and recycled glass (cullets). Emissions are calculated for each carbonate raw material individually.

Information on consumption of carbon containing raw materials in container- and art glass production is available from the environmental reports for 1997-2013 (Ardagh, 2014) and from EU-ETS since 2006 (Ardagh, 2022). For the years prior to 1997 the production of glass is based on information contained in Illerup et al. (1999). Only one industrial art glass producer with virgin glass production exists in Denmark; Holmegaard A/S. Emissions from this production is included in the data on container glass.

Information on consumption of carbon containing raw materials in glass wool production is available from the environmental reports of the plant for 1996-2014 (Saint-Gobain Isover, 2015) and from EU-ETS since 2006 (Saint-Gobain Isover, 2022). For the years prior to 1996 the production of glass wool and consumption of carbonates are estimated.

EU-ETS data for glass production

The applied methodologies for Ardagh Glass Holmegaard and Saint-Gobain Isover are specified in the individual monitoring plan that is approved by Danish authorities (DEA) prior to the reporting of the emissions.

Glass production applies the Tier 3 for both methodology and emission factors as the calculations are based on individual carbonates used as raw materials.

The CO_2 emission from container/art glass production is based on consumption of carbonate raw materials (based on invoices and corrected for changes in inventory by measures on the storage silos; Tier 2: 1.10-1.37% depending on the silo) and standard emission factors except for dolomite where Ca/Mg analysis are performed for each new batch (Ardagh, 2012).

The CO_2 emission from glass wool production is based on weight measures of carbonate raw materials (Tier 1: ±2.5%) and standard emission factors (Saint-Gobain Isover, 2012).

Activity data

The activity data for container/art glass production are presented in Table 4.2.7 and Annex 3C-6.

Table 4.2.7 Production of container/art glass, activity data, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Production of glass[1, 2]	164.0	140.0	183.3	168.2	172.9	155.7	156.2	158.1	140.4	157.2
Consumption of soda ash[3, 4]	17.8	15.2	16.4	13.0	c	c	c	c	c	c
Consumption of limestone[3,4]	14.4	12.3	7.7	5.7	c	c	c	c	c	c
Consumption of dolomite[3,4]	1.0	0.8	9.1	6.1	c	c	c	c	c	c

1 1990-1997: Illerup et al. (1999).
2 1998-2016: Estimated based on Illerup et al. (1999) and consumption of raw materials.
3 1990-1996: Estimated based on Illerup et al. (1999) and the consumption of raw materials in 1997.
4 1997 onward: Environmental reports and EU-ETS data; Ardagh (2014, 2022).
c Confidential: data from EU-ETS (Ardagh, 2022).

The activity data for glass wool production are presented in Table 4.2.8 and Annex 3C-7.

Table 4.2.8 Production of glass wool, activity data, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Production of glass wool[1]	35.6	35.6	39.7	37.3	24.9	33.0	43.5	44.6	42.1	49.4
Consumption of soda ash[2, 4]	3.6	3.6	3.0	3.6	c	c	c	c	c	c
Consumption of limestone[2, 4]	0.8	0.8	0.2	0.6	c	c	c	c	c	c
Consumption of dolomite[3]	1.0	1.0	1.0	1.0	c	c	c	c	c	c

1 1990-1996: Estimated: Assumed constant on the average production from 1997-1999.
2 1990-1995: Estimated: Assumed constant on the average consumption from 1996-1998.
3 1990-2005: Estimated: Assumed constant on the average consumption from 2006-2008.
4 1996-2005: Environmental reports (Saint-Gobain Isover, 2015).
c Confidential: data from EU-ETS (Saint-Gobain Isover, 2022).

Emission factors

The CO_2 emission factors from using soda ash and other carbonate containing raw materials in production of virgin glass and glass wool, based on stoichiometric relationships, are:

- 0.41492 t CO_2/t Na_2CO_3
- 0.43971 t CO_2/t $CaCO_3$
- 0.473-0.517 t CO_2/t $CaMg(CO_3)_2$

The emission factor for dolomite is 0.48 tonnes CO_2 per tonne for glass wool production and 0.46 tonnes CO_2 per tonne for container/art glass production in 2021. The average emission factor for dolomite in container glass production is 0.493 tonnes CO_2 per tonne dolomite for 2008-2020. The calcination of all carbonates in all years is assumed to be 100 %.

From 2006 onward the CO_2 emissions are calculated by the companies and reported to EU-ETS (Ardagh, 2021; Saint-Gobain Isover, 2021), but the applied emission factors remain the same for the entire time series.

Emission trends

For the years from 2006 onward, where EU-ETS data are applied, information is confidential and therefore not presented individually for container/art glass and glass wool production.

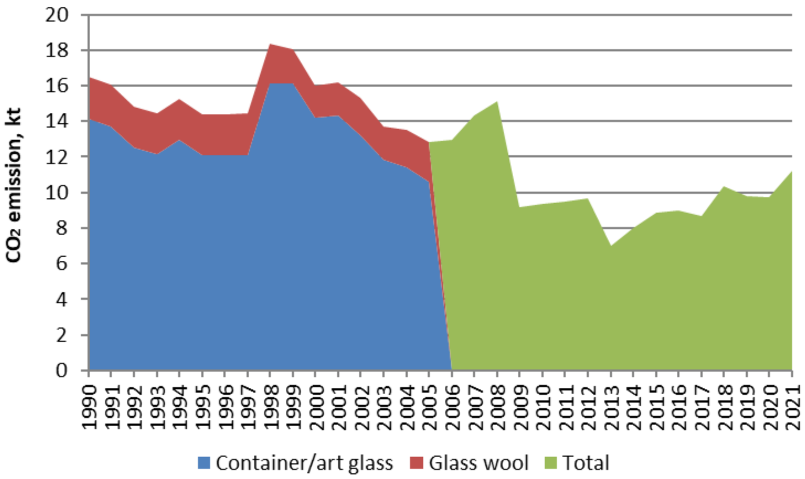

Figure 4.2.4 CO_2 emissions from glass and glass wool production.

Time series consistency and completeness

CO_2 emissions from container/art glass and glass wool production are calculated based on consumption of carbonates and stoichiometric emission factors for the entire time series, the time series is therefore consistent.

In relation to completeness, the production of flat glass does not occur in Denmark. The processes in Denmark are limited to mounting of sealed glazing units. The mounting process does not contribute to greenhouse gas emissions in Denmark.

An effort has been made to ensure that all glass producers are included in the inventory. Smaller facilities producing art glass do exist in Denmark, but none of these were found to produce their own virgin glass. The source category of glass production is therefore considered to be complete.

For verification, please refer to Hjelgaard & Nielsen (2018).

4.2.6 Ceramics

This section covers production of bricks, tiles (aggregates or bricks/blocks for construction) and expanded clay products for different purposes (aggregates as absorbent for chemicals, cat litter, and for other miscellaneous purposes). The following sources are covered:

- Production of bricks
- Production of expanded clay products

The production of bricks (and tiles) is found all over the country, where clay is available. Producers of expanded clay products are located in the northern part of Jutland.

Emissions associated with the fuel use are estimated and reported in the energy sector.

Methodology

Emission of CO_2 is related to the content of carbon bearing material in the clay. The emission estimation is based on the total carbon content of the raw material. Since 2006, the producers of ceramics have measured and reported process CO_2 emissions to EU-ETS and production statistics are known from Statistics Denmark (2022) for the entire time series. From these two datasets, implied emission factors (i.e. t $CaCO_3$ per t product) are calculated for 2006-2013 and emissions are calculated for the years back to 1990.

EU-ETS data for ceramics

The applied methodologies for brickworks and expanded clay producers are specified in the individual monitoring plans that are approved by Danish authorities (DEA) prior to the reporting of the emissions. The production of ceramics applies the ETS Tier 2 methodology for calculating the CO_2 emission.

The CO_2 emission for ceramics production is based on measured carbonate content in all raw materials and consumption of the individual carbonate containing raw materials (Tier 2; ± 5.0 %). The implied CO_2 emission factors for the production facilities are based on stoichiometry and 100 % calcination is assumed.

Activity data

National statistics on bricks, tiles and expanded clay contain a broad range of different products, most of them in units of numbers (no.). The consumption of limestone is therefore used as activity data for these source categories; available for 2006-2021 and calculated for 1990-2005. The national statistics are used as surrogate data; available for 1985-2021. Data on consumption of lime and produced amounts of ceramics are presented in Table 4.2.9 and Annex 3C-8.

Table 4.2.9 Statistics for production of bricks/tiles and expanded clay products.

		1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Bricks and tiles											
Produced[1]	million pieces	315.2	385.6	436.3	426.5	223.0	226.7	286.8	288.1	311.9	333.2
Consumed lime[2]	kt $CaCO_3$	58.6	71.7	81.1	79.2	35.1	46.2	67.0	64.3	61.1	60.6
Expanded clay products											
Produced[1]	kt	331.8	340.9	316.2	310.9	157.4	155.0	185.7	219.8	247.6	263.0
Consumed lime[2]	kt $CaCO_3$ eq.	46.2	47.5	44.0	43.3	19.1	19.5	38.4	41.7	37.5	60.9

[1] Statistics Denmark (2022).

[2] 1990-2005: Calculated from production data and the average implied emission factor for 2006-2013.

Both the brickworks and expanded clay productions displays a significant decrease from 2007 to 2009 that can be explained by the global financial crises. The decreases correspond to 59 % and 71 % respectively for brickworks and expanded clay production. The number of brickworks have been decreasing; in 2006 19 brickworks reported to EU-ETS, by 2014 this number had decreased to 13. Two brickworks closed down in 2008, further two in 2009 and another two in 2013. There are still 13 brickworks reporting emissions for 2021.

Emission factors

The emission factor for lime is 0.43971 kg CO_2 per kg $CaCO_3$. The calcination factor is assumed to be 100 % for all years and all producers.

Since 2006, CO_2 emissions are reported by the brickworks to EU-ETS (confidential reports). The reported emissions are calculated from measured lime contents of the raw materials and the stoichiometric emission factor 0.43971 kg CO_2 per kg $CaCO_3$.

Producers of expanded clay products also report CO_2 emissions to EU-ETS for the years since 2006 (Imerys, 2022; Leca, 2022). The reported emissions are calculated from the difference in C contents measured in the raw materials and products and the stoichiometric emission factor 3.664 kg CO_2 per kg C. The reported emissions are recalculated to match the activity data for brickworks using the stoichiometric factors.

Emission trends

The emission trends for the CO_2 emission from production of bricks/tiles and expanded clay products are available in Annex 3C-9 but is also presented in Figure 4.2.5.

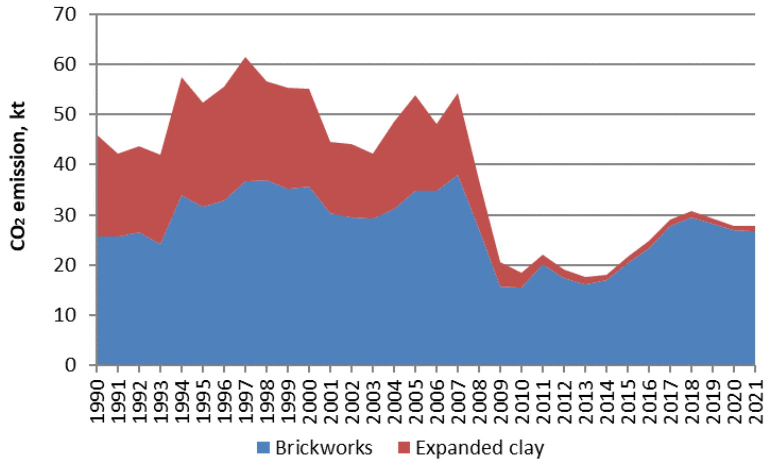

Figure 4.2.5 CO_2 emissions from the production of ceramics.

Emissions from this source category are very dependent on new houses being built as well as old ones being renovated. The significant decline in emissions from 2007-2009 was caused by a reduced production resulting from the economic recession caused by the global financial crisis.

Time series consistency and completeness

Emissions from 2006 onwards are known from the EU-ETS reports and emissions for 1990-2005 are estimated. However, due to the various performed verifications (Hjelgaard & Nielsen, 2018), the ceramics source category is considered to be consistent.

The inventory is based on companies reporting to EU-ETS and national sales statistics, but clay is also burned in minor scale e.g. ceramic art workshops and school art classes. These miniscule sources are however negligible and the source category of ceramics is considered to be complete.

4.2.7 Other uses of soda ash

This section covers the use of soda ash not related to glass production. The following source is covered:

- Other uses of soda ash

Methodology

Emissions from other uses of soda ash (Na_2CO_3) are calculated based on national statistics on import/export (subtracted the amount used in the glass industry) and the stoichiometric emission factor. No information is available on the end uses of soda ash and therefore all use is considered to be emissive.

Activity data

National statistics on import/export and the calculated activity data (supply) are presented in Table 4.2.10 and Annex 3C-10.

Table 4.2.10 Statistics for other uses of soda ash, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Import	54.6	47.6	42.0	59.5	36.5	26.3	50.4	51.4	49.4	54.2
Export	0.09	2.13	0.31	0.01	0.06	0.07	0.14	0.27	0.22	0.30
Glass production	21.4	18.8	19.4	16.6	10.7	8.6	10.9	9.9	9.8	11.9
Supply	33.2	26.7	22.3	42.9	25.7	17.6	39.3	41.2	39.4	42.1

Emission factors

The applied emission factor for other uses of soda ash is 414.92 kg CO_2 per tonne Na_2CO_3. The calculation assumes a calcination factor of 100 %.

Emission trends

The emission trend for the CO_2 emission from other uses of soda ash is available in Figure 4.2.6 and Annex 3C-11.

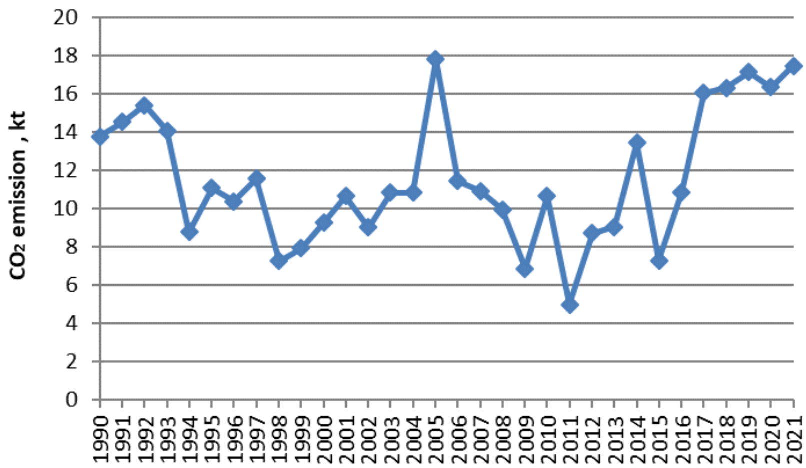

Figure 4.2.6 CO_2 emissions from other uses of soda ash.

Information on the uses of soda ash outside the glass industry is scarce, and descriptions of the trend development are therefore not available.

Time series consistency and completeness

The same methodology is used for calculating emissions for the entire time series, the emissions from other uses of soda ash are therefore consistent. Calculations are based on national import/export statistics and are therefore also complete as there is no production of soda ash in Denmark.

For verification, please refer to Hjelgaard & Nielsen (2018).

4.2.8 Flue gas desulphurisation

Flue gas cleaning systems utilising different technologies are primarily present at major combustion plants i.e. power plants, combined heat and power plants as well as waste incineration plants. The following source is covered:

- Limestone and dolomite use - Flue gas cleaning, wet, power plants and waste incineration plants

Methodology

The emission of CO_2 from wet flue gas desulphurisation can be calculated from the following equation:

$$SO_2\,(g) + \tfrac{1}{2}O_2\,(g) + CaCO_3\,(s) + 2H_2O\,(l) \rightarrow CaSO_4{,}2H_2O\,(s) + CO_2\,(g)$$

The consumed amount of limestone ($CaCO_3$) is used as activity data. Information on limestone consumption is available from EU-ETS for 2006 forward.

Energinet.dk compile environmental information related to energy transformation and distribution. Since the waste incineration plants with desulphurisation are all power producers, these plants are also included in the data from Energinet.dk (2020). Statistics on the generation of gypsum are available from Energinet.dk (2020) for 1990-2017. However, since 2006 information on consumption of limestone at the relevant power plants and waste incineration plants has been compiled from EU-ETS and used in the calculation of CO_2 emission from flue gas cleaning. For 1990-2005, the generation of gypsum data have been used as surrogate data.

The consumption of other carbonates than limestone (e.g. TASP[1]) is measured by the individual power plants and is added to the limestone consumption in $CaCO_3$ equivalents.

The number of waste incineration plants reporting CO_2 emissions based on measurements are increasing. This results in a decreasing number of facilities reporting flue gas cleaning related emissions to the IPPU sector. Since measured emissions cannot be separated in energy and process related emissions, process emissions are in these instances reported under energy.

EU-ETS data for flue gas desulphurisation

The applied methodologies for flue gas desulphurisation are specified in the individual monitoring plans that are approved by Danish authorities (DEA) prior to the reporting of the emissions. The flue gas desulphurisation applies the Tier 1-2 methodology for calculating the CO_2 emission depending on the individual units.

The CO_2 emission for flue gas desulphurisation is based on measured lime consumption (± 1.5 % to ± 7.5 %). The implied CO_2 emission factors for the production facilities are based on stoichiometry.

Since 2013, nine of the 12 waste incineration plants operating wet flue gas cleaning, have applied a reporting method based on measurements. This means that these plants now estimate the total emissions (process and energy related as one), and that process emissions from these plants are therefore reported under the energy sector.

Activity data

During the time series this source has increased due to more plants being fitted with desulphurisation (1990-1999). However, since the main use is in coal fired plants, flue gas desulphurisation is decreasing as some of the coal fired power plants are rebuilt to combust biomass and the need for flue gas desulphurisation ceases. Since 2006, seven of the nine coal fired power plants have changed to alternative fuels and desulphurisation has ceased from these plants.

The Danish waste incineration plants are in general smaller than the coal combustion facilities and owned by smaller companies. Of the approximately 30

[1] "Tørt AfSvovlingsProdukt" (Dry desulphurisation product), the by-product from dry flue gas desulphurisation processes.

waste incineration plants with flue gas desulphurisation only one third uses wet flue gas cleaning.

The activity data are presented in Table 4.2.11, Figure 4.2.7 and Annex 3C-12.

Table 4.2.11 Activity data for flue gas desulphurisation, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Gypsum production[1]	41.6	211.5	354.3	220.4	179.7	91.7	NAV	NAV	NAV	NAV
$CaCO_3$ consumption[2, 3]	22.0	111.8	187.3	116.6	95.6	35.3	35.9	22.4	18.4	18.7

[1] Energinet.dk (2020).
[2] 1990-2005: Estimated from surrogate data and stoichiometric relations.
[3] 2006-2021: EU-ETS of the individual plants.
NAV: Not Available.

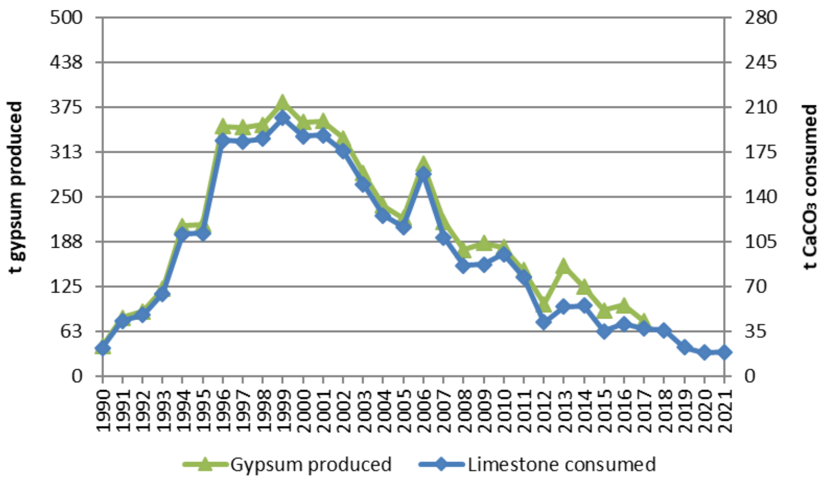

Figure 4.2.7 Activity data for flue gas desulphurisation.

The activity data level varies with the coal consumption that again varies greatly with electricity import/export. And as mentioned above, part of the decreasing trend in this category is caused by the allocation of emissions from some waste incineration plants to the energy sector.

Emission factors

The emission factor applied to the limestone consumption is the stoichiometric emission factor 0.43971 tonnes CO_2 per tonne $CaCO_3$.

Emission trends

The emission trend for the CO_2 emission from flue gas desulphurisation is available in Table 4.2.12 and Annex 3C-13.

Table 4.2.12 CO_2 emissions from flue gas desulphurisation, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Flue gas desulphurisation	9.7	49.2	82.4	51.2	42.0	15.5	15.8	9.9	8.1	8.2

Time series consistency and completeness

The methodology for calculating emission from flue gas desulphurisation is consistent in spite of varying methods; please refer to the verification presented in Hjelgaard & Nielsen (2018). The source category is considered to be complete.

4.2.9 Stone wool production

Only one company produces stone wool in Denmark, Rockwool situated at three localities: Hedehusene[2], Vamdrup and Øster Doense. The following source is covered:

- Limestone and dolomite use – Stone wool production

Emissions associated with the fuel use are estimated and reported in the energy sector.

Methodology

Stone wool is produced from mineral fibres and a binder. The raw materials are melted in a cupola fired by coke and natural gas, several raw materials contribute to the process CO_2 emission e.g. bottom ash, limestone, dolomite, binder etc.. The consumption of raw material as well as amount of produced stone wool is confidential.

Information on emissions from 2006-2021 has in combination with annual production data and raw material consumption data been used to extrapolate the emissions back to 1995. The data have been extracted from company reports (Rockwool, 2014a) and EU-ETS (Rockwool, 2022). CO_2 process emissions are available for the years since 2006 (EU-ETS), the consumption of raw materials for 1995-2013 (environmental reports) and production data for 1995-2004 and 2014-2021 (Statistics Denmark and EU-ETS). Emissions for 1990-1994 are estimated as the constant average of 1995-1999.

Calculations are performed for the three factories individually.

EU-ETS data for stone wool production

Stone wool production applies the ETS Tier 3 methodology for calculating the CO_2 process emission for 2006 onwards.

The implied CO_2 emission factor for Rockwool is plant specific and based on the reporting to the EU-ETS. The EU-ETS data have been applied for the years 2006 onwards.

The CO_2 emission for stone wool production is based on measurements of the consumption of carbonates. These measurements fulfil an ETS Tier 1 or Tier 3 methodology (± 1.6 - 5.0 %) depending on the carbonate. The emission factors are based on carbon content measurements for each carbonate (ETS Tier 2-3). (Rockwool, 2014b).

Activity data

The consumption of limestone equivalents are presented in Table 4.2.13 and Annex 3C-14.

[2] The melting of minerals (cupola) has closed down in 2002.

Table 4.2.13 Activity data for stone wool production, kt $CaCO_3$ equivalents.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Carbonate consumption	16.7	13.5	16.7	18.0	17.1	13.5	25.0	9.6	12.0	12.4

Emission factors

The applied emission factor for stone wool production is the stoichiometric factor 0.43971 tonnes CO_2 per tonne $CaCO_3$.

Emission trends

The emission trend for the CO_2 emission from stone wool production is presented in Figure 4.2.8 below and Annex 3C-15.

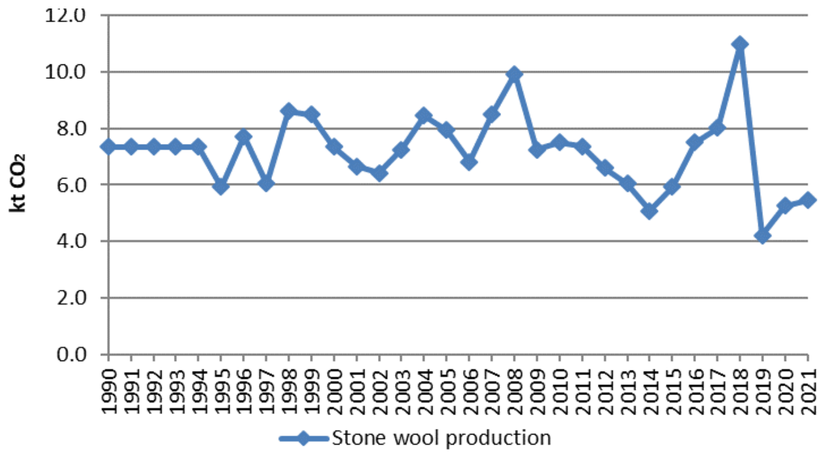

Figure 4.2.8 CO_2 emissions from stone wool production.

The consumption of CO_2 emitting raw materials in stone wool production varies, and so does the carbon content of the waste used as raw material. The strong decrease in emissions from 2018 to 2019 is due to a strong decrease in use of dolomite as raw material. Rockwool strides to reduce CO_2 process emissions from production of stone wool by reducing the consumption of dolomite, but the decrease must also be seen as naturally occurring variation in raw material composition.

Time series consistency and completeness

The source category of stone wool production is complete. Emissions for 2006 onward are known (EU-ETS) but emissions for 1990-2005 are estimated via surrogate data, in spite of this change in method the source category is considered to be consistent.

4.3 Chemical Industry

4.3.1 Source category description

The sector *Chemical industry* (2B) covers the following industries relevant for the Danish air emission inventory:

- 2B2 Nitric acid production; see section 4.4.3.
- 2B10 Catalyst production; see section 4.4.4.

Nitric acid production is identified as a key category in 1990 according to both Approach 1 and Approach 2. The trend is also identified as key category according to both Approach 1 and Approach 2, however this is due to the closing of the lone plant producing nitric acid in Denmark in 2004.

4.3.2 Emissions

Total greenhouse gas emissions from the Chemical Industry sector are available in the CRF Table 10. The emission time series for the source categories within *Chemical Industry* (2B) are presented in Figure 4.3.1 and individually in the subsections below (Sections 4.4.3 – 4.2.4). The following figure gives an overview of which source categories contribute the most throughout the time series.

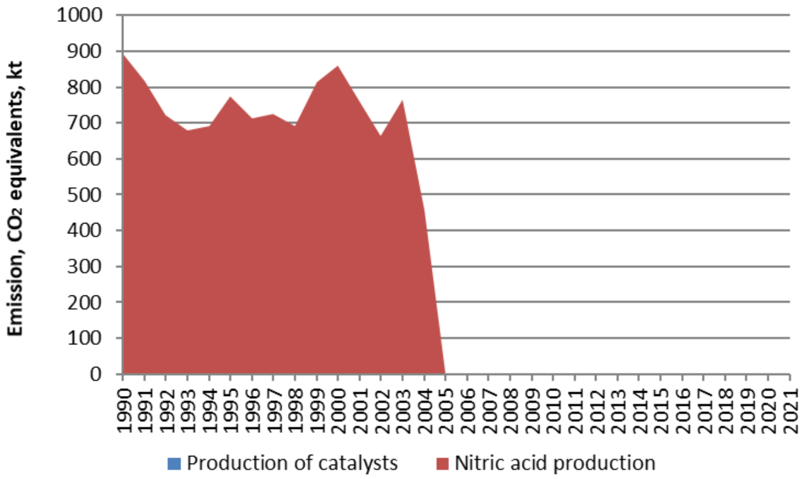

Figure 4.3.1 Emission of CO_2 equivalents from the individual source categories compiling *2B Chemical Industry*, kt.

Greenhouse gas emissions from *Chemical Industry* are made up almost entirely by N_2O emissions from the production of nitric acid; only 0.1 % (1990-2003) to 0.3 % (2004) stems from the production of catalysts, making the emission invisible in the figure above. The production of nitric acid ceased in the middle of 2004.

4.3.3 Nitric acid production

The production of nitric acid as well as NPK fertilisers has been concentrated at one company: Kemira GrowHow A/S situated in Fredericia. The production ceased in the summer of 2004. The following source is covered:

- Nitric acid production

Methodology

The information on the N_2O emissions from the production of nitric acid/fertiliser is obtained from environmental reports (Kemira GrowHow, 2005), contact to the company as well as information from the county. Information on emissions of N_2O is available for 2002. For the remaining years the N_2O emission has been estimated from annual production statistics from the company and an implied emission factor based on 2002.

Specific information on applied technology is not available; however, the emission factor measured by the Danish nitric acid plant is comparable with the default emission factor for a medium pressure plant (IPCC, 2006).

The production of nitric acid in Denmark ceased in the middle of 2004 and the company relocated the production to a more modern facility in another country.

Activity data

The applied activity data for production of nitric acid are presented in Table 4.3.1 and Annex 3C-16.

Table 4.3.1 Production of nitric acid, kt.

	1990	1995	2000	2004
Nitric acid	450	390	433	229

In the time series, the production of nitric acid peaked in 1990 with 450 kt (and 807 kt fertiliser) and then fluctuated around the average of 375 kt nitric acid (694 kt fertiliser) from 1990-2003 until the factory closed down in the summer of 2004; 2004 production of 229 kt nitric acid and 395 kt fertiliser (Kemira GrowHow, 2005).

Emission factors

Default emission factors given by IPCC (2006[3]) are presented in Table 4.3.2 together with the Danish value.

Table 4.3.2 Emission factors for production of nitric acid in Denmark compared with default emission factors (IPCC, 2006) (kg per t nitric acid).

	Danish IEF 2002	Default EF
N_2O	7.476	2-2.5[1]
		5[2]
		7[3]
		9[4]

[1] Modern, NSCR, process-integrated or tailgas N_2O destruction.

[2] Atmospheric pressure plant (low pressure).

[3] Medium pressure combustion plants.

[4] High pressure plants.

Emission trends

The emission trend for the N_2O emission from nitric acid production is available in Figure 4.3.1 and Annex 3C-17.

The trend for N_2O emission from 1990 to 2003 shows a decrease from 3.4 to 2.9 kt, i.e. 14 %, and a 41 % decrease from 2003 to 2004. However, the activity and the corresponding emission show considerable fluctuations in the period considered and the decrease from 2003 to 2004 can be explained by the closing of the plant in the middle of 2004.

Time series consistency and completeness

The applied methodology regarding N_2O is consistent. The activity data are based on information from the specific company/plant. The emission factor applied has been constant for the whole time series and is based on measurements performed in 2002. The production equipment has not been changed during the period. The source category of nitric acid production is complete.

4.3.4 Catalyst production

Production of a wide range of catalysts and potassium nitrate (fertiliser) is concentrated at one company: Haldor Topsøe A/S situated in Frederikssund. The following source is covered:

- Other: Catalyst production

[3] Volume 3 Chemical Industry, Chapter 3.3.2.2 page 3.23 (Table 3.3).

Methodology

The applied methodology corresponds to a country-specific (Tier 3) methodology according to the 2006 IPPC Guidelines.

The one plant in Denmark is owned and operated by Haldor Topsøe and produces a number of different catalysts, e.g. TK catalysts, CKM catalysts and TertiNOx. The specific processes are naturally commercially sensitive and hence not available. The processes involve carbonate compounds i.e. the process leads to emissions of CO_2.

There are two available reported CO_2 emissions from the company; PRTR (Haldor Topsøe 2022b) and environmental reports/EU-ETS (Haldor Topsøe, 2013 and 2022a). EU-ETS only contains information on fuel use and emissions from combustion of fuels. CO_2 emissions from natural gas and LPG combustion reported by companies under the EU-ETS are estimated using measured activity data and carbon content of the fuel. Reported CO_2 emission from PRTR are calculated based on stack measurements by the company and hence also includes CO_2 emissions associated with calcination. The PRTR emissions are on average 5% higher than those from EU-ETS. The difference between the two CO_2 emissions reported by the company are assumed to be from carbonate use.

An average implied emission factor (IEF) was calculated for 2003-2009 using this method, this IEF was used for the entire time series. For the years 1990-1995, the production (activity data) is estimated using linear regression on the years 1997-2012.

Activity data

Table 4.3.3 Source of activity data.

Years	Determined by
1990-1995	Linear regression of 1997-2012
1996	Total production is available, the average split between the two products from 1997-2001 is applied for estimating the individual productions
1997-2012	Information from the company (environmental reports)
2013-2014	Estimated using the consumption of raw materials as surrogate data
2015-2021	Estimated using the production data for catalysts from Statistics Denmark and extrapolated production data for potassium nitrate

The activity data regarding production of catalysts and fertiliser are obtained through environmental reports from Haldor Topsøe (2013) where these are available (2007-2012). For years where environmental reports are not available, production data are estimated using the drivers mentioned in Table 4.3.3. Production data are presented in Table 4.3.4 and Annex 3C-18, the annex also includes the applied surrogate data.

Table 4.3.4 Production of catalysts and potassium nitrate, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Catalysts produced	-	-	17.2	23.2	20.5	27.2	29.7	29.4	27.3	24.3
Potassium nitrate produced	-	-	19.2	23.3	25.9	35.2	30.1	32.5	32.2	27.0
Total produced	23.7	30.5	36.4	46.5	46.4	62.4	59.8	61.9	59.5	51.2

Emission factors

The average calculated implied emission factor for 2003-2009 is 0.0241 tonnes CO_2 per tonne product; this factor is applied for the entire time series.

Emission trends

From 1990 to 2021, the emission of CO_2 from the production of catalysts/fertilisers has increased from 0.57 to 1.23 kt (117 %) with maximum in 2015 (1.50 kt), due to an increase in the production as well as changes in raw material consumption.

The trend for the CO_2 emission from the production of catalysts and fertilisers is presented in Annex 3C-19 and in Figure 4.3.2.

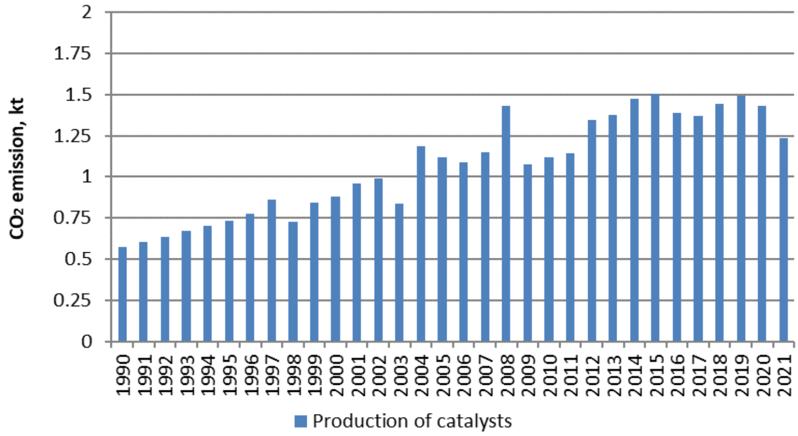

Figure 4.3.2 Emission of CO_2 from catalyst/fertiliser production, kt.

Time series consistency and completeness

There is a change in the applied methodology from 1990-1995 and 1996-onward. Linear regression is used to estimate emissions for 1990-1995, while CO_2 emissions have been provided from the company since 1996. However, the source category is considered to be consistent.

The source category of catalyst production is complete.

4.4 Metal industry

4.4.1 Source category description

The sector *Metal Industry* (CRF 2C) covers the following industries relevant for the Danish air emission inventory:

- 2C1 Iron and steel production; see section 4.4.3
- 2C4 Magnesium production; see section 4.4.4
- 2C5 Secondary lead production; see section 4.4.5

4.4.2 Emissions

The time series for emission of greenhouse gasses from *Metal Industry* (2C) is presented in the CRF tables and in Figure 4.4.1 below.

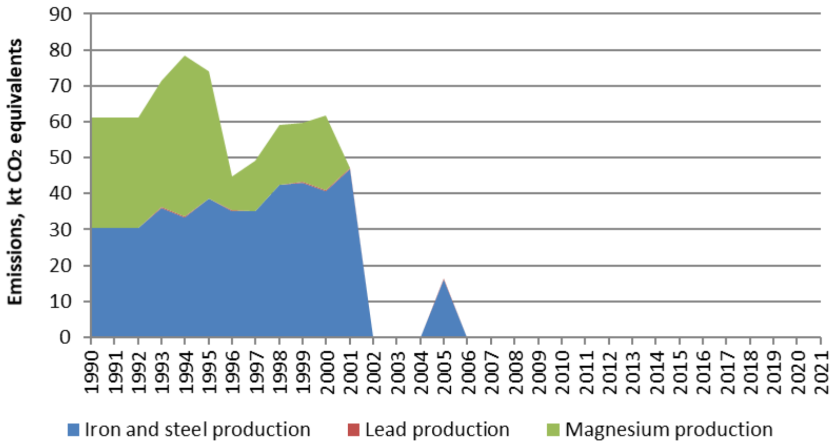

Figure 4.4.1 Emission of greenhouse gasses from the individual source categories compiling *2C Metal Industry*, kt CO_2 equivalents.

From 1990 to 2001, the CO_2 emission from the electro-steelwork increased by 55 % whiles the SF_6 emission from magnesium production decreased with 31 % (1990-2000). The changes in the greenhouse gas emission is similar to the increase and decrease in the activity as the consumption of metallurgical coke per amount of steel sheets and bars produced has almost been constant during the period and the emission factor for magnesium production is constant throughout the time series.

Emissions from secondary lead production are miniscule (0.3-0.4 % of CO_2 equivalent emissions for 1990-2000), but are the only emissions in the *Metal Industry* sector that occur for the entire time series.

The electro-steelwork was shut down in January 2002 and reopened and closed down again in 2005. In 2000, the SF_6 emission from the magnesium production ceased.

Grey iron foundries are active for the entire time series. But this production does not result in any greenhouse gas emissions in the industry sector.

4.4.3 Iron and steel production

The production of semi-manufactured steel products (e.g. steel sheets/plates and bars) was concentrated at one company: Det Danske Stålvalseværk A/S situated in Frederiksværk. After the closure of the electro steelwork in 2002 the two rolling mills were divided in two companies called DanSteel and Duferco, these are both still in operation but are not included here, as they do not emit process greenhouse gas emissions. The following source is covered:

- Electric furnace steel plant

The steelwork was closed down in January 2002 and then partly reopened in November 2002. The production of steel sheets/plates was reopened by DanSteel in 2003, the production of steel bars was reopened by DanScan Metal in March 2004, and the electro steelwork was reopened by DanScan Steel in January 2005. The production at DanScan Metal and Steel ceased in the last part of 2005 and in June 2006 DanScan Metal was taken over by Duferco; the electro steelwork (DanScan Steel) has still not been in operation since 2005. The timeline is presented in Figure 4.4.2.

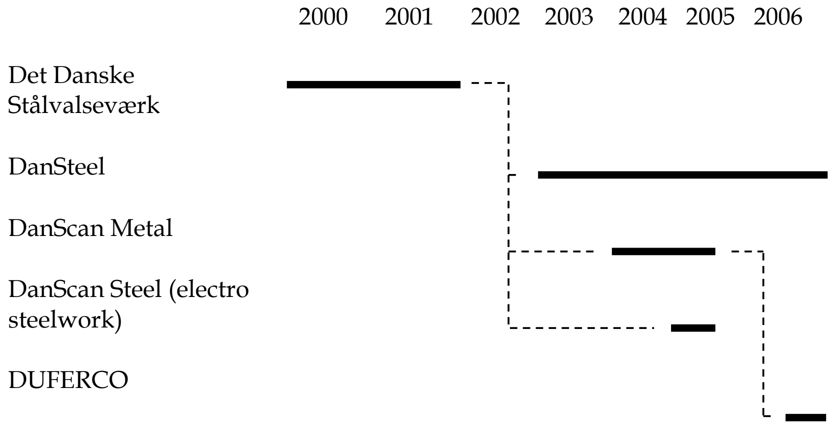

Figure 4.4.2 Timeline for production at the Danish steelwork.

Methodology

Metallurgical coke is used in the melting process to reduce iron oxides and to remove impurities. The overall process is:

$$C + O_2 \rightarrow CO_2$$

The CO_2 emission from the consumption of metallurgical coke at steelworks has been estimated from the annual production of steel sheets and steel bars combined with the consumption of metallurgical coke per produced amount (Stålvalseværket, 2002). The carbon source is assumed to be coke and all the carbon is assumed to be converted to CO_2 as the carbon content in the products is assumed to be the same as in the iron scrap. The emission factor (consumption of metallurgical coke per tonne of product) has been almost constant from 1993 to 2001; steel sheets: 0.012-0.018 tonnes metallurgical coke per tonne and steel bars: 0.011-0.017 tonnes metallurgical coke per tonne.

Production data for 1990-1991 and for 1993 have been determined with extrapolation and interpolation, respectively and data on the consumption of metallurgical coke for 1990-1992 have been extrapolated.

Activity data

Statistical data on steel production activities, i.e. amount of steel sheets and bars produced as well as consumption of metallurgical coke are available in environmental reports from the single Danish steel plant (Stålvalseværket, 2002) supplemented with other literature. In 2002, production stopped. For 2005 the production has been assumed to be one third of the production in 2001 as the steelwork was operating between 4 and 6 months in 2005. The activity data are presented in Table 4.4.1 and Annex 3C-20.

Table 4.4.1 Overall mass flow for Danish steel production, kt.

		1990	1995	2000	2005
Det Danske Stålvalseværk					
Raw material	Iron and steel scrap	-	657	731	-
Intermediate product	Steel slabs etc.	-	654	803	-
Product	Steel sheets	444[1]	478	380	-
	Steel bars	170[1]	239	251	-
	Products, total	614[1]	717	631	250[2]
Raw material	Metallurgical coke	8.3	10.5	11.1	4.4

[1]Extrapolation, [2]Assumed.

The mass balances/flow sheets presented in the annual environmental reports do not for all years tell about the changes in the stock and therefore the balance cannot be completed.

Emission factors

The emission factors for carbon dioxide from using metallurgical coke in manufacturing of iron and steel from scrap is the stoichiometric ratio 3.667 tonnes CO_2 per tonne C.

Emission trends

The greenhouse gas emissions from the steel production are presented in Figure 4.4.3 and Annex 3C-21. The production ceased in 2001 and reopened and closed again in 2005; see Figure 4.4.2.

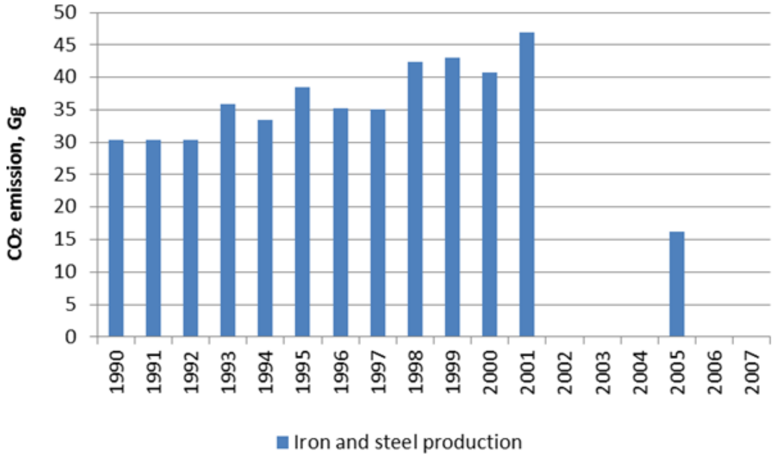

Figure 4.4.3 Emission of greenhouse gasses from the production of steel from scrap.

Time series consistency and completeness

The time series for secondary steel production is consistent as the same methodology has been applied for the whole period. The time series is also considered to be complete.

There is no metallurgical coke production in Denmark.

4.4.4 Magnesium production

For the production of magnesium in Denmark the following source is covered:

- Consumption of SF_6 in magnesium foundries

Methodology

The consumption of SF_6 in the magnesium production is known from information directly from the industry (Poulsen, 2023). The emission can be calculated from the SF_6 consumption and the default Tier 1 emission factor, which is a release of 100 %.

Activity data

Table 4.4.2 presents the activity data.

Table 4.4.2 Production of magnesium, tonnes.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Magnesium produced	1300	1300	1300	1500	1900	1500	400	600	700	700	891

Emission factors

The applied emission factor is 1, i.e. 100 % release of SF_6 used.

Emission trends

The greenhouse gas emissions from the production of magnesium are presented in Figure 4.4.4 below. The consumption of SF_6 ceased in 2000.

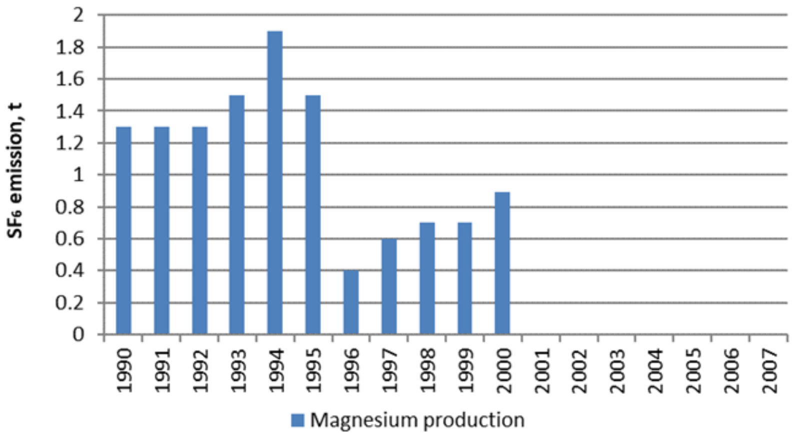

Figure 4.4.4 Emission of greenhouse gasses from the production of magnesium.

Time series consistency and completeness

The time series for magnesium production is considered to be both consistent and complete.

4.4.5 Secondary lead production

One Danish company producing secondary lead has been identified; Hals Metal. The following source is covered:

- Secondary lead production

Methodology

Only one Danish company; Hals Metal, has been identified as producing secondary lead from scrap metal. Hals Metal closed down during 2021, and 2021 will therefore be the last year with reported emissions from Hals Metal. In addition to Hals Metal, old lead tiles from castles, churches etc. are melted and recast on site during preservation of the many historical buildings in Denmark.

Activity data

Activity data from Hals Metal are provided by the company (Hals Metal, 2021). A clause affected in 2002 meant that Hals Metal could no longer burn cables containing lead. The processing of cables was therefore stopped and the company's activity changed to smelting. This transition resulted in a low activity in 2003.

The activity of recasting lead tiles is not easily found because it is spread out on many craftsmen and poorly regulated. However, an estimate by Lassen et al. (2004) states that 200-300 tonnes lead tiles were recast in 2000. Since the building stock worthy of preservation is constant, it is assumed that the activity of recasting of lead tiles is constant.

Activity data for secondary lead production are shown in Table 4.4.3 and Annex 3C-22.

Table 4.4.3 Activity data for secondary lead production, tonnes.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Hals Metal	540	750	540	691	635	745	348	322	194	97
Lead tiles	250	250	250	250	250	250	250	250	250	250
Total	790	1000	790	941	885	995	598	572	444	347

Emission factors

The applied CO_2 emission factor for secondary lead production is the default Tier 1 factor of IPCC (2006)[4]; 0.2 tonnes per tonne product.

Emission trends

The greenhouse gas emissions from the production of secondary lead are presented in Figure 4.4.5 below and Annex 3C-23.

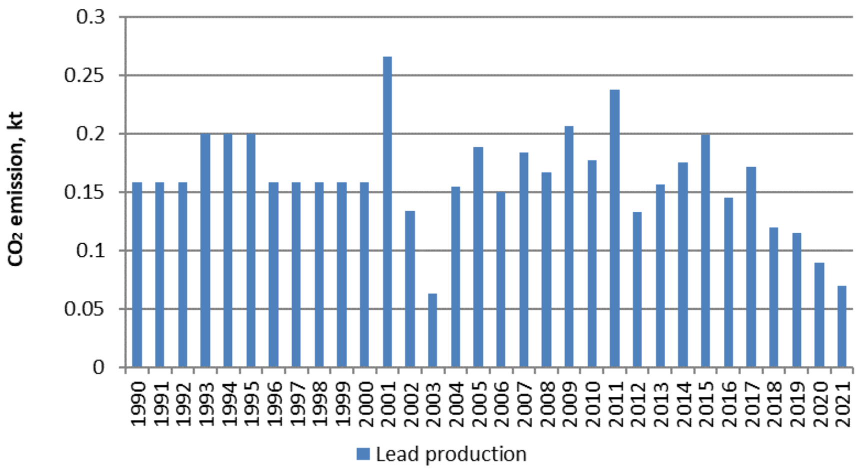

Figure 4.4.5 Emission of greenhouse gasses from secondary lead production.

Time series consistency and completeness

The time series for secondary lead production is considered to be both consistent and complete.

4.5 Non-Energy Products from Fuels and Solvent Use

4.5.1 Source category description

Non-Energy Products from Fuels and Solvent Use (CRF 2D) covers the following categories relevant for the Danish air emission inventory:

- 2D1 Lubricant use; see section 4.5.3
- 2D2 Paraffin wax use; see section 4.5.4
- 2D3 Solvent use; see section 4.5.5
- 2D3 Road paving with asphalt; see section 4.5.6
- 2D3 Asphalt roofing; see section 4.5.7
- 2D3 Urea-based catalysts; see section 4.5.8

[4] Volume 3: Industrial Processes and Product Use, Chapter 4.6.2.2: Choice of emission factors, Table 4.21, page 4.73.

4.5.2 Emissions

The time series for emission of greenhouse gasses from *Non-Energy Products from Fuels and Solvent Use* (2D) is presented in the CRF tables and in Figure 4.5.1 below.

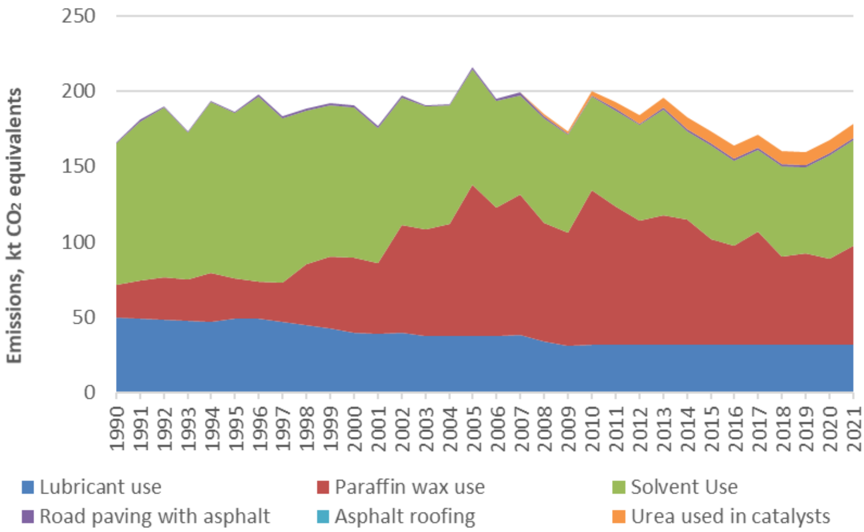

Figure 4.5.1 Emission of greenhouse gasses from the individual source categories compiling *2D Non-Energy Products from Fuels and Solvent Use*, kt CO_2 eq.

The largest source of greenhouse gas emissions from *Non-Energy Products from Fuels and Solvent Use* is for 1990-2004 the use of solvents. As the use of solvents decreases (35 % decrease from 2000-2007) and the use of candles (i.e. paraffin wax use) increases (111 % increase from 2001-2005), the use of candles becomes the largest source of greenhouse gas emissions for 2005-2017. Since the peak in emissions from the use of candles in 2010, emissions have decreased with 36 % (2010-2021). Emissions from solvent use have found a more stable level since 2006 (of 55-70 kt CO_2). Solvent use and paraffin wax use contribute about equally to greenhouse gas emissions from *Non-Energy Products from Fuels and Solvent Use* in 2018-2019. With the introduction of Covid-19, the use of solvents (disinfectants) increased, making solvent use the dominant source in 2020-2021.

4.5.3 Lubricant use

The category Lubricant use (CRF 2D1) covers the following process:

- Oxidation of lubricants during use

Lubricants consumed in machinery (i.e. that is combusted during use) is included in this section. Collection of waste lubricants with subsequent combustion is reported in the energy sector.

Methodology

The emission of CO_2 from oxidation of lubricants during use is calculated according to the equation (IPCC, 2006):

$$E_{CO2} = LC \bullet CC_{lubricant} \bullet ODU_{lubricant} \bullet 44/12 \qquad \text{(Eq. 4.5.1)}$$

Where E_{CO2} is the CO_2 emission, LC is the consumption of lubricants, $CC_{lubricant}$ is the carbon content factor, $ODU_{lubricant}$ is the Oxidised During Use factor and 44/12 is the mass ratio of CO_2/C.

Equation 4.5.1 represents a Tier 1 approach where LC is the total amount of lubricant consumed in Denmark with no differentiation between greases and oils.

Activity data

The time series for consumption of lubricant oil in TJ is obtained from the Danish Energy Agency (2022) along with the calorific value of 41.9 GJ per tonne. The consumption has been reported as constant by the DEA since 2010. The consumption is presented in Table 4.5.1 and the complete time series in Annex 3C-24.

Table 4.5.1 Consumption of lubricant oil, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Lubricants	80.5	79.1	64.3	60.9	51.3	51.3	51.3	51.3	51.3	51.3

Emission factors

Table 4.5.2 Factors for calculation of the lubricant use emission factor.

Factor	Description	Source	Value	Unit
$CC_{lubricant}$	The default carbon content factor	IPCC (2006), page 5.9	20.1	kg C/GJ
$ODU_{lubricant}$	The oxidised during use factor for grease	IPCC (2006), Table 5.2 page 5.9	0.2	-
CO_2/C	Mass ratio, 44/12	IPCC 2006, page 5.5	3.7	kg CO_2/kg C

The emission factor is calculated as the product: $CC_{lubricant} \cdot ODU_{lubricant} \cdot 44/12$ in Eq 4.5.1, and yields an emission factor of 14.7 kg CO_2 per TJ or 0.617 tonnes CO_2 per tonne lubricant used. This is constant for the entire time series.

Emission trends

The time series for CO_2 emission from oxidation of lubricants during use is presented in Table 4.5.3 and Annex 3C-25.

Table 4.5.3 Emissions from oxidation of lubricants during use, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Lubricants	49.7	48.8	39.7	37.6	31.7	31.7	31.7	31.7	31.7	31.7

Time series consistency and completeness

The applied methodology has been the same for all years in the time series, with activity data based on information from the Danish Energy Agency and using the same emission factor. The emission time series is therefore consistent. Since activity data are available from the energy statistics (Danish Energy Agency, 2022), the time series is also complete.

4.5.4 Paraffin wax use

The category Paraffin wax use (CRF 2D2) covers the following activity:

- Combustion of paraffin wax candles

Paraffin waxes are used in applications such as candles, corrugated boxes, paper coating, board sizing, adhesives, food production, packaging, wax polishes, surfactants (used in detergents or in wastewater treatment), and many others. Emissions from the use of paraffin waxes occur primarily when they are combusted during use, e.g. candles, or when incinerated or used in waste water treatment. The latter cases should be reported in the energy or waste sectors, respectively (IPCC, 2006).

Methodology

In the Danish inventory, greenhouse gas emissions (CO_2, N_2O and CH_4) are only included from the main emission source: Combustion of paraffin wax candles. The methodology corresponds to a Tier 2 (IPCC, 2006), and assumes an oxidation factor of 100 %.

Activity data

Activity data are derived from import, export and production data for candles from Statistics Denmark (2022). The activity data are presented in Table 4.5.4 and in Annex 3C-26.

Table 4.5.4 Use of paraffin wax candles, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Paraffin wax use	7.4	9.1	16.9	34.4	35.2	24.0	20.0	20.7	19.4	22.5

Emission factors

The emission factors presented in Table 4.5.5 are constant for the entire time series and are compiled from the scientific literature. The IPCC (2006) CO_2 emission factor is valid for shale oil and is therefore not used.

Table 4.5.5 Emission factors for use of paraffin wax candles.

Pollutant	Unit	Value	Source
CO_2	kt/kt	2.91	Shires et al. (2009)
N_2O	t/kt	0.024	Campbell et al. (2021)
CH_4	t/kt	0.121	Campbell et al. (2021)

Emission trends

The time series for greenhouse gas emissions from paraffin wax use is shown in Table 4.5.6 and Annex 3C-27.

Table 4.5.6 Emissions from the use of paraffin wax candles.

	Unit	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
CO_2	kt	21.7	26.5	49.3	100.2	102.3	70.0	58.3	60.3	56.5	65.5
CH_4	t	0.9	1.1	2.0	4.2	4.3	2.9	2.4	2.5	2.3	2.7
N_2O	t	0.2	0.2	0.4	0.8	0.8	0.6	0.5	0.5	0.5	0.5
CO_2 eq.	kt	21.7	26.6	49.4	100.5	102.7	70.2	58.5	60.5	56.7	65.7

Since the emission factors are constant throughout the time series, any increase or decrease in emissions are caused by an equal development in activity. Emissions increased with 363 % from 1990 to 2005. After 2010, emissions started decreasing (-43 % from 2010-2018). Since 2018, emissions from paraffin wax use has been somewhat steady at 57-66 kt CO_2 eq. The overall development from 1990 to 2021 in an increase of 202 %.

The decrease in the years after 2010 is believed to be caused by an increased awareness on indoor climate/pollution and an increased sale of LED candles. However, the full effect of this seems to already be implemented.

Time series consistency and completeness

The time series is both consistent and complete.

4.5.5 Solvent use

The category Solvent use (CRF 2D3 Other) is aggregated according to the following categories, which correspond to the grouping in IPCC (2006):

- Paint application
- Degreasing, dry cleaning and electronics
- Chemical products manufacturing or processing
- Other use of solvents and related activities
- Printing industry
- Domestic solvent use (other than paint application)

Only NMVOC, which is subsequently oxidised to CO_2 in the atmosphere, is relevant for these categories. To be consistent with the reporting during the first commitment period of the Kyoto Protocol, Denmark has continued to report these indirect CO_2 emissions under sector 2D rather than reporting them separately under indirect CO_2.

Methodology

NMVOC emissions from solvent use are estimated using emission modelling of solvents by estimating the amount of (pure) solvents consumed, thus representing a chemicals approach, where each pollutant is estimated separately. All relevant solvents must be estimated, or at least those together representing more than 90 % of the total pollutant emission. These emissions are summed up to one national total CO_2 (NMVOC) emissions from solvent use.

The method is mainly based on the detailed approach and methodology described in EMEP/EEA (2019) and emissions are calculated for industrial sectors, households and for individual pollutants.

Activity data

Description of compilation of activity data can be found in Nielsen et al. (2022) Chapter 4.5.2. Activity data for solvent use is presented in Table 4.5.7 and Annex 3C-28.

Table 4.5.7 Solvent consumption activity data, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Paint application	83.5	91.0	104.2	74.6	45.1	43.1	37.5	43.6	48.6	50.4
Degreasing, dry cleaning and electronics	1.4	1.5	0.6	0.4	0.2	0.2	0.3	0.2	0.2	0.3
Chemical products manufacturing or processing	406.9	575.0	584.9	750.6	629.1	513.1	511.4	523.0	630.4	595.8
Other use of solvents and related activities	176.4	212.0	196.9	181.9	143.0	145.5	129.2	138.6	175.5	161.5
Printing industry	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.3
Domestic solvent use (other than paint application)	29.1	43.9	41.0	35.5	25.6	38.8	40.9	21.3	24.1	27.9

Emission factors

Emission factors are calculated for a complete conversion to CO_2 of each NMVOC molecule in units g CO_2 per g NMVOC from:

$$n \cdot 12 \frac{g}{mol} \Big/ (molecular\ weight\ NMVOC) \cdot 3.667 \frac{g\ CO_2}{g\ C}$$

where *n* is the number of carbon atoms in the NMVOC molecule. Further description of the methodology for derivation of emission factors in categories can be found in Nielsen et al. (2022) Chapter 4.5.2. The implied emission factors are presented in Table 4.5.8 and Annex 3C-29.

Table 4.5.8 CO_2 emission factors for solvent use.

	Unit	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Paint application	t/kt	154.4	160.3	151.8	138.6	148.9	145.3	142.5	143.1	140.1	150.7
Degreasing, dry cleaning and electronics	t/kt	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Chemical prod. manufacturing/processing	t/kt	47.8	40.5	29.7	20.8	19.3	23.7	24.4	25.1	25.4	24.2
Other use of solvents and related activities	t/kt	294.9	271.3	273.6	215.6	252.8	219.8	224.9	231.4	224.4	246.6
Printing industry	t/kt	81.1	86.4	80.1	70.4	77.6	76.0	75.7	76.6	78.4	76.8
Domestic solvent use (not paint application)	t/kt	321.1	331.3	328.0	315.8	267.8	308.3	318.8	271.8	278.8	307.3

Emission trends

Table 4.5.9, Figure 4.5.2 and Annex 3C-30 show the emissions of CO_2 from solvent use. The general decrease from 1997 to present is an indication of increased implementation of NMVOC emission reducing measures in production facilities, and a general shift to water soluble and high solid products, in e.g. the graphics-, paint-, plastic- and auto paint and repair industries. Further information can be found in Nielsen et al. (2022) Chapter 4.5.2.

Table 4.5.9 CO_2 emissions from solvent use.

	Unit	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Paint application	kt	12.9	14.6	15.8	10.3	6.7	6.3	5.3	6.2	6.8	7.6
Degreasing, dry cleaning and electronics	kg	37.4	40.6	15.8	9.7	5.5	4.1	7.1	6.1	5.1	7.3
Chemical products manufacturing or processing	kt	19.4	23.3	17.4	15.6	12.1	12.2	12.5	13.1	16.0	14.4
Other use of solvents and related activities	kt	52.0	57.5	53.9	39.2	36.2	32.0	29.1	32.1	39.4	39.8
Printing industry	t	16.2	19.8	14.4	13.3	18.0	18.6	16.9	18.5	27.8	25.1
Domestic solvent use (not paint application)	kt	9.4	14.6	13.5	11.2	6.9	12.0	13.0	5.8	6.7	8.6
Total CO_2	kt	93.7	110.0	100.5	76.4	61.9	62.4	59.9	57.3	68.9	70.4

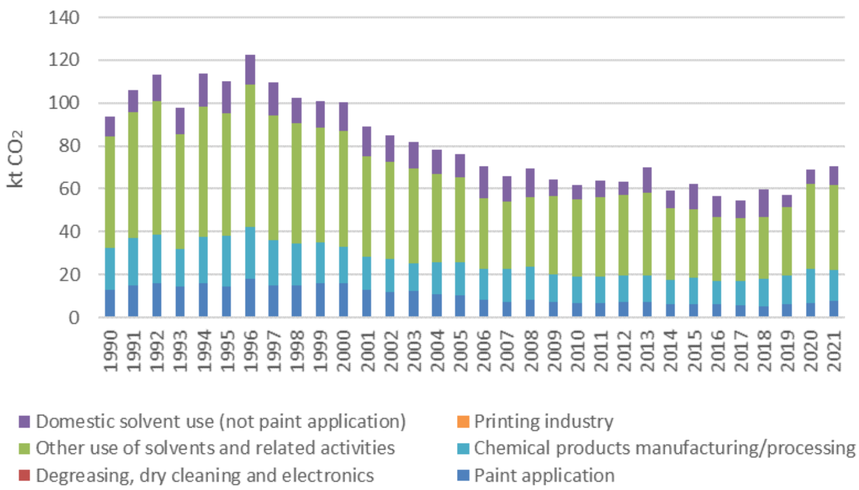

Figure 4.5.2 CO_2 emissions from solvent use, kt.

Time series consistency and completeness

The time series is considered to be both consistent and complete. For verification, please refer to Hjelgaard & Nielsen (2018).

4.5.6 Road paving with asphalt

The category Road paving with asphalt (CRF 2D3 Other) covers the following activity:

- Road paving with asphalt

Methodology

Road paving with asphalt is an activity that can be found all over the country and especially in relation to establishing new traffic facilities. The raw materials for construction of transport facilities are prepared on one of the plants located near the locality of application to limit the transport distance. The asphalt concrete is mixed and brought to the locality of application on a truck.

Transport facilities are constructed by a number of different layers:

- a load bearing layer (e.g. course gravel)
- an adhesive layer (liquefied asphalt e.g. "cutback" asphalt or asphalt emulsion)
- a wearing coarse (e.g. hot mix asphalt concrete).

Different qualities of "cutback" asphalt (e.g. asphalt dissolved in organic solvents/petroleum distillates) and asphalt emulsion contains different kinds and amounts of solvent. Cutback asphalt contains 25-45%v/v solvent e.g. heavy residual oil, kerosene-type solvent, naphtha or gasoline solvent. Approximately 500.000 litre solvent evaporates annually from the use of "cutback" asphalt (Asfaltindustrien, 2003). This amount of solvent, which is added to the asphalt, is comprised in the category 2D3 Other: Solvent use, described above with an emission factor of approximately unity. This means that NMVOC emissions from "cutback" asphalt in Road paving only include emissions from the asphalt fraction, which is included in Table 4.5.10.

Indirect CO_2 emissions are calculated from NMVOC, CH_4 and CO emissions. To be consistent with the reporting during the first commitment period of the Kyoto Protocol, Denmark has continued to report indirect CO_2 emissions from road paving with asphalt under category 2D rather than separately under indirect CO_2.

Activity data

The used amounts of asphalt for road paving have been compiled from production, import and export statistics of asphalt products in Statistics Denmark (2022) and are presented in Table 4.5.10 and Annex 3C-31.

Table 4.5.10 Activity data for asphalt in road paving, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Road paving with asphalt	2535	3144	2933	3879	3005	3440	4089	3508	3833	3606

Emission factors

Emission factors are available in Table 4.5.11 below.

Table 4.5.11 Emission factors for road paving with asphalt incl. cutback.

Pollutant	Unit	Emission factor value	Source
CO_2	kg/t	0.23	Calculated emission factor: Indirect CO_2 from NMVOC, CH_4 and CO
CH_4	g/t	4.4	US EPA (2004)
NMVOC	g/t	16.0	EMEP/EEA (2019)
CO	g/t	120.2	US EPA (2004)

Emission trends

Greenhouse gas emissions from road paving with asphalt are presented in Table 4.5.12 and Annex 3C-32.

Table 4.5.12 Emissions from road paving with asphalt, t.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
CO_2	583	723	675	892	691	791	940	807	882	829
CH_4	11	14	13	17	13	15	18	15	17	16

Time series consistency and completeness

The time series is considered to be both consistent and complete.

4.5.7 Asphalt roofing

The source category Asphalt roofing (CRF 2D3 Other) covers the following activity:

- Asphalt roofing

Methodology

The asphalt industry produces a number of products, e.g. roofing and siding shingles, for use in roofing. Key steps in the total production and roofing process include asphalt storage, asphalt blowing, felt saturation, coating and mineral surfacing.

Asphalt blowing is the process of polymerising and stabilising asphalt to improve its weathering characteristics, and it may take place in an asphalt processing or roofing plant, or in a refinery. Only asphalt blowing is covered in IPCC (2006) and in the Danish inventory, as it leads to the highest emissions of NMVOC and CO in the total production and roofing process.

Indirect CO_2 emissions from NMVOC and CO emissions from asphalt blowing in asphalt roofing are included. To be consistent with the reporting during the first commitment period of the Kyoto Protocol, Denmark has continued to report indirect CO_2 emissions from asphalt roofing under category 2D rather than separately under indirect CO_2.

Activity data

The use amounts of asphalt for roofing have been compiled from production, import and export statistics of asphalt products in Statistics Denmark (2022). Activity data are presented in Table 4.5.13 and Annex 3C-33.

Table 4.5.13 Activity data for asphalt roofing, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Asphalt roofing	56.1	57.0	88.5	69.6	43.9	47.0	59.5	59.1	60.0	63.9

Emission factors

Emission factors are available in Table 4.5.14 below.

Table 4.5.14 Emission factors for asphalt roofing (asphalt blowing).

Pollutant	Unit	Emission factor value	Source
CO_2	kg/t	0.40	Calculated emission factor: Indirect CO_2 from NMVOC and CO
NMVOC	g/t	130	EMEP/EEA (2019)
CO	g/t	9.5	EMEP/EEA (2019)

Emission trends

Greenhouse gas emission from asphalt roofing are presented in Table 4.5.15 and Annex 3C-34.

Table 4.5.15 Emissions from asphalt roofing, t.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
CO_2	22.4	22.8	35.4	27.8	17.6	18.8	23.8	23.6	24.0	25.6

Time series consistency and completeness

The time series is considered to be both consistent and complete.

4.5.8 Urea-based catalysts

Methodology

The category Urea-based catalysts (CRF 2D3 Other) covers CO_2 emissions from urea-based additives used in catalytic converters in heavy duty vehicles to bring down NO_x emissions:

- Urea-based catalysts

The consumption of urea by SCR catalysts for heavy duty vehicles is estimated with the DCE emission model for road transport by using fuel consumption totals and urea consumption rates for relevant engine technologies. The DCE model uses the COPERT 5 detailed methodology as explained in Chapter 3.3. SCR catalysts are used by Euro V and VI trucks and to a smaller extent by Euro IV trucks as an emission abatement technology in order to bring down NO_x emissions.

Activity data

According to COPERT 5, the consumption of urea is 5-7 % by volume of fuel for Euro IV/V heavy duty vehicles (6 % is used) and 3-4 % for Euro VI heavy duty vehicles (3.5 % is used). Activity data for the use of urea is presented in Table 4.5.16 and Annex 3C-35.

Table 4.5.16 Activity data for use of urea in catalysts, kt.

	2001	2005	2010	2015	2018	2019	2020	2021
Urea	0.002	0.041	11.9	34.0	38.1	38.4	38.1	40.0

Emission factors

For each vehicle layer, the emissions of CO_2 are subsequently estimated as the product of urea consumption and a CO_2 emission factor of 0.26 kg CO_2 per l urea (EMEP/EEA, 2019).

Emission trends

CO_2 emissions from the use of urea in catalysts are presented in Table 4.5.17 and Annex 3C-36.

Table 4.5.17 CO_2 emissions from the use of urea in catalysts, kt.

	2001	2005	2010	2015	2018	2019	2020	2021
CO_2	0.001	0.010	2.8	8.1	9.1	9.2	9.1	9.5

Time series consistency and completeness

The time series is considered to be both consistent and complete.

4.6 Electronics Industry

4.6.1 Source category description

The sector *Electronic Industry* (CRF 2E) covers the use of HFCs and PFCs in the production of fibre optics. There is no production of semiconductors, TFT flat panels or photovoltaics with use of F-gases in Denmark. No use of HFCs or PFCs as heat transfer fluids occur in Denmark.

As a result the only relevant category is:

- 2E5 Other: HFC-23, PFC-14 (CF_4) and PFC-318 ($c\text{-}CF_4F_8$) from fibre optics

The description of consumption and emission of F-gases given below is based on an inventory by Poulsen (2023). For further detail refer to this report.

4.6.2 Emissions

The use of F-gases in the production of fibre optics did not start until 2001 and no emissions are reported for 2020-2021. Hence the time series covers the years 2001-2019. The emission time series for *Electronics Industry* (2E) is available in the CRF tables but is also presented in Figure 4.6.1.

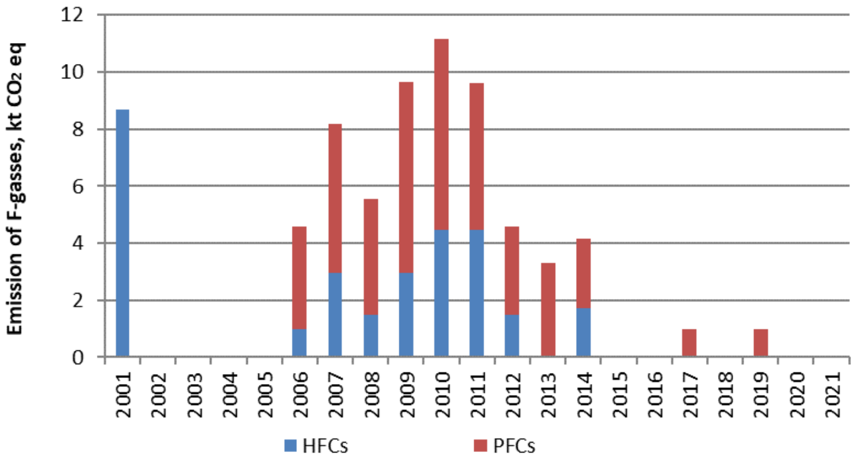

Figure 4.6.1 Emissions of HFCs and PFCs from *Electronics Industry.*

4.6.3 Other electronics industry

As mentioned above, optic fibre production is the only source category relevant for the Danish inventory on electronic industries.

Methodology

Both HFCs (HFC-23) and PFCs (PFC-14 and PFC-318) are used for technical purposes in Danish optics fibre production for protection and as cleaning gases. Information on consumption of HFCs and PFCs in production of fibre optics is derived from annual importers' sales report with specific information on the amount used for production of fibre optics. This is believed to represent 100% of the Danish consumption of F-gases for that purpose. The emission factor is 1, i.e. 100 % release in the production year (i.e. year of consumption). The methodology corresponds to the IPCC Tier 2 method. Stock displacement is believed to be the main reason for the fluctuations in the time series. However, since F-gasses in this industry are only used for tests or product development and not for industry scale production, the use of F-gasses will also be small and will vary.

Activity data

There has been no use of F-gasses in 2002-2005, 2015-2016, 2018 or 2020-2021. The consumption data are provided in Figure 4.6.2 below and Annex 3C-37.

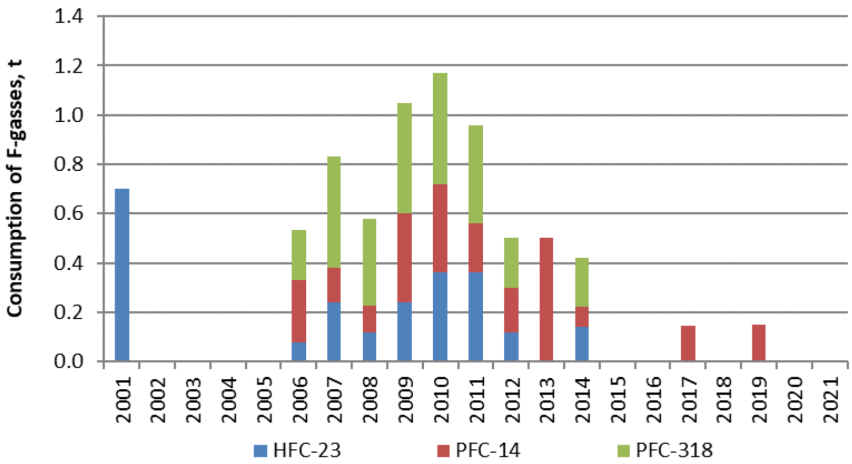

Figure 4.6.2 Consumption of F-gases in production of fibre optics, t.

Emission factors

Since HFC-23 and the PFCs are used as protection and cleaning gases as well as for etching in optics fibre production, the emission factor is defined as 100 % release during production.

Emission trends

Emission trends are presented in Figure 4.6.3 below and Annex 3C-38.

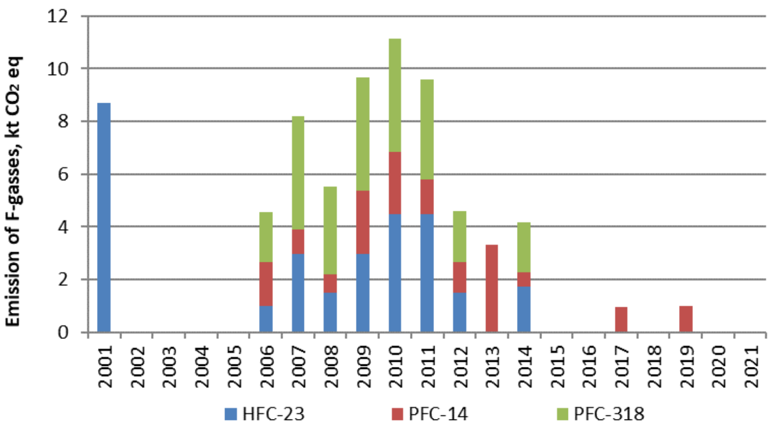

Figure 4.6.3 Emissions from Electronic industry, kt CO_2 eq.

Time series consistency and completeness

The estimates are based on information directly from the importer supplying this sector in Denmark. As Denmark is a small country with a limited consumption of F-gasses, there are only few importers. Data collection for the F-gas report (Poulsen, 2023) is done in close corporation with the industry associations enabling inclusion of any new importers of F-gases or F-gas containing products. The time series is therefore considered both complete and consistent.

4.7 Product Uses as Substitutes for Ozone Depleting Substances (ODS)

4.7.1 Source category description

The sub-sector *Product uses as substitutes for ODS* (2F) includes the following source categories and the following F-gases of relevance for Danish emissions:

- 2F1: Refrigeration and air conditioning: HFC-32, -125, -134a, -143a, -152a, PFC-218 and PFC-14
- 2F2: Foam blowing agents: HFC-134a and HFC-152a
- 2F4: Aerosols: HFC-134a and HFC-227ea
- 2F5: Solvents: PFC-218

It must be noted that the inventories for the years 1990-1994 might not cover emissions of these gases in full. The choice of base-year for these gases under the Kyoto Protocol is 1995 for Denmark.

Two key categories were identified for the emission of HFCs in the sub-sector *Product uses as substitutes for ODS* (2F); refrigeration and air conditioning for level in 2021 and for trend (both Approach 1 and Approach 2) and foam blowing agents for trend (both Approach 1 and Approach 2).

The description of consumption and emission of F-gases given below is based on an inventory by Poulsen (2023). For further details, refer to this report.

All descriptions in Chapter 4 of this report, refer to activities in mainland Denmark. Emissions presented in DNK CRF tables include emissions from Greenland and the Faroe Islands; including some F-gasses. Inter-annual variations in the DNK time series are naturally likely to occur, e.g. if F-gas consumption decreases significantly in mainland Denmark but not in Greenland.

4.7.2 Emissions

The emission time series for *Product uses as substitutes for ODS* (2F) are presented in Figure 4.7.1 and Figure 4.7.2 below.

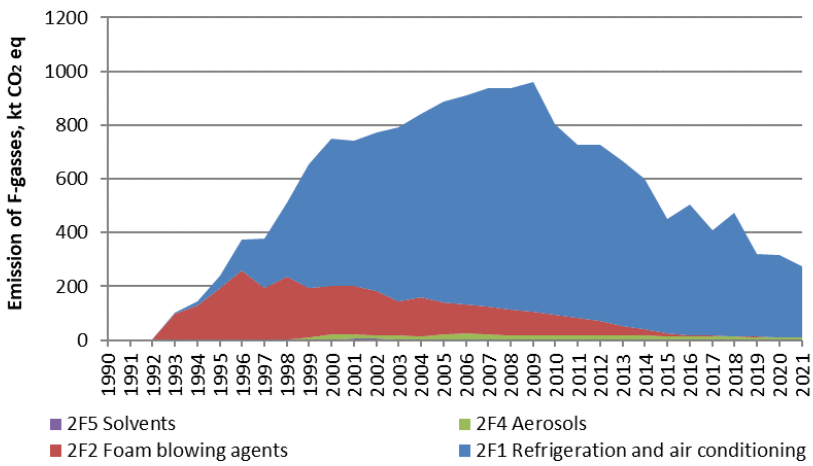

Figure 4.7.1 Emission of F-gases from the individual source categories within *2F Product uses as substitutes for ODS*, kt CO_2 eq.

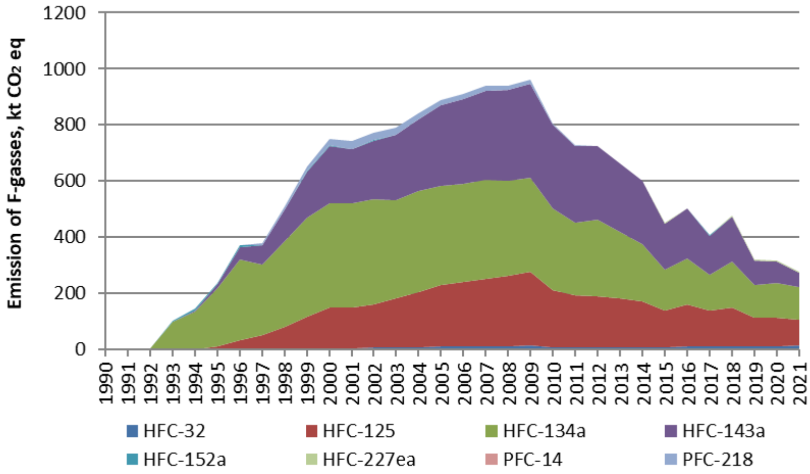

Figure 4.7.2 Emission of F-gases from the individual gases within 2F Product uses as substitutes for ODS, kt CO_2 eq.

The emission of HFCs increased rapidly in the 1990s and, thereafter, increased more modestly due to a moderate increase in the use of HFCs as a refrigerant and a decrease in foam blowing. The F-gases have been regulated in two ways since 1 March 2001. For some types of use there is a ban on use of the gases in new installations and for other types of use, taxation is in place. These regulations seem to have influenced emissions so that since 2009, an overall decreasing trend can be observed.

General trends

The phase out of F-gases has in particular been effective within the foam blowing sector and refrigeration and air conditioning installations. Regarding foam blowing, there was a stepwise phase-out of HFC-134a used for foam blowing in closed cell and open cell foam production, during the period 2001-2004. Especially the phase-out of HFCs in open cell foam is significant for the emission in this period.

Since the introduction of taxes on HFCs in 2001, the consumption and emissions from foams has seen a steady decrease and is now almost entirely gone. Emissions still occur from stock in closed cell foams, but no HFCs have been filled into new products (nor imported in new products) since 2016.

The emission of HFCs for refrigeration continued to increase until 2009, especially HFC-404a and HFC-134a increased. This increase is explained with other initiatives in Danish legislation, where new refrigeration systems containing HCFC-22 (ODS) was banned from 2001. It caused a boom in refrigeration systems using HFCs during 2002-2004, because the HFC technology was cheap and well proven. The consumption of HFCs for refrigeration changed significantly after 1 January 2007, where new larger HFC installations with charges exceeding 10 kg were banned. The emission of HFC-134a peaked in 2007, but the peak for HFC-125 and HFC-143a is not seen until 2009. Alternative refrigeration technologies based on CO_2, propane/butane and ammonia are now introduced and available for customers.

The import of PFC-218 (C_3F_8) has been very low since 2006, and as expected, this refrigerant has been phased out of the marked. Emissions have been decreasing since the peak in 2002, and no emissions of PFC-218 are reported after 2014. Emissions from the use of PFC-218 (C_3F_8) as a solvent only occurred from 2000 to 2003.

A quantitative overview is given below (Figure 4.7.3 – Figure 4.7.6) for each of the four source categories, showing their emissions in tonnes of CO_2 equivalents through the times series.

4.7.3 General methodology

The data for emissions of HFCs and PFCs have been obtained in continuation of the work on previous inventories. The determination includes the quantification and determination of any import and export of HFCs and PFCs contained in products and substances in stock form. This is in accordance with the IPCC guidelines (IPCC, 2006).

For the Danish inventories of F-gases, a Tier 2 bottom-up approach is basically used. In Annex 3 to the F-gas inventory report (Poulsen, 2023), there is a specification of the approach applied for each sub-source category.

The following sources of information have been used:

- Importers, agency enterprises, wholesalers and suppliers
- Consuming enterprises, and trade and industry associations
- Danish Environmental Protection Agency
- Recycling enterprises and chemical waste recycling plants
- Statistics Denmark
- Danish Refrigeration Installers' Environmental Scheme (KMO)
- Previous evaluations of HFCs, PFCs and SF_6

Suppliers and/or producers provide consumption data of F-gases. Emission factors are primarily defaults from the IPCC guidelines, which are assessed to be applicable in a national context. In the case of commercial refrigerants and Mobile Air Conditioning (MAC), information from Danish suppliers has been used. The actual amount of F-gas used for refilling is used as an estimate on the actual emission.

Import/export data for sub-source categories where import/export is relevant (e.g. MAC and fridges/freezers for households) are quantified on estimates from import/export statistics of products + default values of the amount of gas in the product. The estimates are transparent and described in Appendix 3 of Poulsen (2023).

The Tier 2 bottom-up analysis used for determination of emissions from F-gasses covers the following activities:

- Screening of the market for products in which F-gases are used
- Determination of averages for the content of F-gases per product unit
- Determination of emissions during the lifetime of products and disposal
- Identification of technological development trends that have significance for the emission of F-gases
- Calculation of import and export is based on defined key figures, and information from Statistics Denmark on foreign trade and industry information

The determination of emissions of F-gases is based on a calculation of the actual emission. The actual emission is the emission in the evaluation year, accounting for the time lapse between consumption and emission. The actual emission includes Danish emissions from production, from products during their lifetimes and from disposal.

Consumption and emissions of F-gases are determined for individual substances, even though the consumption of certain HFCs has been very limited. This has been carried out to ensure transparency of evaluation in the determination of GWP values.

The substances have been accounted for in the annual survey according to their trade names, which are mixtures of HFCs used in the CRF, etc. In the transfer to the "pure" substances used in the CRF reporting tables, the ratios provided in Table 4.7.1 have been used.

Table 4.7.1 Content (w/w%)[1] of “pure” HFC in HFC-mixtures, used as trade names.

HFC mixtures	HFC-32	HFC-125	HFC-134a	HFC-143a	HFC-152a	HFC-227ea
	%	%	%	%	%	%
HFC-365						8
HFC-401a					13	
HFC-402a		60				
HFC-404a		44	4	52		
HFC-407c	23	25	52			
HFC-410a	50	50				
HFC-507a		50		50		

[1]The mixtures also contain substances that do not have GWP values and therefore, the substances do not sum up to 100 %.

The national inventories for F-gases are provided and documented in an annual report (Poulsen 2023). Furthermore, detailed data and calculations are available and archived in an electronic version. The report contains summaries of methods used and information on sources as well as further details on methodologies.

4.7.4 Refrigeration and air conditioning

2F1 Refrigeration and air conditioning consists of the following subcategories:

- 2F1a Commercial refrigeration
- 2F1b Domestic refrigeration
- 2F1c Industrial refrigeration (included under commercial)
- 2F1d Transport refrigeration
- 2F1e Mobile air conditioning
- 2F1f Stationary air conditioning

The use of HFCs in industrial refrigeration was previously surveyed and the conclusion was that large-scale industrial refrigeration e.g. slaughterhouses, fish factories and medico companies use ammonia based refrigeration units. This is particularly caused by the tax on HFCs in Denmark that makes HFC based refrigeration units with large charges too expensive and furthermore the ban from 2007. Smaller HFC based units will occur in industry, but is then similar to commercial refrigeration units. Since it is not possible to separate small-scale industrial and commercial refrigeration units, all consumption and emissions are reported under commercial refrigeration.

Methodology

For refrigeration and air conditioning, Denmark uses mainly the Tier 2 top-down approach (Tier 2b). However, for Domestic Refrigeration the methodology is a combination of Tier 2a and 2b. For more information on the applied methodology please refer to Poulsen (2023).

According to Danish law, refrigerators and air conditioning equipment must be emptied before decommissioning by recovery, reuse or destruction of the remaining gases. It is reasonable to assume that this law is upheld in Denmark since waste collection is mandatory and there are no extra charges for e.g. getting rid of a used refrigerator. In addition, to recycling plants where companies and individuals can deliver their waste, there is also a collection scheme where e.g. used refrigerators are collected at the sidewalks and disposed of. Due to this there is no reason why people would chose to illegally dispose of an appliance when the legal disposal is both free and easy.

For the early period of the time series (1994-2000), transport refrigeration and mobile air conditioning were included in one common activity reported under 2.F.1.e Mobile air conditioning. When data became available to allow for the split between these two activities this was implemented. For the transport refrigeration category is used a decommissioning rate of 10 % four years after the consumption. This results in small amounts of HFC-125 and -143a (from HFC-404a) for decommissioning in 1997-2000 in 2.F.1.e. After this period, HFC-404a is no longer reported in 2.F.1.e, but only as used in transport refrigeration (2.F.1.d).

Activity data

The data collection is described in the Chapter 4.7.3 General methodology.

The activity data expressed as total amount of HFCs and PFCs filled into new products, present in operating systems and remaining in products at decommissioning are included in the CRF tables and are not repeated here.

PFC-14 was used in Denmark for a brief period as refrigerant for specialized low-temperature (-60ºC) freezers for laboratory purposes. Use of PFC-14 for these extreme low temperature laboratory freezers has been registered for 2015-2018, and is placed under 2.F.1.a Commercial refrigeration. By 2019 CF_4 was already substituted with other refrigerants. In 2017 and 2018 the consumption figures were identical.

Heat pumps are part of category 2.F.1.f Stationary air conditioning. There is however no production of heat pumps in Denmark and the stock of HFC-32, HFC-125 and HFC-134a in heat pumps therefore increases without any emissions from manufacture. Import of F-gasses in heat pumps is included in "filled into new products" in the CRF table, this causes the "product manufacturing factor" to be below the 0.2 displayed in Table 4.7.2 below.

Emission factors

The applied emission factors are presented in Table 4.7.2.

Table 4.7.2 Applied emission factors for refrigeration and air condition systems.

		Assembly, %	Stock, % per annum	Lifetime, years	Recovery, %
2.F.1.a	Commercial and industrial refrigerators[1]	0.5-1.5	10	15	88.5
2.F.1.b	Household fridges and freezers	2	1	15	100
2.F.1.d	Transport refrigeration	0.5	17	7	88.5
2.F.1.e	Mobile air conditioning systems[2]	4.5	30	3-15	88.5-100
2.F.1.f	Stationary air conditioning[3]	0.2-1.5	3-10	15	88.5-100
	- Heat pumps[4]	0.2	3	10	80

[1] For commercial refrigerators EFs change from 2010 onward, from 1.5 % to 0.5 % for assembly. This is not the case for retail and industrial refrigeration systems.
[2] For pure HFC-134a, EFs are 4.5 % from assembly, 30 % leakage, 15 years and 88.5 % recovery and for HFC-404a, EFs are 4.5 %, 30 %, 3 years and 100 % recovery.
[3] EFs change for all HFCs from 2010 onward, from 1.5 % to 0.2 % for assembly, and from 10 % to 3 % for stock. For PFC-218 recovery is 100 %.
[4] EFs for heat pumps are mentioned separately from the remaining 2.F.1.f category.

2.F.1.a

The reduction in emission factor from 2010 for all sources in 2.F.1.a from 1.5 % to 0.5 % leakage rate at assembly, is implemented based on an expert judgement of when the technologies improved and next generation units were introduced to the market (Poulsen 2023). This reduction in leakage rate has been investigated, and also discussed in the Nordic working group on F-gases. 1.5 % emission at assembly of commercial refrigerators is the correct factor for historic years, while 0.5 % is correct for recent years. While technological development occurs gradually, emission calculations often display a more step wise trend, as is the case here where the year 2010 was chosen as the split line.

2.F.1.b

For domestic refrigeration, the emission from stock presented in the CRF tables is a sum of annual emissions in the product lifetime. The product life factor is therefore not exactly equal to 1% as otherwise stated in Table 4.7.2. The notation key "Not occurring" (NO) is used in the CRF for the amounts of HFCs remaining in products at decommissioning because all appliances are either exported or dismantled at specialised facilities where all refrigerants are drawn of and sent to reuse of destruction.

As described in the methodology section above, all Danish household fridges and freezers are collected at end use. Appliances are either exported or treated in Denmark at specialised dissemble plants. F-gasses are drawn off the appliances under a fume hood, and collected gasses are reused or destroyed through incineration. It is therefore reasonable to assume 100 % recovery. Regarding accidents and breakdown in stand-alone fridges (and MACs) where the entire stock might escape is accounted for in the lifetime emissions. Emissions that might potentially escape incineration at the specialised incineration plants with extremely high temperatures, have been estimated and proven insignificant, see the section on completeness below.

2.F.1.e

Detailed information on the amount of HFCs used for refilling of mobile A/C has been available and applied for the years 2009 - 2011, and therefore, a new approach has been implemented in the calculation of emissions from these years onward. Starting from 2009, the refilled and consumed amount of HFC-134a is calculated based on a Tier 2 top-down approach were the importers of HFC-134a for mobile A/C systems are isolated. The consumption of HFC-

134a for mobile A/C systems is used solely for refilling. Car manufacturers outside Denmark carry out initial filling. (Poulsen, 2023):

Consumption of HFC for MAC = refilled stock = emission

From 2012 onward, the applied methodology for mobile air conditioning results in a product life factor around 30 % (21-36 %). For years prior to the shift in methodology mentioned above, the product life factor was exactly 30 % as mentioned in Table 4.7.2.

2.F.1.f

The reduction in emission factor from 2010 for 2.F.1.f from 10% to 3% leakage rate, is implemented based on an expert judgement of when the technologies improved and next generation units were introduced to the market (Poulsen 2023). This reduction in leakage rate has been investigated, and also discussed in the Nordic working group on F-gases. Based on the discussions among experts, it is clear that the actual level of leakage from stationary air conditioning units is in the range of 1-4 % and that this has been the level for a number of years. Considering the negligible impact on the emissions, it has been decided to use this approach with a sharp drop in 2010, until more detailed knowledge becomes available that can form the basis for recalculations.

Emission resulting from disposal of items and equipment in the applications differs from 0-20%. For most categories the emission is calculated as 0% because Danish legislation ensures that management and treatment of refrigerants prevent uncontrolled emissions. For heat pumps the emission at decommissioning is estimated as 20% due to lack of control measures with decommissioning of air-air heat pumps from private household. (Poulsen, 2023).

For heat pumps, emission from stock is a sum of annual emission over lifetime. This results in varying odd numbers for the product life factor. Emission at decommissioning is 20% for heat pumps and 11.5% for stationary air conditioning, the disposal loss factor presented in the CRF tables therefore end up around 13-14%.

Emission trends

Figure 4.7.3 present the emissions of F-gases from consumption of HFCs and PFCs in the individual sub-categories of refrigeration and air conditioning systems.

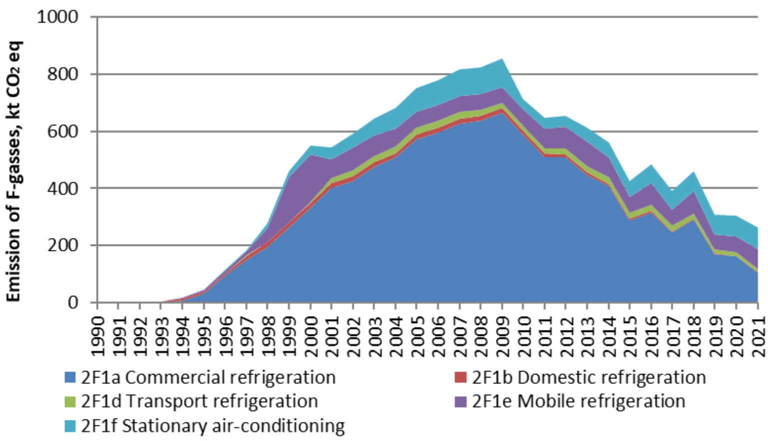

Figure 4.7.3 Emissions from refrigeration and air conditioning.

F-gas emissions from commercial refrigeration are dominating the overall emissions from this source. Hence, the increasing trend from the mid-1990s to 2009 and the subsequent decrease in emissions are explained in Chapter 4.7.2 Emissions.

The decrease in emissions from mobile air -conditioning in the recent years, is related to the lower consumption of HFC-134a. HFO-1234yf (GWP value of <1) is increasingly being used as a substitute for HFC-134a in new mobile air conditioning systems. HFO-1234yf is not reported under the UNFCCC and is therefore not included in this report.

EU F-gas Regulation 517/2014, Annex III entered into force on 1 January 2015 placing a ban on sale/installation of domestic refrigeration appliances containing F-gases with a GWP>150. However, for 2015-2021 amounts of HFC 125 (GWP 3170), HFC-134a (GWP 1300) and HFC 143a (GWP 4800) are reported as "filled into new manufactured products" in the domestic refrigeration subcategory. The single producer responsible for this consumption confirms the consumption of HFC 134a and HFC-404a for domestic appliances and biomedical coolers and freezers. The amounts are decreasing and very small for recent years.

Completeness

Emissions from decommissioning of domestic refrigeration appliances are reported as "Not Estimated" (NE) in the CRF tables. Direct contact to the Danish industry for destruction of ozone-depleting substances, confirms that no F-gas emissions escape the combustion at extremely high temperatures. However, in acceptance of the possibility of miniscule amounts of F-gases, the notation key is as mentioned "NE".

Estimations of the potential emission from decommissioning show that these are well below 0.05 % of the national total greenhouse gas emission. Using a removal efficiency of 99.99 % and considering that only 50 % of appliances are treated in Denmark, the potential emission at decommissioning is 0.5 - 8.2 t CO_2-eq (0.000001 % - 0.00001 % of national total emission incl. LULUCF) and thereby negligible.

4.7.5 Foam blowing agents

2F2 Foam blowing agents consists of the following processes:

- Closed cells (hard PUR foam plastics and polyether foam)
- Open cells (soft PUR foam plastics)

In Denmark, five specific processes have occurred during the time series, i.e. foam in household fridges and freezers (closed cell), soft foam (open cell), joint filler (open cell), foaming of polyether for shoe soles (closed cell) and system foam for panels, insulation etc. (closed cell).

Methodology

The methodology used varies between the different processes. For all processes the methodology corresponds to the Tier 2 level of IPCC (2006). For some processes a bottom-up methodology is applied while for others a top-down approach or a combination of top-down and bottom-up is used. For more information on the details of the applied methodology, please refer to Poulsen (2023).

Activity data

The data collection is described in the Chapter 4.7.3 General methodology.

There is no longer production of HFC-based hard PUR insulation foam in Denmark. This production has been banned in statutory order since 1. January 2006 (MIM, 2002).

Emission factors

The applied emission factors for foam blowing agents are presented in Table 4.7.3 (Poulsen, 2023 – Appendix 3).

Table 4.7.3 Applied emission factors for foam blowing agents (2F2).

	Consumption %	Stock %	Lifetime years
Foam in household fridges and freezers (closed cell)	10[4]	4.5[4]	15[5]
Soft foam (open cell)[1]	100[4]		
Joint filler (open cell)[1]	100[4]		
Foaming of polyether for shoe soles (closed cell)	15[5]	4.5[5]	3[5]
System foam (for panels, insulation, etc.)	0[2]	-[3]	

[1]100 % emission during the first year after production. [2] HFC is used as a component in semi-manufactured goods and emissions first occur when the goods are put into use. [3] System foam is only produced for export. [4] IPCC (2006) default, [5] Danish default.

System foam is produced in a closed environment and is only produced for export. Therefore, the consumption of HFCs does not contribute to the Danish stock.

The emission factors for foam in fridges and freezers, soft foam and joint filler are default values from (IPCC, 2006[5]). The emission factors for foaming of polyether are country-specific (Poulsen, 2023).

The F-gases remaining in products at decommissioning (closed cell products) are destroyed by incineration and hence there are no F-gas emissions related to disposal of these products.

Emission trends

Figure 4.7.4 presents the emissions of F-gases from consumption of HFCs in foam blowing agents.

[5] Volume 3: Industrial Processes and Product Use, Chapter 7.4.2.1: Foam blowing agents, Choice of method, Table 7.5, page 7.35 and Chapter 7.4.2.3: Foam blowing agents, Choice of activity data, page 7.38.

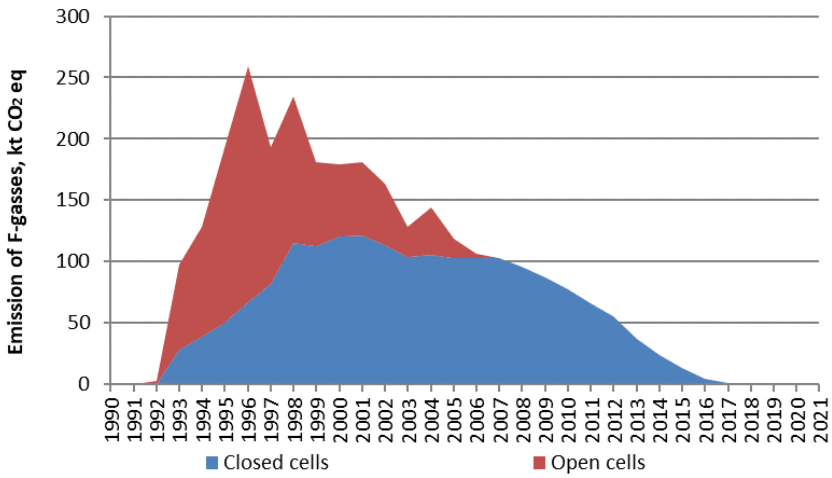

Figure 4.7.4 Emissions from foam blowing agents.

The sharp fluctuations in the time series are caused by fluctuations in the consumption of HFCs in production of open cell foam, with an emission factor of a 100 % in the given year. For the later part of the time series the trend reflects the limited use of HFCs and reflects the emission from the stock of previous use of HFCs.

Completeness

Emissions from decommissioning of hard foam (closed cells) are reported as "Not Estimated" (NE) in the CRF tables. Direct contact to the Danish industry for destruction of ozone-depleting substances, confirms that no F-gas emissions escape the combustion at extremely high temperatures. However, in acceptance of the possibility of miniscule amounts of F-gases, the notation key is as mentioned "NE".

Estimations of the potential emission from decommissioning show that these are well below 0.05 % of the national total greenhouse gas emission. Using a removal efficiency of 95% and considering that only 50 % of products are treated in Denmark, the potential emission at decommissioning is 0.1 – 3.9 kt CO_2-eq (0.0002 % - 0.007 % of national total emission incl. LULUCF) and thereby negligible.

4.7.6 Fire protection

No HFCs or PFCs are used in fire protection in Denmark. The use of halogen substituted hydrocarbons has been banned since 1977 (MIM, 1977), this ban is still in place (MIM, 2015).

Halon-1301 has been used in planes, in the military, in server rooms and on ships. New fire protection systems use other technologies, e.g. early fire detection, inert gases or gas mixtures (argon, nitrogen and CO_2) or water vapour. For mobile systems halon-1211 has been replaced with CO_2 or foam fire extinguishers.

4.7.7 Aerosols

2F4 Aerosols consist of HFCs used for:

- Propellant in aerosols
- Metered dose inhalers

Methodology

The general data collection process is described in the section 4.7.3 General methodology.

For HFC use as propellant in aerosol cans the IPCC (2006) Tier 2a default methodology is used. A default emission factor of 50 % of the initial charge per year is used for aerosols. For metered dose inhalers (MDI) a Tier 2 bottom-up approach is used and an emission factor of 100 % of the initial charge per year is applied.

Information on propellant consumption is derived from reports on consumption from the only major producers of HFC-containing aerosol sprays in Denmark. The import and export are estimated by the producer.

Information on consumption of F-gasses in MDIs is based on data from the national medical trade statistic and information on product content of HFCs from the producers.

As all F-gasses are assumed to be released during the product lifetime for all aerosols, there are no F-gasses remaining in products at decommissioning and therefore no emission from decommissioning and no recovery of F-gasses. The notation key used for these is therefore "NO" (not occurring).

Activity data

From 2019 and forth, the use of HFC-134a is phased out and substituted with HFO-1234ze[6] (GWP value of 7) as propellants in aerosols for specific industrial purposes. 2019 will therefore be the last year of submitted HFC emissions from source category 2.F.4.b Other aerosols.

HFC-134a has been used in medical metered dose inhalers since 1998, but HFC-227ea is only introduced from 2015.

Emission factors

The applied emission factors are presented in Table 4.7.4 (Poulsen, 2023).

Table 4.7.4 Applied emission factors for aerosols/medical dose inhalers.

	Consumption/filling	Stock	Lifetime
Aerosols	0 %	50 % first year 50 % second year	2 years
Medical dose inhalers	0 %	100 % in year of application	1 year

Emission trends

Figure 4.7.5 presents the emissions of F-gases from consumption of HFCs in aerosols.

[6] HFOs are not reported under the UNFCCC and is therefore not included in this report.

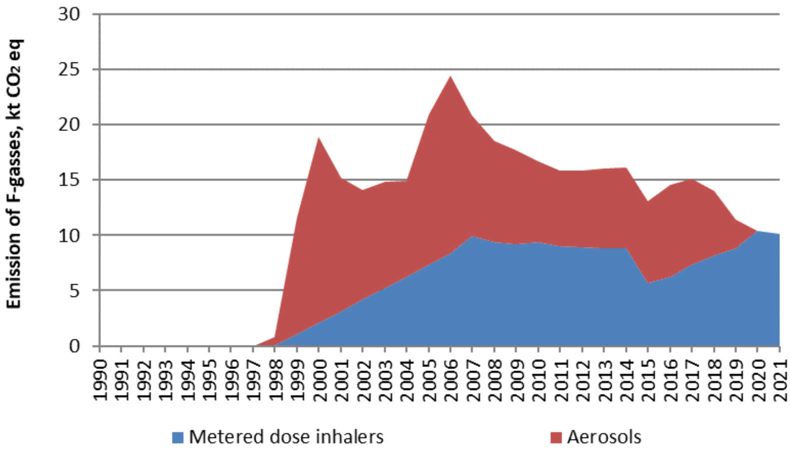

Figure 4.7.5 Emissions from aerosols.

Due to the methodology used, the fluctuations in the time series are a result of changes in import, production and export. Baring these fluctuations in mind the emission level has been rather constant at a level between 13 and 21 kt CO_2 equivalents in 2000-2018, but has dropped to 10-11 kt CO_2 equivalents from 2019 due to the phase out of HFC-134a in Aerosols.

4.7.8 Solvents

C_3F_8 was used as cleaner from 2000 to 2002 (emissions in 2000-2003) and the use then ceased following the ban in accordance with the Executive Order (MIM, 2002).

Methodology

The methodology used is the IPCC (2006) default and the fraction of chemical emitted from solvents in the year of initial use is assumed to be 50 % in line with good practice. The other 50 % is assumed to be emitted in the second year and hence there is no subtraction of any destruction of solvents.

Activity data

The general data collection process is described in the section 4.7.3 General methodology.

Information on consumption of PFCs in liquid cleaners is derived from two importers' sales reports. This is representing 100% of the Danish consumption.

Emission factors

In accordance with IPCC (2006)[7], the emission factor is 50 % in year 1 and 50 % in year 2.

Emission trends

Figure 4.7.6 presents the emissions of F-gases from consumption of PFCs used as solvents.

[7] Volume 3: Industrial Processes and Product Use, Chapter 7.2.2.1: Solvents (non-aerosol), Choice of method, Equation 7.5, page 7.23 and Chapter 7.2.2.2: Solvents (non-aerosol), Choice of activity data, page 7.24.

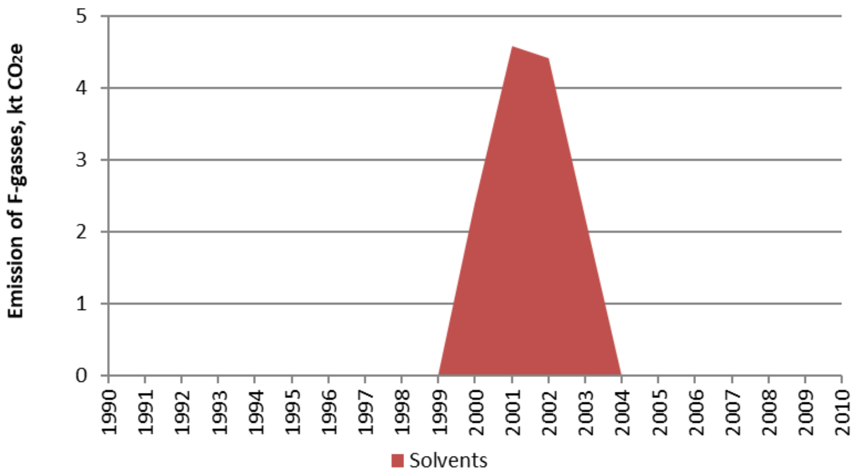

Figure 4.7.6 Emissions from PFCs used as solvents.

As mentioned the use of PFCs as solvent only occurred from 2000 to 2002 and hence emissions only occurred from 2000 to 2003.

4.8 Other Product Manufacture and Use

4.8.1 Source category description

The sector *Other Product Manufacture and Use* (CRF 2G) covers the following processes relevant for the Danish air emission inventory:

- 2G1 Electrical equipment; see section 4.8.3
- 2G2 SF_6 from other product uses; see section 4.8.4
- 2G3a Medical applications; see section 4.8.5
- 2G3b N_2O used as propellant for pressure and aerosol products; see section 4.8.6
- 2G4 Other product uses; see section 4.8.7

4.8.2 Emissions

Total greenhouse gas emissions from the *Other Product Manufacture and Use* (2G) sector are available in the CRF Table 10. The emission time series for the source categories within 2G are presented in Figure 4.8.1 and individually in the subsections below (Sections 4.8.3 – 4.8.7). The following figure gives an overview of which source categories contribute the most throughout the time series.

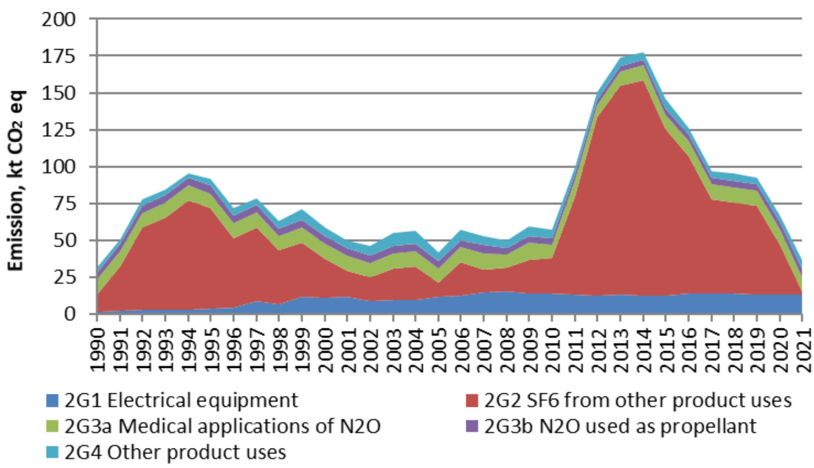

Figure 4.8.1 Emission of CO_2 equivalents from the individual source categories compiling *2G Other Product Manufacture and Use*.

4.8.3 Electrical equipment

Use of electrical equipment (2G1b) is the only source relevant for the Danish inventories in the sub sector of 2G1 *Electrical equipment*.

Methodology

High voltage power switches are filled or refilled with SF_6, either for new installation or during service and repair. Filling is usually carried out on new installations and a smaller proportion of the consumption of SF_6 is due to refilling.

The methodology uses annual data from importers' statistics with detailed information on the use of the gas. This corresponds to the country-level mass-balance Tier 3c methodology of IPCC (2006). A release of 5 per cent on filling with new gas and a gradual release of 0.5 per cent from the stock are applied. Both figures are averages, covering normal operation and failure/accidents.

No emissions are assumed to result from disposal since the used SF_6 is drawn off from the power switches and re-used internally by the sole Danish supplier (Siemens) or appropriately disposed of through waste collection schemes. The notation key used for the activity data for the amount of SF_6 remaining in products at decommissioning of electrical equipment in the CRF is therefore "not occurring" (NO).

Activity data

The data collection is described in the Chapter 4.7.3 General methodology.

Information on consumption of SF_6 in high-voltage power switches is derived from importers' sales reports (gas or gas-containing products). The importers account for 100% of the Danish sales of SF_6 for this purpose.

The electricity sector also provides information on the installation of new plants and thus whether the stock is increasing.

Emission factors

The applied emission factors are presented in Table 4.8.1. Special attention has been given to use of SF_6 as insulation in high-voltage plants (Poulsen, 2001; ELTRA, 2004).

Table 4.8.1 Applied emission factors for other processes (Poulsen, 2023).

	Consumption/ filling	Stock, per annum	Disposal	Lifetime
Insulation gas in high voltage switches	5 %	0.5 %	0 %	-[1]

[1] Lifetime unknown.

Emission trends

Figure 4.8.2 presents the emissions of SF_6 from electrical equipment.

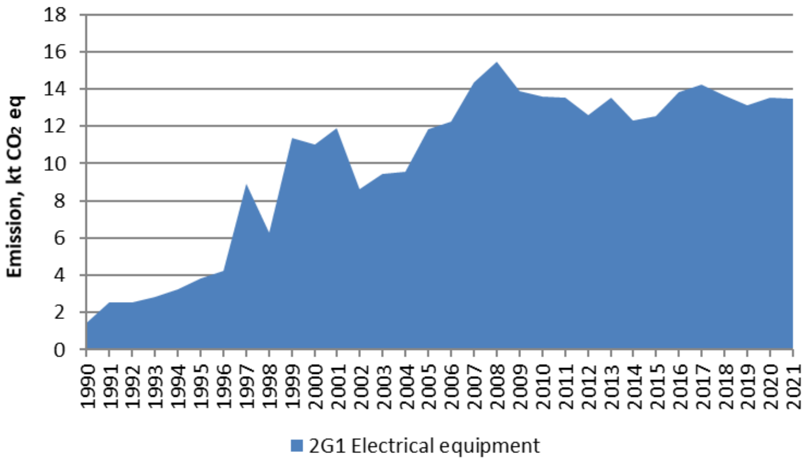

Figure 4.8.2 Emissions from SF_6 from electrical equipment.

The trend in emissions from use of SF_6 in electrical equipment has been increasing. However, significant inter-annual variations occur depending on the specific activity level in a given year.

4.8.4 SF_6 from other product use

2G2 SF_6 from other product use consists of the following subcategories:

- Consumption of SF_6 in running shoes
- Consumption of SF_6 in laboratories
- Consumption of SF_6 in double glazed windows

An overview of when emissions from these three sources occurred are available in Table 4.8.2 below.

Table 4.8.2 Occurrence of emissions from the sources compiling 2G2.

	From manufacture	From stocks	From disposal
Running shoes	-	-	1995-2003
Laboratories	1990-1997, 2001-2004, 2006-2021	-	-
Windows	1991-2001	1991-2020	2011-2021

Methodology

A mass balance approach is used for laboratory use of SF_6. For double glazed windows the default Tier 2 IPCC methodology is used with country-specific emission factor. For more information, please refer to Poulsen (2023).

Consumption of SF_6 in laboratories includes consumption for a particle accelerator, a radiotherapy device, electron microscopes, plasma erosion in connection with the manufacture of microchips in clean-room laboratories and to a limited extend analytical purposes. Importers/suppliers of SF_6 have been questioned with regard to their knowledge of SF_6 consumption in laboratories, but no further details could be obtained. The yearly consumption reached a maximum of 1.1 tonnes of SF_6 in 2013 and is below 0.8 tonnes for all other years in the time series. It is therefore not considered relevant to introduce national emission factors for e.g. particle accelerators. As soon as individual emission factors are available in the Guidelines, Denmark will include these in the submission. But for now, consumption of SF_6 for these special purposes are reported as part of the consumption in laboratories.

Use of SF_6 in double-glazed windows was phased out in 2002, and the last stack emissions were emitted in 2020. However, there are still emissions from disposal of the last existing double-glazed windows in Danish buildings. The stock is estimated from consumption data from Danish producers of double-glazed windows 1991-2001 and lifetime for double-glazed windows are determined to 20 years. This country specific lifetime was determined in collaboration with the Danish industry and matches the warranty. This is further corroborated by the Association of Danish Window Manufacturers (Vindues Industrien, 2023) who state an expected lifetime of 20 years.

Activity data

The data collection is described in the Chapter 4.7.3 General methodology.

Information on consumption of SF_6 in double glazing is derived from importers' sales reports to the application area. The importers account for 100% of the Danish sales of SF_6 for double glazing. In addition, the largest producer of windows in Denmark has provided consumption data, with which import information is verified.

Importers have estimated imports to Denmark of SF_6 in training footwear.

Emission factors

The applied emission factors are presented in Table 4.8.3.

Table 4.8.3 Applied emission factors for SF_6 from other product use (Poulsen, 2023).

	Consumption	Stock	Lifetime
Laboratories	100 %		
Insulation gas in double glazed windows	15 %	1 % annual	20 years
Shock-absorbing in Nike Air training footwear	-[1]	-[2]	5 years

[1] No emission from production in Denmark.
[2] Yearly emissions have been estimated to 0.11 t in 1995-2003.

80 % of the content filled into new manufactured double glazed windows is assumed to be disposed at decommissioning.

Emission trends

Figure 4.8.3 presents the emissions of SF_6 from shoes, double glazed windows and other uses (laboratories etc.).

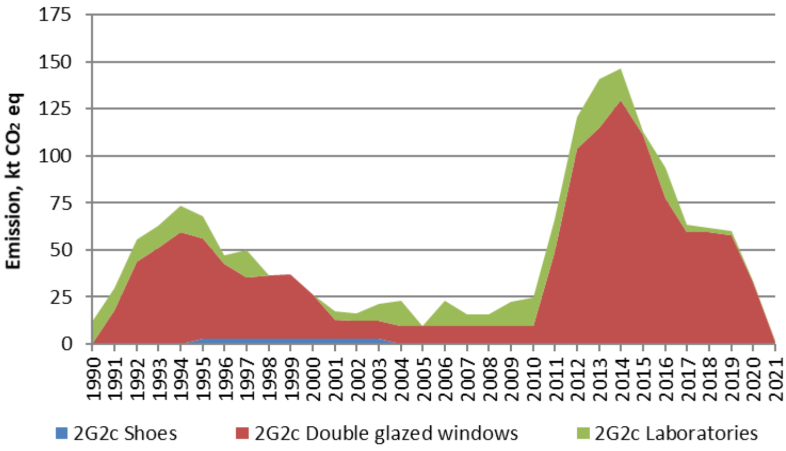

Figure 4.8.3 Emissions from SF_6 from other product uses.

Double-glazed windows using SF_6 was introduced in 1991 and ceased 10 years later. While there is annual emissions, the lifetime is assumed to be 20 years meaning that all remaining SF_6 contained in the windows is assumed to be emitted 20 years after the last production, i.e. starting from 2011. Emissions of SF_6 from this source is therefore high from 2011 (where the first windows are scrapped) and the following 10 years. However, since the use of SF_6 in double glazed windows was banned in 2002, by 2021 all emissions are assumed to have taken place.

4.8.5 Medical applications of N_2O

The category *Medical applications* of N_2O (CRF 2G3a) covers the following activity:

- Use of anaesthesia

Methodology

N_2O has been used as anaesthetics for more than a hundred years but has also had other smaller applications in newer times. N_2O in this source category is predominantly used as anaesthesia and a small amount is used as fuel in race cars and in chemical laboratories.

In the mid-1990s, introduction of air quality limit values for N_2O together with requirements of expensive extraction systems reduced the application of N_2O for anaesthetics at smaller facilities like dentists.

Five companies sell N_2O in Denmark and only one company produces N_2O. N_2O is primarily used in anaesthesia by hospitals, dentists and veterinarians and in minor use in laboratories, racing cars and in the production of electronics. Due to confidentiality, no data on produced amount are available and thus the emissions related to N_2O production are unknown. For 2005-2012, sold amounts are obtained from the respective distributors and the produced amount is estimated from communication with the company. For the remaining years, data are estimated.

Activity data

Data on total sold and estimated produced N_2O for sale in Denmark is only available for the years 2005-2012, activity data for the years 1990-2004 and 2013-2019 have therefore been estimated as the average value of 2005-2012. Activity data for the time series are presented in Table 4.8.4.

Table 4.8.4 Activity data for N_2O mainly used for medical applications, t.

	1990-2004	2005	2006	2007	2008	2009	2010	2011	2012	2013-2021
N_2O consumption	38[1]	37	38	43	33	46	34	42	30	38[1]

1) Calculated: average 2005-2012.

Emission factors

An emission factor of 1 is assumed for all uses.

Emission trends

The emission trend for the N_2O emission from medical applications is presented in Figure 4.8.4 below.

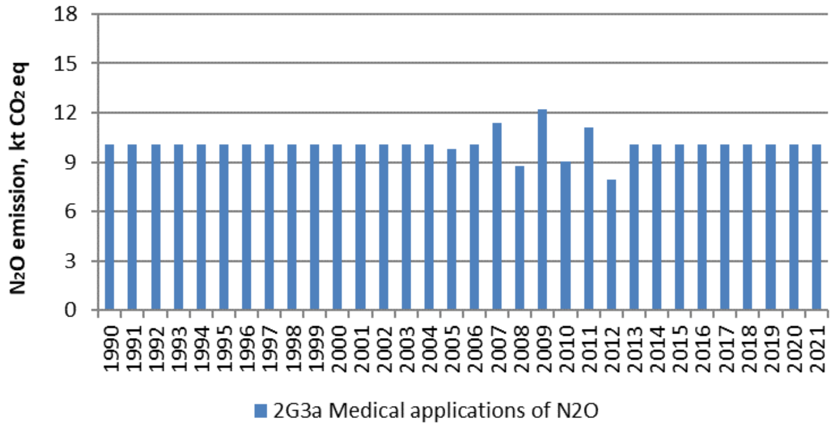

Figure 4.8.4 N_2O emissions from the use of anaesthetics.

Time series consistency and completeness

The methodology is consistent throughout the time series. It is not possible to obtain reliable data prior to 2005, but the source category is considered to be complete although uncertainties going back from 2005 and forth from 2012 are increasing.

4.8.6 N_2O used as propellant for pressure and aerosol products

The category *N_2O used as propellant for pressure and aerosol products* (CRF 2G3b) covers the following activity:

- Aerosol can use

Methodology

There is a strong tradition of fresh dairy products in Danish culture and while canned whipped cream is used for e.g. hot beverages in the winter months this product is not widely used.

There are no statistics on production, import/export and/or sales of canned whipped cream in Denmark and the content of propellant is confidential. The consumption of canned whipped cream is therefore estimated as 1 % of the regular cream sale. Further assumptions made include 5 mass% propellant in a can, 250 ml (250 g) cream per can and 95 % release of N_2O.

Activity data

Data on total sold cream and the estimated sale of canned cream are presented in Table 4.8.5 and in Annex 3C-39.

Table 4.8.5 Consumption of cream in Denmark, t.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Cream[1]	37378	46279	39380	37333	34835	31772	34683	34575	41713	46584
Canned cream	374	463	394	373	348	318	347	346	417	466

[1]Statistics Denmark (2022).

Emission factors

The applied emission factor is 0.0475 tonnes N_2O per tonne canned cream sold; 5 % propellant and 95 % release.

Emission trends

The emission trend for the N_2O used as propellant is available in Annex 3C-40 but is also presented in Figure 4.8.5 below.

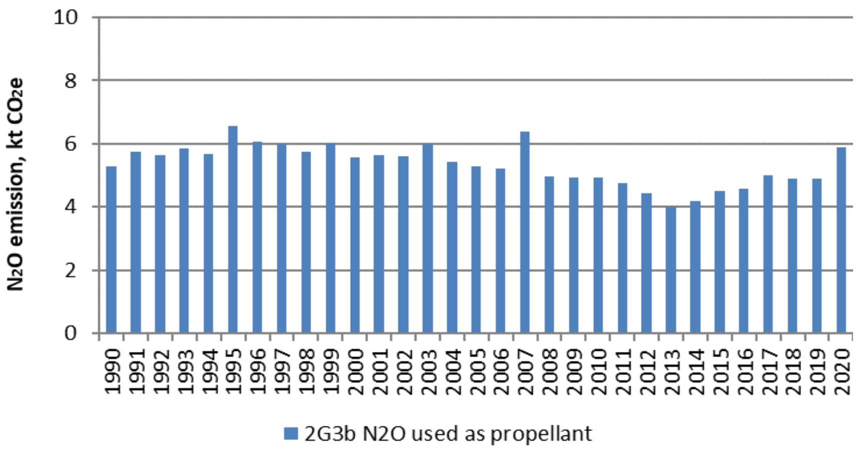

Figure 4.8.5 N_2O emissions from the use of canned whipped cream.

Time series consistency and completeness

The methodology is consistent throughout the time series. The estimate is considered too rough to be certain of completeness. For verification, please refer to Hjelgaard & Nielsen (2018).

4.8.7 Other product uses

The category *Other Product Uses* (CRF 2G4) covers the following activities:

- Use of fireworks: CO_2, N_2O and CH_4
- Use of tobacco: N_2O and CH_4
- Use of charcoal for barbequing: N_2O and CH_4

Methodology

Methane and nitrous oxide emissions are calculated for all three product uses but carbon dioxide is only relevant for fireworks since CO_2 emissions from the two remaining product uses are biogenic.

The applied methodology follows a Tier 2 technology-specific approach from EMEP/EEA (2019)[8] for calculating emissions from fireworks, tobacco and charcoal for barbeques (BBQ).

Activity data

Activity data are derived from import, export and production data from Statistics Denmark (2022) and are available in Table 4.8.6 and Annex 3C-41.

Table 4.8.6 Activity data for other product uses, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Fireworks	1.3	3.0	4.9	3.7	5.4	5.8	6.2	4.3	4.2	5.0
Tobacco	13.1	11.7	11.4	10.5	9.5	7.3	6.3	6.6	5.6	5.7
Charcoal for BBQ	7.2	7.9	13.4	14.9	7.8	16.3	8.1	9.1	6.6	12.8

The assumption of the weight of cigarettes and cigars of 1 g and 5 g respectively was made to derive the activity data from Table 4.8.6.

[8] 2.D.3.i- 2.G Other solvent and product use, Chapter 3.3 Tier 2 technology-specific approach.

Emission factors

Emission factors for use of fireworks, tobacco and charcoal for BBQ are found through literature studies and are presented in Table 4.8.7.

Table 4.8.7 Emission factors for other product uses.

	Unit	Fireworks[1]	Tobacco[2]	BBQ[3]
CO_2	kg/t	43.3	NA	NA
N_2O	kg/t	1.94	0.06	0.03
CH_4	kg/t	0.83	3.2	5.9

[1] Netherlands National Water Board (2008).
[2] Emission factors for wood (111A) in residential plants (1A4b i), the energy content used in the calculation is the average of wood pills and wood waste (16.1 GJ/t).
[3] IPCC (2006), calculated using default EFs[9] a net calorific value[10].

Emission trends

The emission trend for the greenhouse gases from other product uses is available in Annex 3C-42 and in Figure 4.8.6 below.

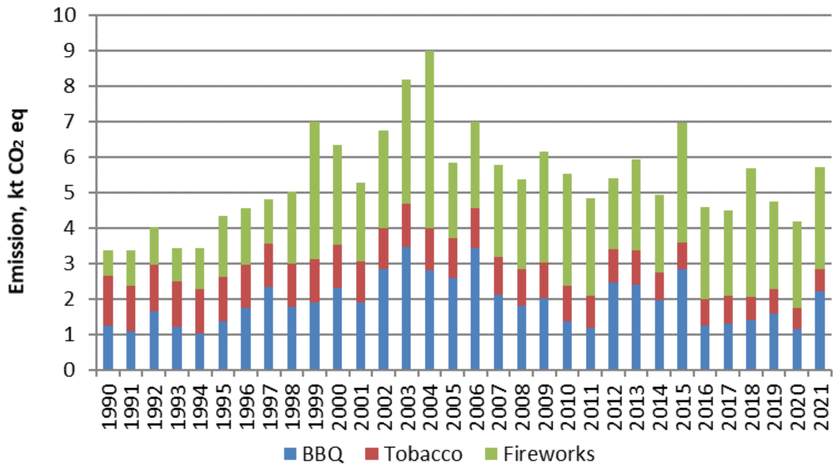

Figure 4.8.6 Greenhouse gas emissions from other product uses.

The consumption of charcoal for BBQs is highly influenced by the summer season weather and the number of smokers has been decreasing throughout the time series.

For fireworks, two peaks are visible in the time series, the peak in 1999 is caused by the celebration of the new millennia and the peak in 2004 by the Seest incident where 284 t net explosive mass (NEM) corresponding to a gross weight of about 1.5 kt of fireworks exploded (Report Seest, 2005). From 2005, the new restrictions put on fireworks meant a lower general consumption than before 2004, but the increasing trend continued.

Time series consistency and completeness

Activity data for fireworks are based on import/export data. There is no significant firework production industry in Denmark and the use of illegal products is assumed negligible. Cross-border shopping of fireworks is also considered negligible since most fireworks from e.g. Germany is illegal in Denmark due to the strict Danish laws on the content of net explosive mass (NEM).

[9] Volume 2: Energy, Chapter 2.3.2.1 Stationary combustion, Tier 1, Table 2.4, page 2.21, solid biofuels, charcoal.
[10] Volume 2: Energy, Chapter 1.4.1.3 Introduction, Activity data sources, Table 1.2, page 1.19, solid biofuels, charcoal.

Activity data for tobacco includes cross-border shopping. Data for cross-border shopping is known for 2000-2020 and estimated for the remaining years of the time series. From 2000 to 2020 the cross-border shopping of tobacco decreased from 14 % of retail sale to 6 % in 2020. Cross-border shopping is highly influenced by regulations in the Danish tax system and on e.g. the closure of borders in 2020 caused by the global pandemic of covid-19.

The activity data for charcoal for barbeques are determined from import/export data and includes:

- Charcoal, including coal of nutshells or nuts, also agglomerated
- Bamboo, including coal of nutshells or nuts, also agglomerated (except for medical use, charcoal mixed with incense, activated charcoal and charcoal for drawing)
- Charcoal, including coal of nutshells or nuts, also agglomerated (except bamboo, charcoal dosed or packaged as medicines, charcoal mixed with incense, activated charcoal and charcoal for drawing).

The product called Heat Beads® BBQ briquettes consist of a certain blend of hardwood charcoal and mineral carbon made by carbonising brown coal and is therefore emitting some non-biogenic CO_2. Due to confidentiality it is not possible to determine neither the market share of this product nor the share of non-biogenic CO_2 emitted from the product. The amount of non-biogenic CO_2 from barbequing is assumed to be negligible. It is further more assumed that the cross-border shopping of charcoal is negligible.

The time series is considered to be complete for the included sources, the time series is also considered consistent.

4.9 Uncertainty

4.9.1 Uncertainty input

The source specific uncertainties for industrial processes and product uses are presented in Table 4.9.1. The uncertainties are based on IPCC (2006) combined with assessment of the individual processes.

Mineral Industry

The single Danish producer of cement has delivered the activity data for production as well as calculated the emission factor based on quality measurements. For activity data, there is a shift in methodology from 1997 to 1998. Prior to 1998 activity data are derived by the Tier 2 (1-2 % uncertainty) methodology for grey cement production and the Tier 1 (<35 % uncertainty) for white cement production (20-25 % of total production). Activity data have fulfilled the Tier 3 methodology since 1998 and is assumed to have an uncertainty of 1 %. Since uncertainties cannot vary over time in Approach 1 uncertainty calculations, the activity data uncertainty is assumed to be 2 % for the entire time series. The estimation of emission factors fulfils the Tier 3 methodology for the entire time series and uncertainties are therefore assumed to be 2 %.

The activity data for production of lime, including non-marketed lime in the sugar production, are based on information compiled by Statistics Denmark. The uncertainty for the entire time series is assumed to be 1 % for activity data. The emission factor for marketed lime production cover many producers and a variety of high calcium products, assumptions that influence the uncertainty includes the assumptions of no impurities, 100 % calcination and for sugar production also the assumptions on the lime consumption and sugar content in beets. Since 2006 and the introduction of EU-ETS data, the uncertainty decreased as many of the mentioned assumptions were no longer needed, the combined uncertainty for emission factors are estimated to be 4 %.

The activity data uncertainty associated with glass production (including glass wool production) are low for recent years (EU-ETS data) but higher for historic years (carbonate data were not available for 1990-1996 and were therefore estimated for these years), since uncertainties cannot vary over time in Approach 1 calculations, activity data uncertainties are assumed to be 1 % for the entire time series. Uncertainties associated with the emission factors from glass production are low. Denmark uses the Tier 3 methodology and therefore stoichiometric CO_2 factors, some uncertainty is however connected to assuming a calcination factor of 1, and the overall emission factor uncertainty is therefore estimated to be 2 %.

The activity data for production of ceramics are based on information compiled by Statistics Denmark and EU-ETS and the uncertainty is assumed to be 5 % (Tier 2). The emission factor is based on stoichiometric relations and the assumption of full calcination; the uncertainty is assumed to be 2 %.

The CO_2 emission from other uses of soda ash is calculated based on national statistics and the stoichiometric emission factor for soda ash (Na_2CO_3) assuming the calcination factor of 1. Uncertainties are assumed to be 5 % and 2 % for activity data and emission factor respectively.

The category "Other Process Uses of Carbonates" in the Danish inventory includes flue gas desulphurisation and stone wool production. The activity data uncertainty for flue gas desulphurisation is assumed to be 10 %. For stone wool the activity data uncertainty is low for recent years (EU-ETS data) but higher for historic years (calculated/estimated), the uncertainties are assumed to be 2% and 15 % respectively. The overall activity data uncertainties for other process uses of carbonates are assumed to be 4 %. The uncertainty of the stoichiometric emission factors for both source categories is assumed to be 2 %.

Chemical Industry

The producers have registered the production of nitric acid during many years and, therefore, the activity data uncertainty is assumed to be 2 %. The measurement of N_2O is problematic and is only carried out for one year. Therefore, the emission factor uncertainty is assumed to be 25 %.

The uncertainty for the activity data as well as for the emission factor is assumed to be 5 % for production of catalysts/fertilisers.

Metal Industry

The uncertainty for the activity data and emission factor is assumed to be 5 % and 10 % respectively for production of secondary steel.

The uncertainty for the activity data and emission factor is assumed to be 10 % and 30 % respectively for production of magnesium (SF_6) and 10 % and 50 % respectively for lead production.

Non-Energy Products from Fuels and Solvent Use

Emissions from consumption of lubricant oil is derived from the energy statistics and standard emission factors. Uncertainties are assumed to be 5 % and 10 % respectively for activity data and emission factors.

For paraffin wax use the activity data are known for the entire time series (Statistics Denmark) and emission factors from literature. The fraction of candles made from beeswax is unknown, beeswax candles emit biogenic CO_2. Candles produced and sold at e.g. souvenir shops (less than 10 employees) are not included in the activity data from Statistics Denmark. Uncertainties are assumed to be 10 % and 20 % respectively for the two data sets.

Important uncertainty issues related to the mass-balance approach used for solvent use are: (i) Identification of pollutants that qualify as NMVOCs (The definition in Directive (1999) is used) as it is possible that relevant pollutants are not included, e.g. pollutants that are not listed with their name in Statistics Denmark but as a product. (ii) Distribution of solvent consumption between appliances. Although the total consumption is set, a change in distribution of consumption between industrial sectors and households will affect the total emissions, as different emission factors are applied in industry and households, respectively. Uncertainties are assumed to be 10 % for activity data and 15 % for emission factors, except for "other use of solvents and related activities" where the emission factor uncertainty is set at 20 %.

While the activity data for the use of asphalt products are known for the entire time series from Statistics Denmark (uncertainty set at 5 %), the emission factors are calculated using a number of assumptions (uncertainty set at 75 %).

Activity data for urea based catalysts are calculated by the COPERT 5 model. The emission factor includes a number of assumptions. Uncertainties are assumed to be 5 % and 10 % for activity data and emission factors respectively.

Product Uses as Substitutes for Ozone depleting Substances

Uncertainty varies from substance to substance. Uncertainty is highest for HFC-134a due to its widespread application in products imported and exported. The largest uncertainty in the analysis of substances by application areas is assessed to concern the breakdown of consumption of HFC-404A and HFC-134a between commercial stationary refrigerators and mobile A/C systems. This breakdown is significant for the short-term (about 5 years) emissions calculations, but will balance in the long term. This is because the breakdown is only significant for the rate at which emissions are released. (Poulsen, 2023)

The emission of F-gases is dominated by emissions from refrigeration equipment and therefore, the uncertainties assumed for this sector will be used for all the F-gases. The IPCC propose an uncertainty at 30-40 % for regional estimates. However, Danish statistics have been developed over many years and, therefore the uncertainty on activity data is assumed to be 10 %. The uncertainty on the emission factor is assumed to be 50 %. The base year for F-gases for Denmark is 1995.

Other Product Manufacture and Use

The uncertainty of N_2O used for medical applications is assumed to be 25 % for activity data and 20 % for the emission factor.

The uncertainty of N_2O used as propellant for pressure and aerosol products is estimated to be 100 % for activity data and 150 % for the emission factor.

The main issues leading to uncertainties for activity data for “Other Product Use” are collection of data for quantifying production, import and export of products. Some data, like private import (cross-border shopping) of fireworks, are not available. Other missing data like the composition of mineral containing charcoal for barbequing are unobtainable due to confidentiality. The uncertainty for activity data for all three product uses (fireworks, tobacco and BBQs) is estimated to be 5 %. Reliable emission factors are difficult to obtain for the other product use categories. Some chosen emission factors apply to countries that are not directly comparable to Denmark, and hereby is introduced an increased uncertainty. The uncertainties for emission factors are estimated to be 50 % for fireworks, 50 % for tobacco and 100 % for barbeques.

4.9.2 Approach 1 uncertainty

All uncertainty input values are discussed in Section 4.9.1 above. Table 4.9.1 presents the uncertainty inputs for activity data and emission factors and the calculated total emission and uncertainty for Approach 1 for the individual pollutants. The total greenhouse gas emission from the IPPU sector in 2021 is 1851 kt CO_2 equivalents and the calculated Approach 1 uncertainty for the year is 7.6 %. The trend decreases with 23.7 % during the time series and the trend uncertainty is 9.3 %.

Table 4.9.1 Input uncertainties and calculated Approach 1 emission and uncertainties.

CRF	Category	Activity data uncertainty	Emission factor uncertainty					
			CO_2	CH_4	N_2O	HFCs[2]	PFCs[2]	SF_6[2]
		%	%	%	%	%	%	%
2A1	Cement production	2	2					
2A2	Lime production	1	4					
2A3	Glass production	1	2					
2A4a	Ceramics	5	2					
2A4b	Other uses of soda ash	5	2					
2A4d	Other process uses of carbonates	4	2					
2B2	Nitric acid production[1]	2			25			
2B10	Catalysts/fertiliser production	5	5					
2C1	Iron and steel production	5	10					
2C4	Magnesium production	10						30
2C5	Secondary lead production	10	50					
2D1	Lubricant use	5	10					
2D2	Paraffin wax use	10	20	20	20			
2D3	Paint application	10	15					
2D3	Degreasing, dry cleaning and electronics	10	15					
2D3	Chemical products manufacturing or processing	10	15					
2D3	Other use of solvents and related activities	10	20					
2D3	Printing industry	10	15					
2D3	Domestic solvent use (other than paint applicat.)	10	15					
2D3	Road paving with asphalt	5	75	75				
2D3	Asphalt roofing	5	75					
2D3	Urea from fuel consumption	5	10					
2E5	Other electronics industry[3]	-						
2F1	Refrigeration and air conditioning	10				50	50	
2F2	Foam blowing agents	10				50		
2F4	Aerosols	10				50		
2F5	Solvents[3]	-						
2G1	Electrical equipment	10						50
2G2	SF_6 from other product use	10						50
2G3a	Medical application	25			20			
2G3b	Propellant for pressure and aerosol products	100			150			
2G4	Fireworks	5	50	50	50			
2G4	Tobacco	5		50	50			
2G4	Barbeques	5		100	100			
Emission 2021, kt			1538	0.1	0.1	275[4]	0.01[4]	15.0[4]
Overall uncertainty in 2021, %			2.3	66.3	59.1	49.0	51.0	46.1
Trend 1990-2020 (1995-2021), %			31.5	19.9	-97.9	15.8	-99.0	-85.9
Trend uncertainty, %			2.8	31.0	1.5	66.2	0.1	7.5

[1] The production closed down in the middle of 2004.

[2] The base year for F-gases is for Denmark 1995.

[3] Uncertainties are not calculated for this source category because the activity occurs in neither 1995 nor 2021.

[4] CO_2 equivalents.

4.10 Quality assurance/quality control (QA/QC)

4.10.1 Internal QA/QC

The approach used for quality assurance/quality control (QA/QC) is presented in Chapter 1.6; see also Nielsen et al. (2020). The present chapter presents QA/QC considerations for industrial processes and product use based on a series of Points of Measuring (PMs); see Chapter 1.6.

Data Storage level 1	1. Accuracy	DS.1.1.1	General level of uncertainty for every dataset including the reasoning for the specific values.

The uncertainty assessment has been performed on Approach 1 level by using default and country specific uncertainty factors. The applied uncertainty factors are presented in Chapter 4.9.

The sources of data described in the methodology sections and in DS.1.2.1 and DS.1.3.1 are used. It is the accuracy of these data that define the uncertainty of the inventory calculations. Any data value obtained from Statistics Denmark and SPIN are given as a single point estimate and no probability range or uncertainty is associated with this value. Information from reports is sometimes given in ranges. Uncertainties are therefore assessed from DCE judgement and guidebook estimates.

Data Storage level 1	2.Comparability	DS.1.2.1	Comparability of the emission factors/calculation parameters with data from international guidelines, and evaluation of major discrepancies.

Comparability of the data has not been performed at "Data Storage level 1". However, investigation of comparability at CRF level is in progress and is described in verification sections under each source category in Hjelgaard & Nielsen (2018) as they are performed.

The applied data sets are presented in Table 4.10.1.

Production and import/export data from Statistics Denmark for single products/chemicals can be directly compared with data from Eurostat for other countries. This has been done for a few chosen products/chemicals and countries. Furthermore, chosen Danish data from Eurostat have been validated with data from Statistics Denmark in order to check the consistency in data transfer from national to international databases.

Use categories for chemicals in products are found from the Nordic SPIN database. Data for all Nordic countries are available and reported uniformly. For chosen chemicals a comparison of chemical amounts and use has been made between countries.

Regarding Non-energy products from fuels and solvent use, a joint Nordic project funded by the Nordic Council of Ministers has been used on methodological issues and for emission factors (Fauser et al., 2009).

Data Storage level 1	3.Completeness	DS.1.3.1	Ensuring that the best possible national data for all sources are included, by setting down the reasoning behind the selection of datasets.

The data sources - in general - can be grouped as follows:

- Company specific environmental reports.
- Personal communication with individual companies.
- Company specific information compiled by Danish Energy Agency in relation to the EU-ETS.
- Industrial organisations.
- Statistics Denmark.
- SPIN database.
- Secondary literature.
- IPCC guidelines.

The environmental reports contribute with company-specific emission factors, technical information and, in some cases, activity data. The environmental reports are primarily used for large companies and, for some companies, are supplemented with information from personal contacts, especially for completion of the time series for the years before the legal requirement to prepare environmental reports (i.e. prior to 1996) and after the removal of the requirement (i.e. after 2014).

For reports from and personal contacts with industrial branches it is fundamental to have information from the industrial branches that have direct contact with the activities, e.g. chemicals and products of interest. The information can be in the form of personal communication, but also reported surveys are of great importance. In contrast to the more generic approach of collecting information from large databases, the expert information from industries may give valuable information on specific production processes, chemicals and/or products and industrial activities. By considering both sources a verification as well as optimum reliability and accuracy is obtained.

Statistics Denmark is often used as source for activity data as they are able to provide consistent data for the entire time series. In the cases where the statistics do not contain transparent data, statistics from industrial organisations are used to generate the required activity data. Statistics Denmark is used as the main database for collecting data on production, import and export of products, single chemicals, chemical groups and in some cases surrogate data. In order to obtain a uniform and unique set of data, it is important that the data for e.g. production of single chemicals is in the same reporting format and from the same source. The amount of data is very comprehensive and is linked with the data present in Eurostat whenever possible. The database covers all sectors and is regarded as complete on a national level.

Nordic SPIN database provides data on the use of chemicals in Norway, Sweden, Denmark and Finland. It is financed by the Nordic Council of Ministers, Chemical group, and the data is supplied by the product registries of the contributing countries. The Danish product register (PROBAS) is a joint register for the WEA and the EPA and comprises a large number of chemicals and products. The information is obtained from registration according to the EPA rules and from scientific studies and surveys and other relevant sources. The product register is the most comprehensive collection of chemical data in products for Denmark and with the availability of data from the other Nordic countries it enables an inter-country comparison. For each chemical the data is reported in a uniform way, which enhances comparability, transparency and consistency.

For some of the processes, the default emission factors are based on chemical equations (stoichiometric) and are, therefore, the best choice. In some cases, the default emission factor has been modified in order to reflect local conditions.

Secondary literature may be used in the interpretation or in disaggregation of the public statistics.

Regarding Non-energy products from fuels and solvent use, the present inventory procedure builds partly on information from the previous Danish solvent emission inventory, which is based on questionnaires to industrial branches. Furthermore, a joint Nordic collaboration on solvent inventories has given important information on methods and data.

Data Storage level 1	4.Consistency	DS.1.4.1	The original external data has to be archived with proper reference.

The original data files are archived in the following folder:

O:\Tech_ENVS-Luft-Emi\Inventory\2021\2_IPPU\Level_1a_Storage.

All data extracted from the internet (e.g. Statistics Denmark, SPIN, online PRTR) are saved as original copies in their original form. Specific information from industries and experts are saved as e-mails and reports.

Data Storage level 1	6.Robustness	DS.1.6.1	Explicit agreements between the external institution holding the data and NERI about the condition of delivery.

An agreement regarding inclusion of information - compiled by Danish Energy Agency for EU-ETS - in the Danish greenhouse gas inventory has been signed. The implementation of this information has been introduced for production of cement, lime production, glass production, glass wool production, bricks, expanded clay products, flue gas desulphurisation and stone wool production.

Data Storage level 1	7.Transparency	DS.1.7.1	Listing of all archived datasets and external contacts.

The datasets applied are presented in Table 4.10.1. For the reasoning behind their selection, see DS.1.3.1.

Table 4.10.1 Applied datasets (archived in: O:\Tech_ENVS-Luft-Emi\Inventory\2021\2_IPPU\Level_1a_Storage).

\Grønne regnskaber\	Ardagh Glass Holmegaard GR 2013
	Danisco Assens GR 2007
	Faxe Kalk GR 2013
	Haldor Topsøe GR 2012
	Kemira GR 2005
	Nordic Sugar Nakskov Miljøberetning 2012
	Nordic Sugar Nykøbing GR 2009
	Rockwool Miljøredegørelse 2013
	Saint-Gobain Isover GR 2014
	Stålvalseværket GR 2000
	Aalborg Portland 2019 Miljøredegørelse
\CO_2 kvote indberetninger\	Ceramics (folder with 17 files)
	Ardagh Glass Holmegaard EU-ETS
	Faxe Kalk EU-ETS
	Haldor Topsøe EU-ETS
	Isover EU-ETS
	Nordic Sugar Nakskov EU-ETS
	Rockwool Doense EU-ETS
	Rockwool Vamdrup EU-ETS
	Aalborg Portland EU-ETS
\Danmarks Statistik\	Afgrøder
	Animal feed
	Asphalt
	BBQ
	Beverages
	Bread
	Bricks and tiles
	Cast iron
	Catalysts
	Chemical ingredients
	Coffee
	Construction, road
	Construction, rådata
	Dolomite and lime
	Expanded clay
	Fats
	Fireworks
	Fløde
	Folketal
	Meat
	Paraffin wax
	Rødgods
	Slaughterhouse waste
	Soda ash
	Solvents
	Stenbrud og minedrift
	Stenuld
	Sugar production
	Tobacco

Data Processing level 1	1. Accuracy	DP.1.1.1	Uncertainty assessment for every data source not part of DS.1.1.1 as input to Data Storage level 2 in relation to type and scale of variability.

The uncertainty assessment has been performed on Approach 1 level, assuming a normal distribution of activity data as well as emission data, by application of default uncertainty factors. Therefore, no considerations regarding distribution or type of variability have been performed.

Data Processing level 1	2.Comparability	DP.1.2.1	The methodologies have to follow the international guidelines suggested by UNFCCC and IPCC.

All methodologies follow UNFCCC and IPCC unless better national methodologies have been identified.

Data Processing level 1	3.Completeness	DP.1.3.1	Identification of data gaps with regard to data sources that could improve quantitative knowledge.

This is discussed for each source category individually in the "Time series consistency and completeness" chapters.

Data Processing level 1	4.Consistency	DP.1.4.1	Documentation and reasoning of methodological changes during the time series and the qualitative assessment of the impact on time series consistency.

Recalculations are described in the chapter 4.11. A manual log is included in the tool used for data processing at Data Processing level 2. This log also includes changes on Data Processing level 1.

Data Processing level 1	5.Correctness	DP.1.5.2	Verification of calculation results using time series.

The calculations are verified by checking the time series.

Data Processing level 1	5.Correctness	DP.1.5.3	Verification of calculation results using other measures.

The calculation of results is verified using other measures where other measurements are available. Some are presented in the "Verification" sections, in the sector report (Hjelgaard & Nielsen, 2018) and some are only used internally.

Data Processing level 1	7.Transparency	DP.1.7.1	The calculation principle, the equations used and the assumptions made must be described.

The calculation principles and equations are based on the methodology presented by the IPCC. A detailed description can be found in the sector report for industrial processes and product use (Hjelgaard & Nielsen, 2018).

Data Processing level 1	7.Transparency	DP.1.7.2	Clear reference to dataset at Data Storage level 1

The calculation files contain links to the original data files.

Data Processing level 1	7.Transparency	DP.1.7.3	A manual log to collect information about recalculations.

A log on information about recalculation is included in CollectER.

Data Processing level 2	5.Correctness	DS.2.5.1	Check if a correct data import to level 2 has been made

The sector report for industrial processes and product use (Hjelgaard & Nielsen, 2018) presents the connection between the datasets on Data Storage level 1 and Data Processing level 2. Individual calculations are used to check the output of the data processing tool used at Data Processing level 2.

Data Storage level 4	4. Consistency	DS.4.4.3	The IEFs from the CRF are checked regarding both level and trend. The level is compared to relevant emission factors to ensure correctness. Large dips/jumps in the time series are explained.

The implied emission factors (IEFs) are checked by using a tool developed especially for that purpose and outliers are explained.

4.10.2 External QA/QC

External QA/QC is described for one source: cement production.

Cement production

Aalborg Portland has an environmental management system that meets the requirements in DS/ISO 14001, EMAS etc. (Aalborg Portland, 2013b). The environmental management system is part of an integrated process management system. The system is certified according to the standards by the accredited body: Danish Standards. Information on raw material consumption as well as internal recycling is compiled in an environmental database. Some pollutants (NO_x, SO_2, CO and TSP) are measured continuously. Emission of CO_2 is calculated based on (fuel and) raw material consumption and raw material flow according to an approved CO_2 emission plan (EU-ETS). The CO_2 emission plan has to fulfil the requirements in the guidelines developed by EU (EU Commission, 2018).

4.11 Recalculations

Table 4.11.1 shows recalculations of the CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 emissions. Emissions reported this year have been compared to emissions reported last year.

Table 4.11.1 Recalculations, %.

	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
CO_2	-8.43	2.36	NR	0.00002	0.03	-0.00002	0.12	0.05	-0.04	-0.11
CH_4	NA	NA	NA	NA	NA	NA	0.34	0.81	-3.19	-0.62
N_2O	NA	NA	NA	NA	NA	NA	0.01	0.02	0.01	0.03
HFCs		NA	NA	NA	NA	NA	NA	NA	NA	NA
PFCs		NA	NA	NA	NA	NA	NA	NA	NA	NA
SF_6		NA	NA	NA	NA	NA	NA	NA	NA	NA
GHG*	-9.3	-2.6	-3.9	-1.4	-1.7	-0.8	-0.7	-0.9	-0.9	-1.0

NA: Not Applicable
*In the total greenhouse gas recalculations are included the effect of the transition from AR4 to AR5 GWP values, this is not included for the individual pollutants or in sections 4.11.1 - 4.11.4.

The main recalculations are discussed for each sub-sector below.

4.11.1 Mineral industry

An error was corrected for cement production, resulting in decreased CO_2 emissions in 1990-1997.

Some previously unavailable data for 2016-2017 on flue gas cleaning are now available, resulting in an increase in CO_2 emissions from this source of in 2016-2020.

An update from Statistics Denmark results in recalculations for other soda ash for 2018-2020.

Table 4.11.2 Recalculations in Mineral industries, kt CO_2.

	1990	1991	1992	1993	1994	1995	1996	1997	2016	2017	2018	2019	2020
Cement production	-108	-95	-64	-63	-25	39	31	-31					
Flue gas desulphurisation									0.1	1.9	0.7	0.6	0.7
Other uses of soda ash											-0.001	0.003	-1.0
Total	-108	-95	-64	-63	-25	39	31	-31	0.1	1.9	0.7	0.6	-0.3

4.11.2 Chemical industry

The only recalculation made in Chemical industry, is a decrease of 24 kg CO_2 (+0.002 %) in 2019. This recalculation is a result of an update of data from Statistics Denmark.

4.11.3 Non-energy products from fuels and solvent use

The largest recalculations in this sub-category are made Paraffin wax use (2019-2020). Recalculations also occur for Solvent use (2019-2020), Urea based catalysts (2003-2020) and minor recalculations for Asphalt roofing (2019-2020). Changes made for Urea based catalysts are caused by the annual update of the traffic model, specifically the change in road work (total km driven) for heavy duty vehicles equipped with SCR catalysts. All other changes made in the Non-energy products from fuels and solvent use (2D) category, are related to updated activity data from Statistics Denmark.

Table 4.11.3 Recalculations in Non-energy products from fuels and solvent use, tonnes CO_2 equivalents.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2019	2020
Use of urea in catalysts	2.4	11.9	22.4	23.4	325	23.4	9.9	-90	13.4	-0.3	-1.6	-1.1	0.03	0.04
Paraffin wax use													-756	-1057
Asphalt roofing													-0.3	-0.04
Solvent use													-401	-213
Total	2.4	11.9	22.4	23.4	325	23.4	9.9	-90	13.4	-0.3	-1.6	-1.1	-1157	-1270

4.11.4 Other product manufacture and use

Recalculations were made due to updated activity data published by Statistics Denmark for 2017-2020 concerning the use of fireworks, tobacco and charcoal for barbequing. All of the recalculations are minor (maximum 0.08 kt CO_2 equivalents per year for the sum of all three categories).

Table 4.11.4 Recalculations in Other product manufacture and use, tonnes CO_2 equivalents.

	2017	2018	2019	2020
Charcoal for barbeques			-110.8	-33.7
Use of Fireworks			6.5	6.4
Use of Tobacco	10.4	25.1	20.8	22.9
Total	10.4	25.1	-83.5	-4.4

4.12 Improvements

4.12.1 Responses to the review process

The table below contains the recommendations of the most recent UNFCCC review of the Danish greenhouse gas inventory. The table details the status of implementation of the recommendations as well as references to where improvements have been implemented in this report.

A review of the Danish 2021 submission took place in September 2021. The table below lists the issues relevant for IPPU from the report from this most recent review.

Table 4.12.1 Recommendations of the most recent UNFCCC review of the Danish greenhouse gas inventory.

Para.	CRF	ERT Comment	Denmark's response	Reference
2021 submission (Review report: https://unfccc.int/sites/default/files/resource/arr2021_DNK.pdf)				
I.3	2.F.1 Refrigeration and air conditioning – HFCs	Investigate the reasons for the outlier values of the HFC-143a product manufacturing factor for commercial refrigeration reported for 2017–2018 and revise them, as necessary, providing a transparent explanation in the NIR if there continues to be significant inter-annual variation in the values reported.	The outliers are caused by different PMF being used for Denmark and Greenland. It has been further repeated in Chapter 4.7.1 that this Chapter 4 IPPU only describes emissions from Denmark	Chapter 4.7.1 Source category description
I.4	2.F.1 Refrigeration and air conditioning – HFCs	Ensure consistent reporting of the emissions from laboratory freezers in the CRF tables across the time series and include in the NIR an explanation on the methodology used and allocation of the emissions for this subcategory.	Laboratory freezers are allocated to 2.F.1.a Commercial refrigeration	Chapter 4.7.4 Refrigeration and air conditioning, Activity data
I.5	2.F.1 Refrigeration and air conditioning – HFC	Recalculate the emissions for the subcategory for 2010 onward by correcting the product manufacturing factor values used for the calculation of HFC-125 emissions from commercial refrigeration.	This will not be implemented. Further information on why the emission factor is lowered in 2010 has been added to this submission.	Chapter 4.7.4 Refrigeration and air conditioning, Emission factors
I.6	2.F.1 Refrigeration and air conditioning – HFCs	The Party reported in its NIR (p.354) and CRF table 2(II)B-Hs2 that according to Danish law, refrigerants must be emptied from refrigerators and air-conditioning equipment before decommissioning by recovering, reusing or destroying the remaining gases. It is reasonable to assume that this law is upheld in Denmark since waste collection is mandatory and there are no extra charges for getting rid of used equipment. In addition to recycling plants, where companies and individuals can take their waste, there is also a collection scheme where items such as used refrigerators are collected at the roadside to be disposed of. As a result, there is no reason why people would choose to illegally dispose of an appliance given that legal disposal is both free and easy. The amount of HFCs remaining in products at decommissioning was therefore reported as "NO" in the CRF table. During the review, the Party clarified that most of the waste from refrigerators and air-conditioning equipment is exported for treatment abroad (mainly in Germany) and only a small fraction is disposed of in Denmark (through incineration). The ERT noted that the estimations are likely not in accordance with equation 7.14 of the 2006 IPCC Guidelines (vol. 3, chap. 7) because there are emissions at the end of life of equipment. The ERT recommends that the Party estimate the amount of HFCs emitted during system disposal considering the destruction and removal efficiency of incinerators. Given that incinerators' destruction and removal efficiency is over 99.99 per cent for concentrated sources of ozone-depleting substances, the Party could justify the exclusion of emissions at disposal on the basis that they are insignificant and report "NE" instead of "NO". The ERT believes that future ERTs should consider this issue further to ensure that there is no underestimation of HFC emissions for this category.	This has been implemented	Chapter 4.7.4 Refrigeration and air conditioning, Completeness
I.7	2.F.2 Foam blowing agents – HFCs	The Party reported in its NIR (p.358) and CRF table 2(II)B-Hs2 that F-gases remaining in products at decommissioning (closed-cell products) are destroyed by incineration and hence there are no F-gas emissions related to the disposal of these products. "NO" was therefore reported. However, this is not in accordance with equation 7.7 from the 2006 IPCC Guidelines (vol. 3, chap. 7) because destruction by incineration produces some F-gas emissions owing to the destruction and removal efficiency of incinerators. During the review, the Party clarified that most waste from closed-cell products is exported for treatment (mainly in Germany) and only a small amount is disposed of in Denmark (through incineration). HFCs	This has been implemented	Chapter 4.7.5 Foam blowing agents, Completeness

Table 4.12.1 Recommendations of the most recent UNFCCC review of the Danish greenhouse gas inventory.				
Para.	CRF	ERT Comment	Denmark's response	Reference
		are categorized as hazardous waste under national waste legislation (executive order 2159 of 9 December 2020) and hence there are strict requirements for the collection and disposal of this waste type. The ERT recommends that the Party estimate the amount of HFCs emitted during the decommissioning process considering the destruction and removal efficiency of incinerators. Given that incinerators' destruction and removal efficiency is over 95 per cent for diluted sources of ozone-depleting substances, the Party could justify the exclusion of emissions from the decommissioning process on the basis that they are insignificant and report "NE" instead of "NO". The ERT believes that future ERTs should consider this issue further to ensure that there is no underestimation of HFC emissions for this category.		

4.12.2 Planned improvements

There are currently no planned improvements for the greenhouse gas inventory for industrial processes and product use.

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5 Agriculture

The data presented in Chapter 5 relate to Denmark only, whereas information for Greenland is included in Chapter 11 and for the Faroe Islands in Chapter 12.

The emission of greenhouse gases from agricultural activities includes:

- CH_4 emissions from enteric fermentation, manure management and field burning
- N_2O emissions from manure management, agricultural soils and field burning
- CO_2 emissions from liming, urea use and use of other carbon-containing fertilisers

For emissions of air pollutants covered by the NEC Directive or the UNECE LRTAP Convention, see the Danish Informative Inventory Report (Nielsen et al., 2022).

Emissions from rice production and burning of savannahs do not occur in Denmark and consequently these categories have been reported as Not Occurring.

5.1 Overview of sector

In CO_2 equivalents, the agricultural sector contributes with 28 % of the Danish greenhouse gas emissions (GHG) in 2021 excl. LULUCF. Next to the energy sector, the agricultural sector is the largest source of GHG emission in Denmark. The majority of agricultural greenhouse gas emissions are covered by N_2O and CH_4, which contributes in 2021 with 89 % and 81 % respectively of the total Danish emissions of N_2O and CH_4.

From 1990 to 2021, the emissions decreased from 13.8 million tonnes CO_2 equivalent to 12.1 million tonnes CO_2 equivalent, which corresponds to a 13 % reduction (Table 5.1). CH_4 is the largest contributor to the overall agricultural greenhouse gas emission, accounting for 60 % in CO_2 equivalents in 2021. The decrease in the total agricultural emission is mainly caused by a decrease in N_2O emission, while the CH_4 emission is nearly unaltered.

Table 5.1 Emission of GHG in the agricultural sector in Denmark 1990 – 2021.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
CH_4, kt CO_2 eqv.	7 013	7 354	7 315	7 379	7 289	7 171	7 273	7 087	7 257	7 209
N_2O, kt CO_2 eqv.	6 270	5 566	5 092	4 831	4 640	4 682	4 629	4 807	4 877	4 590
CO_2, kt CO_2 eqv.	613	534	268	222	156	176	244	185	254	276
Total, kt CO_2 eqv.	13 896	13 453	12 674	12 432	12 085	12 029	12 146	12 079	12 389	12 074

The major part of the emission is related to livestock production, which in Denmark is dominated by the production of cattle and swine.

Figure 5.1a-b shows the distribution of N_2O and CH_4 emissions across the main agricultural sources. The total N_2O emission from 1990-2021 has decreased by 27 % and can largely be attributed to the decrease in N_2O emissions from agricultural soils. This reduction is due to a proactive national environmental policy over the last thirty years to prevent loss of nitrogen from agricultural soil to the aquatic environment. The emission from agricultural soil is based on emission from a range of sources, where emission from inorganic fertiliser, animal manure applied to soil and organic soils are the most important emission sources. The main reason for the decrease is a strong decrease in use of inorganic fertiliser. In 2016, 2017, 2019 and 2020 is seen an increase in use of inorganic fertiliser which increases the emission of N_2O from agricultural soils. In 2018, the emission decreases due to decrease in emission from inorganic fertiliser mainly due exceptional weather conditions this year. The higher amount of used N in inorganic fertiliser in 2016, 2017, 2019 and 2020 is caused by a political agreement on Food and Agricultural package, adopted in December 2015 (MEFD, 2017). The purpose of the agreement was to establish better framework conditions for the agricultural production, to ensure opportunities for economic growth and increased exports and increased employment in interaction with nature and the environment. This agreement made it legally possible to use more nitrogen for some areas. I 2021 the emission decreases mainly due to decrease in emission from inorganic fertiliser, manure applied to soil and crop residue.

The CH_4 emissions from 1990 to 2021, shown in Figure 5.1b, indicate a decrease in emission from enteric fermentation, which is mainly due to a decrease in the number of cattle. A contrasting development has taken place in emission from manure management. Structural changes in the sector have led to a move towards the use of slurry-based housing systems, which have a higher emission factor than systems with solid manure. The decrease and the increase almost balance each other out and the total CH_4 emission from 1990 to 2021 has increased 3 %.

CO_2 emissions from liming and inorganic N-fertiliser has decreased by 55 % from 1990 to 2021, mainly due to decrease in emission from liming. The decrease in use of lime is due to change in fertiliser practice where the use of inorganic N-fertiliser has decreased and use of N from manure has increased (Knudsen, 2004).

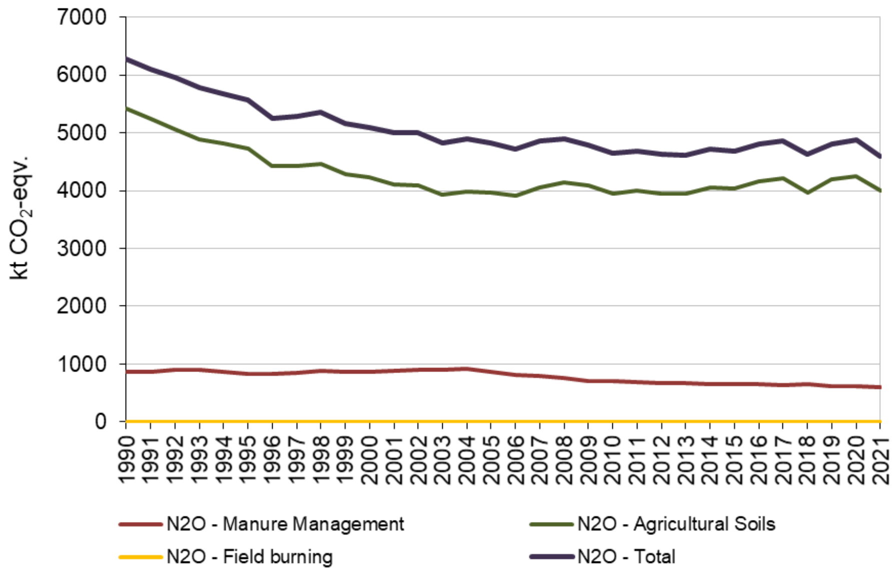

Figure 5.1a Danish agricultural N_2O emissions 1990 – 2021.

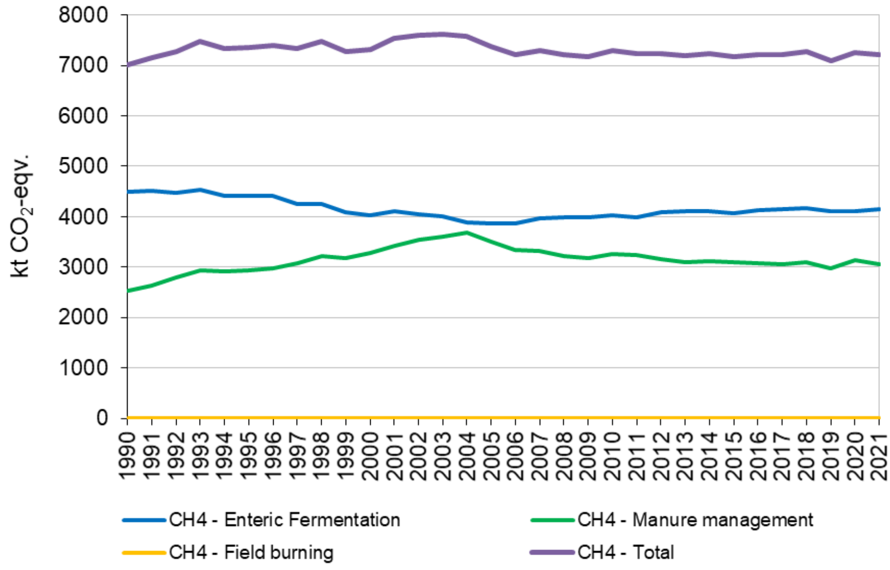

Figure 5.1b Danish agricultural CH_4 emissions 1990 – 2021.

5.1.1 Methodology overview, tier

Table 5.2 shows the methodology and emission factor used at subcategory level.

Table 5.2 Overview for methodology and emission factor used.

CRF code	Category	Substance	Tier[1)]	EF[2)]
3A	Enteric fermentation:			
3A1a	Dairy cattle	CH_4	Tier2	CS
3A1b	Non-dairy cattle	CH_4	Tier2	D
3A2	Sheep	CH_4	Tier2	D
3A3	Swine	CH_4	Tier2	OTH
3A4	Other livestock - deer	CH_4	Tier2	D
	Other livestock – goats	CH_4	Tier2	D
	Other livestock - horses	CH_4	Tier2	OTH
	Other livestock - poultry	CH_4	Tier1	OTH
	Other livestock – other[3]	CH_4	Tier1	OTH
3B	Manure management:			
3B1a	Dairy cattle	CH_4	Tier2/CS	CS
3B1b	Non-dairy cattle	CH_4	Tier2/CS	CS
3B2	Sheep	CH_4	Tier2/CS	D
3B3	Swine	CH_4	Tier2/CS	CS
3B4	Other livestock - deer	CH_4	Tier2/CS	D
	Other livestock – goats	CH_4	Tier2/CS	D
	Other livestock - horses	CH_4	Tier2/CS	D
	Other livestock - poultry	CH_4	Tier2/CS	D
	Other livestock – other[3]	CH_4	Tier2/CS	D
3B	Manure management:			
3B1a	Dairy cattle	N_2O	Tier2/CS	D
3B1b	Non-dairy cattle	N_2O	Tier2/CS	D
3B2	Sheep	N_2O	Tier2/CS	D
3B3	Swine	N_2O	Tier2/CS	D
3B4	Other livestock - deer	N_2O	Tier2/CS	D
	Other livestock – goats	N_2O	Tier2/CS	D
	Other livestock - horses	N_2O	Tier2/CS	D
	Other livestock - poultry	N_2O	Tier2/CS	D
	Other livestock – other[3]	N_2O	Tier2/CS	D
3B5	Indirect N_2O emission	N_2O	Tier2/CS	D
3D	Agricultural soil:			
3Da1	Inorganic N fertilisers	N_2O	Tier1/CS	D
3Da2a	Animal manure applied to soils	N_2O	Tier2	D
3Da2b	Sewage sludge applied to soils	N_2O	Tier1/CS	D
3Da2c	Other organic fertiliser applied to soils	N_2O	Tier1/CS	D
3Da3	Urine and dung deposited by grazing animals	N_2O	Tier2	D
3Da4	Crop residue	N_2O	Tier1/CS	D
3Da5	Mineralization	N_2O	Tier2	D
3Da6	Cultivation of organic soils	N_2O	Tier1	D
3Db1	Atmospheric deposition	N_2O	Tier2	D
3Db2	Nitrogen leaching and run-off	N_2O	Tier2	D
3F	Field burning of agricultural residues	CH_4	Tier1	D
3F	Field burning of agricultural residues	N_2O	Tier1	D
3G	Liming	CO_2	Tier1*	D*
3H	Urea application	CO_2	Tier1*	D*
3I	Other carbon-containing fertilisers	CO_2	Tier1*	D*

[1]Tier 1 and T2: IPCC (2019) default, *IPCC (2006) default, CS: Country specific.

[2]D: IPCC (2019) default, *IPCC (2006) default, CS: Country specific. OTH: Other.

[3]Ostrich, pheasants, fur bearing animals.

5.1.2 Key category identification

The key category analysis (KCA) divides the agricultural emissions into 19 subcategories. Table 5.3 lists the KCs covering Approach 1 and Approach 2. Approach 1 only gives key category identification based on the quantitative emission, while Approach 2 also includes the uncertainties (refer to Chapter 1.5). In 1990, 10 of the 19 agricultural sources were identified as key categories and 13 sources were key categories if uncertainties were taken into account (Approach 2). In 2021, six of the sources are listed as key categories according to level and trend for Approach 1 and 11 sources in Approach 2. For the methodological choice, Denmark uses the key categories identified using both Approach 1 and Approach 2 for the latest year as well as key categories identified for the trend from 1990 to the latest year.

The two key categories with the highest emissions are CH_4 from enteric fermentation and CH_4 emissions from manure management. Regarding the enteric fermentation, the cattle production is the main contributor, while the swine production is the most important category for manure management.

Table 5.3 Key category identification Tie1 and Tier 2 from the agricultural sector 1990 and 2021.

CRF table	Compounds	Emission source	Key category identification	
2021			Approach 1	Approach 2
3.A	CH_4	Enteric fermentation	Level/trend	Level/trend
3.B	CH_4	Manure management	Level/trend	Level/trend
3.F	CH_4	Field burning of agri. residues	-	-
3.B	N_2O	Manure management	Level/trend	Level/trend
3.B.5	N_2O	Atmospheric deposition	-	Level
3.Da.1	N_2O	Inorganic N fertilisers	Level	Level/trend
3.Da.2a	N_2O	Animal manure applied to soils	Level/trend	Level/trend
3.Da.2b	N_2O	Sewage sludge applied to soils	-	Trend
3.Da.2c	N_2O	Other organic fertiliser applied to soils	-	Level/trend
3.Da.3	N_2O	Urine and dung deposited by grazing animals	-	Level
3.Da.4	N_2O	Crop residue	Level/trend	Level/trend
3.Da.5	N_2O	Mineralization	-	Level/trend
3.Da.6	N_2O	Cultivation of organic soils	Level/trend	Level/trend
3.Db.1	N_2O	Atmospheric deposition	Level	Level/trend
3.Db.2	N_2O	Nitrogen leaching and run-off	Level	Level
3.F	N_2O	Field burning of agri. residues	-	-
3.G	CO_2	Liming	Level	Level/trend
3.H	CO_2	Urea application	-	-
3.I	CO_2	Other carbon-containing fertilisers	-	-
1990				
3.A	CH_4	Enteric fermentation	Level	Level
3.B	CH_4	Manure management	Level	Level
3.F	CH_4	Field burning of agri. residues	-	-
3.B	N_2O	Manure management	Level	Level
3.B.5	N_2O	Atmospheric deposition	-	Level
3.Da.1	N_2O	Inorganic N fertilisers	Level	Level
3.Da.2a	N_2O	Animal manure applied to soils	Level	Level
3.Da.2b	N_2O	Sewage sludge applied to soils	-	-
3.Da.2c	N_2O	Other organic fertiliser applied to soils	-	-
3.Da.3	N_2O	Urine and dung deposited by grazing animals	-	Level
3.Da.4	N_2O	Crop residue	Level	Level
3.Da.5	N_2O	Mineralization	-	Level
3.Da.6	N_2O	Cultivation of organic soils	Level	Level
3.Db.1	N_2O	Atmospheric deposition	Level	Level
3.Db.2	N_2O	Nitrogen leaching and run-off	Level	Level
3.F	N_2O	Field burning of agri. residues	-	-
3.G	CO_2	Liming	Level	Level
3.H	CO_2	Urea application	-	-
3.I	CO_2	Other carbon-containing fertilisers	-	-

5.2 Data sources

The calculated emissions are based on methods described in the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) and 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019).

Activity data and emission factors are collected and discussed in cooperation with specialists and researchers in various institutes with agricultural expertise, such as the DCA - Danish Centre for Food and Agriculture – Aarhus University, Statistics Denmark, SEGES, the Danish Agricultural Agency, the Danish Environmental Protection Agency and the Danish Energy Agency. In this way, both data and methods will be evaluated continually, according to the latest knowledge and information. DCE - Danish Centre for Environment and Energy, Aarhus University has established data agreements with the institutes and organisations to assure that the necessary data are available to prepare the emission inventory on time.

Table 5.4 List of institutes involved in the emission inventory for the agricultural sector.

References	Link	Abbreviation	Data/information
Statistics Denmark – Agricultural Statistics	www.dst.dk	DSt	- livestock production - milk yield - slaughtering data - export of live animal - poultry - land use - crop production - crop yield
Danish Centre for Food and Agriculture, Aarhus University	www.dca.au.dk	DCA	- N-excretion - feeding situation - animal growth - use of straw for bedding - N-content in crops - modelling of data regarding N-leaching/runoff - NH_3 emissions factor
SEGES	www.seges.dk	SEGES	- housing type (until 2004) - grazing situation - manure application time and methods - estimation of extent of field burning of agricultural residue - acidification of slurry
Danish Environmental Protection Agency	www.mst.dk	EPA	- sewage sludge used as fertiliser (until 2004) - industrial waste used as fertiliser
The Danish Agricultural Agency	www.lbst.dk	DAA	- inorganic N fertiliser (consumption and type) - housing type (from 2005) - sewage sludge used as fertiliser (from 2005 based on the register for fertilization) - number of animals from the Central Husbandry Register
The Danish Energy Agency	www.ens.dk	DEA	- manure delivered to biogas plants

The emissions from the agricultural sector are calculated in a comprehensive agricultural model complex called IDA (Integrated Database model for Agricultural emissions). The model complex is designed in a relational database system (MS Access). Input data are stored in tables in one database called IDA_Backend and the calculations are carried out as queries in another linked database called IDA. This model complex, as shown in Figure 5.2, is implemented in great detail and is used to cover emissions of air pollutants and greenhouse gases. Thus, there is a direct link between the NH_3 emission and the emission of N_2O.

IDA - Integrated Database model for Agricultural emissions

Data collection, processing and preparing

Data collected from:

- Statistics Denmark
- Danish Centre for Food and Agriculture, Aarhus University
- SEGES
- Danish Environmental Protection Agency
- The Danish Agricultural Agency
- The Danish Energy Authority

↓

IDA-backend

Variables:

Animals	Number Housing type distribution N-excretion Amount of straw Days on grass Amount of feed Amount of manure
Crops	Area
Inorganic fertiliser	Amount of N and of product
N-leaching and run-off	Amount of N
Sewage sludge and industrial waste used as fertiliser	Amount of N
Crop residue	Amount of N
Organic soils	Area
Field burning of agricultural residues	Amount of burnt straw
Mineralisation	Amount of N
Pesticides	Amount of product
Liming	Amount of lime
All	Emission factors

↓

IDA

Emission calculations of:

- CH_4
- N_2O
- NH_3
- PM
- NMVOC
- CO
- HCB
- NO_x
- SO_2
- Heavy metals
- PAHs
- Dioxin
- CO_2
- PCB
- BC

→

CRF and NFR templates

Output:

Emissions and additional information required in the template.

Figure 5.2 IDA - Integrated Database model for Agricultural emissions.

Most emissions relate to livestock production, which is based on information on the number of animals, the distribution of animals according to housing type and, finally, information on feed consumption and excretion.

IDA operates with 42 different livestock categories, according to livestock type, weight class and age. These categories are subdivided into housing type and manure type, which results in 288 different combinations of livestock subcategories and housing types (see Annex 3D Table 3D-1). For each of these combinations, information on e.g. feed intake, digestibility, excretion and grazing days is included. The emission is calculated from each of these subcategories and then aggregated in accordance with the IPCC livestock categories given in the CRF.

Table 5.5 Livestock categories and subcategories.

CRF 3B	Aggregated livestock categories as given in IPCC	Includes	No. of subcategories in IDA, animal type/housing system
3B 1a	Dairy Cattle[1]	Dairy Cattle	40
3B 1b	Non-dairy Cattle[1]	Calves (<½ yr), heifers, bulls, suckling cattle	129
3B 2	Sheep	Sheep and lambs	2
3B 3	Swine	Sows, weaners, fattening pigs	52
3B 4	Deer		1
	Goats	Including kids (meet, dairy and mohair)	3
	Horses	<300 kg, 300 - 500 kg, 500 - 700 kg, >700 kg	4
	Poultry	Hens, pullets, broilers, turkeys, geese, ducks	43
	Fur-bearing animals	Mink and foxes	8
	Ostriches	Mother ostriches, chickens	4
	Pheasants	Hens, chickens	2

1) For all subcategories, large breed and jersey cattle are distinguished from each other.

It is important to point out that changes over the years, both to the national emission and the implied emission factor, are not only a result of changes in the numbers of animals, but also depend on changes in the allocation of subcategories, changes in feed consumption and changes in housing type.

5.2.1 Number of animals

Livestock production is primarily based on the agricultural census from Statistics Denmark (DSt). For many animal categories, the number given in the annual Agricultural Statistics can be used directly. However, for weaners, fattening pigs, bulls and poultry the number is based on slaughter data also collected from the Agricultural Statistics. This is because the production cycle for these animals is under one year and the normative figures are based on produced animals.

Only farms larger than five hectares are included in the annual census from Statistics Denmark. Especially horses, goats and sheep are placed on small farms, which mean that the number of animals given in the Agricultural Statistics is not representative (underestimates the actual animal population). Therefore, the number of sheep and goats is based on the Central Husbandry Register (CHR), which is the central register of farms and animals managed by the Ministry of Environment and Food of Denmark. From 2010, the annual census includes farms with more than 20 goats and sheep, but the CHR is considered as more reliable because the register include all animals regardless of farm size. The number of horses is based on data from SEGES (Holm, 2022).

The number of deer and ostriches is also based on CHR because these are not included in the Agricultural Statistics published by Statistics Denmark. The number of pheasants is based on expert judgement from Department of Ecoscience, Aarhus University and the Danish pheasant breeding association (Stenkjær, 2010, pers. comm.).

The agricultural annual census in present form goes back to 1977 (DSt, 2010). The survey has taken place every year as a questionnaire based survey, where the farmer has received a questionnaire in a letter with an obligation to complete it. The questionnaire has varied from year to year depending on EU requirements and national needs. From 1977 to 1983, the survey was based on total censuses where all farms where included, which also is the case for the years; 1985, 1987, 1989, 1999 and 2010. The remaining surveys is based on sample surveys; 1984, 1986, 1988, 1990-98, 2000-09 and 2011-21 and include around 20-35 % of all farms and around 50 % of the farms in 2003, 2005 and 2007.

As soon as the data from the questionnaires are processed, tested and quality assured, the data are published annually at Statistics Denmark's homepage; http://www.statistikbanken.dk and are available in both English and Danish.

Annex 3D Table 3D-2 provides number of animals allocated on all livestock subcategories.

5.2.2 Housing type

From 2005, all farmers have to report to the Danish Agricultural Agency (DAA) information concerning the housing type. Annex 3D Table 3D-1 shows the housing types for each livestock category for the years 1990 – 2021.

Before 2005, there exists no official statistics, which cover the distribution of animals according to housing type. Therefore, the distribution is based on an expert judgement from SEGES and DCA (Rasmussen, 2006, Lundgaard 2006). Approximately 90-95 % of Danish farmers are members of SEGES, which regularly collects statistical data from the farmers on different issues, as well as making recommendations with regard to farm buildings. Hence, SEGES has a good understanding of which housing types that are currently in use and also the changes over time.

5.2.3 NH_3 reducing technology

NH_3 reducing technology in housings and storage has been taken in to account in the emission calculations. The technologies included are acidification in housings with cattle and swine, cooling of swine manure in housings, frequent removal of manure in fur animal housings, heat exchangers in housing of broilers and solid cover of manure tanks.

Reducing of NH_3 emission in housing and storage increase the amount of N in storage and for application, which increase the emission of N_2O from agricultural soils.

No possible reduction in CH_4 emissions, because of NH_3 reducing technology, is taken in to account.

5.2.4 Feed consumption and manure excretion

The DCA provide Danish standards related to feed consumption, excreted volumes, nutrient content of nitrogen, phosphor and potassium, dry matter in manure and contribution of different manure type. These standards are all a part of the "Danish Normative System", which is used for fertiliser planning and control by the Danish farmers and authorities (Børsting et al., 2021, Børsting & Hellwing, 2022). The complexity and dynamics of the system has increased during the years to secure the development of accurate values. Furthermore, the normative system includes emission factors for NH_3, which is based on a combination of measurements and model calculations. Emission factors for NH_3 from the housing unit and storage are given in Annex 3D Table 3D-3 (a-d) and 3D-4.

The Danish normative standards are based on practical farming and thus reflect the actual Danish agricultural production conditions. DCA receive data from SEGES, which is the central office for all Danish agricultural advisory services. SEGES carries out a considerable amount of research itself, as well as collecting efficacy reports from the Danish farmers for dairy production, meat production, pig production, etc., to optimise productivity in Danish agriculture. Feeding plans are used to provide values to the Danish Normative System and for dairy cows; the values are based on approximately 800 feeding plans. In total the normative standards covers feed plans from 15-18 % of the Danish dairy production, 25-30 % of the pig production, 80-90 % of the poultry production and approximately 100 % of the fur production. A high fraction of the pig production is represented, which is caused by the intensive focus on the possibilities to optimize the feed intake to increase the feed efficiency. The values covering the cattle production can be considered as reliable, even though only 15-18 % of the productions are represented. These values include mainly feeding plans from the farmers with a production efficiency corresponding to a middle level. The farmers with a high productivity level are often not users of SEGES, which also is the case for farmers with a low productivity level.

Previously, the normative standards were updated and published every third or fourth year (Laursen, 1987; Laursen, 1994; Poulsen and Kristensen, 1997). From 2001, these standards are updated annually and available to download at the homepage of DCA:
http://anis.au.dk/forskning/sektioner/husdyrernaering-og-fysiologi/normtal/ (Dec. 2022).

One of the reports concerning the normative data is published in English in Poulsen and Kristensen (1998) and is available at the homepage of DCA, see list of references. The latest edition of the report are Børsting et al. (2021) (in Danish). The normative data are updated every year.

5.3 Enteric fermentation

5.3.1 Description

The major part of the agricultural CH_4 emission originates from digestive processes. In 2021, this source accounts for 34 % of the total GHG emission from agriculture. The emission is primarily related to ruminants and, in Denmark, particularly to cattle, which, in 2021, contributed with 86 % of the emission from enteric fermentation. The emission from swine production is the second largest source and covers 10 % of the emission from enteric fermentation, followed by horses (3 %) and sheep, goats, deer and poultry (1 %).

From 1990 to 2021, the emission from enteric fermentation has overall decreased by 8 %, which is primarily related to a decrease in the number of cattle, combined with increase in milk yield and gross energy (GE) for dairy cattle. The number of swine has increased from 9.5 million in 1990 to 13.2 million in 2021, but this increase is only of minor importance in relation to the total CH_4 emission from enteric fermentation. The emission where lowest in 2005 but have increased slightly until 2020, mainly due to a slightly increase in emission from cattle.

5.3.2 Methodological issues

The methodology for estimating emissions from enteric fermentation is based on 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019). The methodology for poultry, ostrich and pheasants is based on Tier 1, while the remaining animal categories are based on a Tier 2/Country Specific (CS) approach. CH_4 emission from enteric fermentation from fur farming is considered to be non-applicable based on country-specific information (Hansen, 2010, pers. comm.) and therefore the notation key NA are used for fur-bearing animals in CRF for enteric fermentation. Feed consumption for all animal categories is based on the Danish normative figures. Default values for the methane conversion rate (Y_m) given by the IPCC are used for all livestock categories, except for dairy cattle, where a national Y_m is used for all years.

Tier 1

Emission factors used for poultry, ostrich and pheasants are based on the emission factors given by Wang & Huang (2005). EF for broilers with a life cycle of 30-56 days is scaled in proportion to 42 days for broilers given by Wang & Huang (2005). Organic broilers with a life cycle of 81 days are scaled in proportion to the Taiwan country chicken with 91 days of life cycle and pullets with a life cycle of 112-119 days are scaled in proportion to the 140 days given for pullets by Wang & Huang (2005). EF for ducks, geese, turkeys, ostrich chickens and pheasant chickens is scaled by weight in proportion to a Danish broiler with 40 days of life cycle. For laying hens, the EF given by Wang & Huang (2005) is used and for ostrich hens and pheasant hens, the EF is scaled by weight in proportion to a laying hen. All EFs for CH_4 from enteric fermentation for poultry are shown in Annex 3D Table 3D-5.

Tier 2

The Tier 2/CS equation for EF of enteric fermentation is the sum of the feeding situation in winter and summer. The EF is based on actual feeding plans, which is provided from data for feed units (FU) in the feed for each livestock category. Except from dairy cattle, where the EF is based on kg dry matter (DM) in the feed. For dairy cattle, feeding with sugar beets is taken into account, because sugar beet feeding gives a higher methane production rate compared to grass and maize due to the high content of easily convertible sugar. However, it is only dairy cattle, which have sugar beets in the feed. The parts of the equation concerning sugar beet will be left out for the remaining animal categories.

$$EF = EF_{winter} + EF_{summer}$$

Dairy cattle:

$$EF_{winter,dairy\ cattle} = F \cdot \Big((GE_{F\ winter}/55.65) \cdot Y_{m\ excl\ beet} \cdot (1 - grazing\ days/365 - days\ with\ beet/365) + (GE_{F\ winter}/55.65) \cdot Y_{m\ incl\ beet} \cdot days\ with\ beet/365 \Big)$$

$$EF_{summer,dairy\ cattle} = F \cdot \left(\frac{GE_{F\ summer}}{55.65}\right) \cdot Y_{m\ grazing} \cdot \frac{grazing\ days}{365}$$

Where:

EF_{winter} = Emission factor for winter feed, kg CH_4 per head per year
EF_{summer} = Emission factor for summer feed, kg CH_4 per head per year

F	= feed, kg DM
$GE_{F,winter}$	= gross energy per kg DM, MJ per kg DM in winter
$GE_{F, summer}$	= gross energy per kg DM, MJ per kg DM in summer
Y_m	= methane conversion factor, per cent of gross energy in feed converted to methane
55.65	= energy content of CH_4, MJ per CH_4

Other animals:

$$EF_{winter} = FU \cdot \left(\left(\frac{GE_{FUwinter}}{55.65} \right) \cdot Y_m \cdot \left(1 - \frac{grazing\ days}{365} \right) \right)$$

$$EF_{summer} = FU \cdot \left(\frac{GE_{FU\ summer}}{55.65} \right) \cdot Y_{m\ grazing} \cdot \frac{grazing\ days}{365}$$

Where:

EF_{winter}	= Emission factor for winter feed, kg CH_4 per head per year
EF_{summer}	= Emission factor for summer feed, kg CH_4 per head per year
FU	= feeding units
$GE_{FU,winter}$	= gross energy per feeding unit, MJ per FU in winter
$GE_{FU, summer}$	= gross energy per feeding unit, MJ per FU in summer
Y_m	= methane conversion factor, per cent of gross energy in feed converted to methane
55.65	= energy content of CH_4, MJ per CH_4

Thus, to calculate the total gross energy (GE) intake, the GE per kg DM or GE per feed unit – defined as GF_F or GE_{FU}, respectively – needs to be estimated. A feed unit in Denmark is defined as the feed value in 1.00 kg barley with a dry matter content of 85 % (DSt, 2010). For other cereals, e.g. wheat and rye one feed unit is 0.97 kg and 1.05 kg, respectively.

Gross energy intake

GE_F for dairy cattle are estimated by DCA (Aaes, 2016, pers. comm.). From 2014 feed intake for dairy cattle given in the normative figures are given in kg DM per year and the energy in the feed is given in MJ per kg DM. The energy intake is a standard winter feed regardless of whether the animal grazes or not. As recommended by previous expert review teams, the feed intake and energy in the feed for the years 1990-2013 is recalculated. Previous the calculation was based on FU for the years 1990-2013, which is now replaced by the calculation based on DM for all years. See Annex 3D Table 3D-10 for time series for GE for dairy cattle.

For all other livestock categories than dairy cattle, the estimation of GE is GE_{FU}. GE_{FU} is based on the composition of feed intake and the energy content in proteins, fats and carbohydrates based on actual efficacy feeding controls or actual feeding plans at farm level, collected by SEGES or DCA. The data are given in Danish feed units or kg feedstuff and these values are converted to mega joule (MJ). The calculation is shown in the equation below:

$$GE_{FU} = \frac{MJ/day}{FU/day}$$

$$FU/day = \frac{kg\ dm}{day} \cdot \frac{FU}{kg\ dm}$$

$$\text{MJ/day} = \frac{\text{kg dm}}{\text{day}} \cdot \frac{\text{MJ}}{\text{kg dm}}$$

$$\text{MJ/kg dm} = \%_{\text{Crude protein}} \cdot E_{\text{Crude protein}} + \%_{\text{Crude fat}} \cdot E_{\text{Crude fat}} + \%_{\text{Carbonhydrates}} \cdot E_{\text{Carbonhydrates}}$$

$$\%_{\text{Carbonhydrates}} = 100 - (\%_{\text{Crude protein}} + \%_{\text{Crude fat}} + \%_{\text{Raw ashes}})$$

Where:

GE_{FU}	= gross energy per feed unit, MJ per FU
FU	= feed unit
MJ	= mega joule
DM	= dry matter
$\%_{\text{crude protein}}$	= share of crude protein in the feed, %
$E_{\text{crude protein}}$	= energy factor for crude protein, 24.24 MJ per kg DM
$\%_{\text{raw fat}}$	= share of crude fat in the feed, %
$E_{\text{raw fat}}$	= energy factor for crude fat, 34.12 MJ per kg DM
$\%_{\text{carbohydrates}}$	= share of carbohydrates in the feed, %
$E_{\text{carbohydrates}}$	= energy factor for carbohydrates, 17.30 MJ per kg DM
$\%_{\text{raw ashes}}$	= share of raw ashes in the feed, %

For horses, heifers, suckling cattle, sheep and goats an average winter feed plan is provided based on information from DCA and SEGES on which the calculation of the GE content is based. Feeding conditions for deer is comparable with goats, why the GE for deer is based on feed plans for goats. In Annex 3D Table 3D-6 and 3D-7 are listed all parameters for winter feeding plans covering the amount of proteins, fats and carbohydrates in the feed, FU per kg, kg dry matter per day and MJ per day. Annex 3D Table 3D-8 and 3D-9 provides additional information about feed intake given in FU and grazing days for each livestock category.

Estimation of $GE_{FU,\ summer}$ covers the time where animals are grazing.

Table 5.6 GE per feeding unit, MJ per FU.

	$GE_{FU,winter}$	$GE_{FU,summer}$
Calves and bulls	18.3	18.8
Heifers	25.8	18.8
Suckling cattle	34.0	18.8
Sows	17.5	17.5
Weaners	16.5	16.5
Fattening pigs	17.3	17.3
Horses, sheep, goats and deer	30.0	18.8

In Annex 3D, Table 3D-11, the annual average feed intake given in GE as MJ per day is shown, from 1990 to 2021, for each livestock category. As seen in Annex 3D Table 3D-11, GE for heifers increases from 2005 to 2007. In 2007, new estimations and measurements received from DCA shows that the GE for heifers differs from the previous estimates. This development is not caused by a single year change in feed intake but due to changes in feed practice during some years. Therefore, interpolation of GE for heifers was chosen from year 2004 to 2007 to avoid a significant jump from 2006 to 2007. The GE for non-dairy cattle is an average of GE for calves, heifers, bulls and suckling cattle. However, heifers are the most important subcategory and thus affect the weighed GE average for non-dairy cattle, which also increases from 2004 to 2007.

The Tier2/CS for enteric fermentation differs from the IPCC Tier 2 in the calculation of GE. A comparison between these two methods is shown in Chapter 5.13.1.

Methane conversion rate (Y_m)

For dairy cattle, investigations from DCA have shown a change in fodder practice over the years where among others change in fodder practice from use of sugar beet to maize (whole cereal) is seen. Sugar beet feeding gives a higher methane production rate compared to grass and maize due to the high content of easily convertible sugar.

The estimation of the national values of Y_m is for the years 1990-2002 based on the model "Karoline" developed by DCA and based on average feeding plans for 20 % of all dairy cows in Denmark obtained from SEGES (Olesen et al., 2005). DCA have estimated the CH_4 emission for a winter feeding plan for two years, 1991 (Y_m=6.7) and 2002 (Y_m=6.0). Y_m for the years between 1991 and 2002 are estimated by interpolation. Sugar beets are only included in the winter feeding plan and the Y_m is therefore also adjusted for days on winter and summer feeding plan. It is assumed that winter feeding plan covers 200 days. See Table 5.7a.

New measurements (Hellwing et al., 2016) have developed an updated model for estimating a national Y_m. Based on this updated model and fodder practice were rations with sugar beet are phased out, the Y_m value for dairy cattle are kept at 6.00 from 2002 to 2017 (Lund, pers. comm., 2014). See Table 5.7b.

For 2018 and 2020 the updated model have been run with updated fodder practice and Y_m has been estimated for large breed and jersey cows, respectively (Lund et al., 2020, Lund et al., 2021) – see Table 5.7c. Y_m for 2019 are kept at the same level as for 2018 and Y_m for 2021 are kept at the same level as for 2020.

For non-dairy cattle, sheep and goats, Y_m given in IPCC (2019) are used. For lamp a Y_m are given in IPCC (2006). For swine and horses Y_m are based on Crutzen et al. (1986). See Table 5.8.

Table 5.7a CH_4 conversion rate (Y_m) 1990-2001, based on model Karoline, fodder practice with sugar beet, %

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Y_m incl. sugar beet	6.7	6.7	6.6	6.6	6.5	6.4	6.4	6.3	6.3	6.2	6.1	6.1
Y_m excl. sugar beet	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Y_m grazing	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Average Y_m	6.4	6.4	6.3	6.3	6.3	6.2	6.2	6.2	6.1	6.1	6.1	6.0

Table 5.7b CH_4 conversion rate (Y_m) 2002-2017, based on updated model, fodder practice without sugar beet, %

	2002-2017
Y_m winter	6.0
Y_m grazing	6.0
Average Y_m	6.0

Table 5.7c CH_4 conversion rate (Y_m) 2018-2021, based on updated model, Y_m for large breed and jersey cows, %

	2018	2019	2020	2021
Y_m winter				
- Large breed	5.94	5.94	5.76	5.76
- Jersey	5.92	5.92	5.80	5.80
Y_m grazing	6.00	6.00	6.00	6.00
Average Y_m	5.94	5.94	5.78	5.78

Table 5.8 CH_4 conversion rate (Y_m) for non-dairy cattle, swine, sheep, goats and horses, %.

	Y_m
Bulls and bull calves	3.00
Heifers, heifer calves and suckling cattle	6.30
Swine	0.60
Sheep	6.70
Lamp	4.50
Goats	5.50
Horses	2.50

5.3.3 Emission factor

IEFs vary across the years for dairy cattle, non-dairy cattle, swine, goats, horses and poultry due to changes in feed intake, distribution of animals in subcategories and number of grazing days. For goats, new subcategories are introduced in 2005 and for horses new subcategories are introduced in 2003 and the distribution between subcategories are changed in 2020 and therefore the IEF differs from the other years. For sheep, deer, ostrich and pheasants the IEF is constant. For IEFs for all categories for all years, see Annex 3D, Table 3D-12. The emission from fur farming is considered not applicable (Hansen, 2010, pers. comm.).

The IEF for dairy cattle has increased from 128 kg CH_4 per cow per year in 1990 to 162 kg CH_4 in 2021. The IEF depends on milk yield and feed intake – see Figure 5.3. From 1990 to 2000, the IEF is almost unchanged but increases significant from 2000 to 2021. The development in feed intake follows the same development as the IEF, while the milk yields in percentage increases even more and especially from year 2000. This is caused by an improvements of the feed utilization.

A significant increase of GE is seen from 2013 to 2014, which can be explained by a markedly increase of the average milk yield. In 2011 and 2012 is seen a decrease in the average milk yield, but from 2013 is seen a significant increase of milk yield to a level of approximately 11 160 litre per cow (large breed) in 2021 (Børsting & Hellwing, 2022). This development has to be set in context with the EU milk quota, which no longer existed from 2015. It was possible for the Danish dairy cattle farmers to increase the milk yield from 2010/2011, but the farmers choose to hold back the feeding because of the EU milk quota.

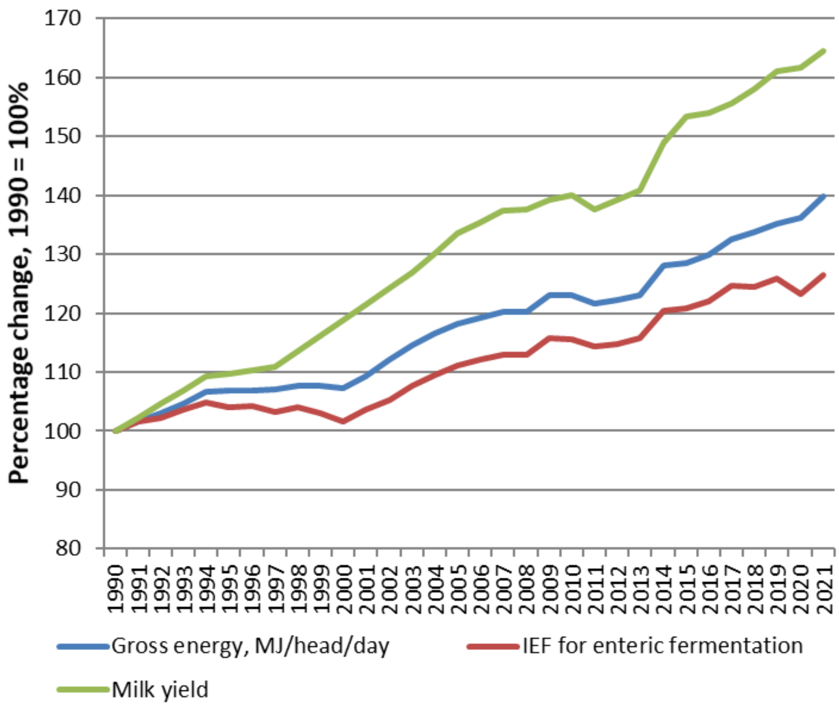

Figure 5.3 Comparison of feed intake, milk yield and IEF for dairy cattle (1990 = 100 %).

A comparison with the IPCC Tier 2 calculation in Chapter 5.13.1 shows that the IEFs using the country specific approach are higher. However, the national IEF reflects the Danish agricultural conditions and the higher level can be explained by high milk production and high feed intake.

The category "Non-Dairy Cattle" includes calves, heifers, bulls and suckling cattle and the IEF is a weighted average of these different subcategories. Changes in allocation of animals between subcategories are reflected in the IEF. The development 1990 - 2008 shows a slight increase due to a higher feed consumption for heifers. From 2008 – 2021 the IEF is stable.

The Danish IEF for non-dairy cattle is lower than the Tier 1 default value given in the 2019 IPCC Refinement. This is due to a lower weight/lower feed intake (Table 5.9). In Chapter 5.13.1 the national IEF is compared with IPCC Tier 2 calculation and the result shows a good correlation, which indicates the Danish estimate is correct.

Table 5.9 Subcategories for Non-Dairy Cattle 2021 – enteric fermentation.

Non Dairy Cattle – subcategories		Number of animals (DSt)	Energy intake, MJ per day	Methane conversion rate (Y_m), %	IEF, kg CH_4 per head per yr
Calves, bull (0-6 month)	200 kg	109 448	66.41	3	13.07
Calves, heifer (0-6 month)	150 kg	167 607	50.86	6.3	42.04
Bulls (6 month to slaughter)	large breed: 440 kg sl. weight		107.09	3	21.07
	jersey: 330 kg sl. weight	116 730			
Heifers (6 month to calving)	325 kg	451 647	129.44	6.3	53.49
Suckling cattle	Up to 800 kg	78 795	158.89	6.3	65.65
Average - Non-Dairy Cattle			103.8		39.67
IPCC – default value				6.3	52

The annual variations for swine primarily reflect the changes in the distribution of animals in subcategories (sows, weaners and fattening pigs). The feed intake for sows and weaners has overall increased while the feed intake for fattening pigs has decreased as a result of improved fodder efficiency (Annex 3D Table 3D-8 and 3D-11).

Table 5.10 shows the IEFs for swine subcategories. The Danish IEF for swine is lower than the IPCC default value. The energy intake for fattening pigs is nearly the same as the default value, while the energy intake for weaners is significantly lower. The lower Danish IEF can be explained by the relatively high share of weaners.

Table 5.10 Subcategories for swine 2021 – enteric fermentation.

Swine – subcategories	Number of animals (DSt)	Energy intake, MJ per day	Methane conversion rate (Y_m), %	IEF, kg CH_4 per head per year
Sows (incl. piglets until 6.7 kg)	1 041 809	72.37	0.60	2.82
Weaners (6.7 – 31 kg)	6 543 510	10.31	0.60	0.41
Fattening pigs (31 – 115 kg)	5 583 147	38.44	0.60	1.51
Average - Swine		21.8		1.07
IPCC – default value			0.60	1.5

It is important to point out that the IEF for goats includes emission from kids due to the Danish normative data. This explains why the Danish IEFs are nearly twice as high as the IPCC default values.

5.3.4 Activity data

Activity data are the number of animals from the agricultural statistics (Statistics Denmark), SEGES and CHR (see Chapter 5.2.1). For numbers see Annex 3D Table 3D-2.

Since 1990, the number of swine and poultry has increased, in contrast to the number of cattle, which has decreased. The number of cattle has decreased because the milk yield has increased while the total production of milk has been fixed by the EU milk quota. Buffalos, camels & llamas and mules & asses are not occurring in Denmark. In 2021 the production of fur bearing animals are not occurring (NO) because all mink were put down in the end of 2020 to prevent spreading of COVID-virus.

5.3.5 Time series consistency

The main part of the emission of CH_4 from enteric fermentation comes from cattle. The development in the milk production has been a high increase in milk per cow, which has increased the feed per cow and thereby increased the implied emission factor. Due to fixing of the total production of milk by the EU milk quota, the number of dairy cattle has decreased. The EU milk quota ended in 2015 and the total milk production has increased, but due to higher feed efficiency, the IEF and emission is almost unaltered. The emission of CH_4 from enteric fermentation from dairy cattle has decreased from 1990 to 2007 and increased from 2008 to 2021.

The emission from non-dairy cattle decreases from 1990 to 2007 and from 2008 to 2021, the emission is almost unaltered.

Emission from swine increases slightly due to increase in number of animals.

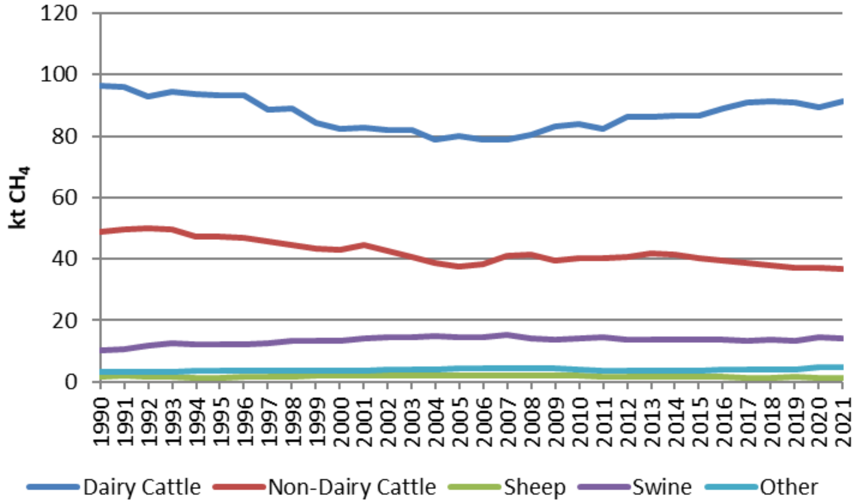

Figure 5.4 Emission of CH_4 from enteric fermentation, 1990-2021. For all numbers see Annex 3D Table 3D-13.

5.4 Manure management – CH_4

5.4.1 Description

This source contributes with 25 % of the total GHG from the agricultural sector in 2021. The major part of the emission originates from the production of swine (55 %) followed by cattle production (44 %). The remaining part is mainly from horses (1 %).

5.4.2 Methodological issues

The IPCC Tier 2 methodology is used for the estimation of the CH_4 emission from manure management. The calculation is based on manure excretion instead of feed intake as described in 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019). Default values for maximum methane producing capacity (B_0) given by the IPCC are used (see Table 5.11). For cattle and swine, a national MCF factor are used while for the other animal categories, MCF are based on IPCC (Annex 3D Table 3D-15 and Table 3D-16). The calculation of volatile solids (VS) is based on national data.

Table 5.11 Maximum methane producing capacity (B_0), m^3 CH_4 per kg VS.

	B_0
Dairy cattle	0.24
Non-dairy cattle	0.18
Swine	0.45
Sheep	0.19
Goats	0.18
Deer	0.18
Fur bearing animals	0.25
Horses	0.3
Hens	0.39
Broilers, turkeys, ducks and geese	0.36
Ostrich	0.25

Table 5.12 CH_4 – Manure management – use of national parameters and IPCC default values.

CH_4 – Manure management	Data source
Volatile solids, VS	Based on amount of manure (Annex 3D Table 3D-14)
Maximum methane producing capacity, B_0	IPCC, 2019
Methane conversion factor, MCF	
- Cattle and swine, liquid manure	Based on national measurements (Annex 3D Chapter 3D-1)
- Other	IPCC, 2019

The amount of manure is calculated for each combination of livestock subcategory and housing type and then aggregated to the IPCC livestock categories. In the calculation, grazing days and use of straw in the housing are taken into account. Equation for CH_4 calculation:

$$CH_{4,manure} = EF\ CH_{4,housing} \cdot n_{animals} + EF\ CH_{4,grazing} \cdot n_{animals}$$

Where:

$n_{animals}$ = number of animals

$$EF\ CH_{4,housing} = VS_{housing} \cdot MCF \cdot 0.67 \cdot B_0$$

$$EF\ CH_{4,grazing} = VS_{grazing} \cdot MCF \cdot 0.67 \cdot B_0$$

Estimation of VS

VS is calculated from data concerning amount of manure, dry matter content, share of VS in dry matter, amount of bedding and grazing days. Except for grazing days for dairy cattle and heifers, all these parameters are based on Danish Normative data. The determination of VS is country-specific, given that it is based on the amount of manure excreted.

$$VS_{housing} = \frac{m}{365} \cdot DM_M \cdot VS_{DM} \cdot (365 - g_1) + s \cdot DM_s \cdot \left(1 - \frac{\%\ ash}{100}\right) \cdot (365 - g_2)$$

$$VS_{grazing} = \frac{m}{365} \cdot DM_M \cdot VS_{DM} \cdot g_1$$

Where:
VS = volatile solids, kg per animal per year
m = amount of manure excreted, kg per animal per year
DM = dry matter of M manure or S straw, %
VS_{DM} = volatile solids of dry matter, %
g_1 = feeding days on grass, days per year [1]
g_2 = actual days on grass, days per year
s = amount of straw, kg per animal per year
% ash = ash content in straw

The ash content in straw is set to 4.5 % (SEGES, 2005). VS of dry matter are 80 % for all livestock categories (Sommer et al., 2013). The number of days on grass are based on information from DCA and SEGES (Poulsen et al., 2001,

[1] Actual days on grass are the number of days that heifers are outside. Feeding days on grass is higher than actual days on grass due to a higher feed intake during grazing compared to the period in housing. Feeding days on grass is a conversion of this higher feed intake on grass. This is only relevant for heifers.

Aaes, 2008, Clausen 2008) and is shown in Annex 3D Table 3D-9. The amount of manure excreted and straw used, depends on housing type and is given in the normative figures table (Børsting & Hellwing, 2022).

The VS daily excretion in average for all main livestock categories and cattle subcategories is shown in Annex 3D Table 3D-14.

MCF - Methane conversion factor

A country specific MCF is developed for liquid cattle- and swine manure for both untreated slurry and slurry treated in anaerobic digestion systems. For other animal categories and manure types, default values provided in the IPCC guidelines for MCF are used. For liquid systems for fur bearing animals, the MCF is a weighted value depended on the situation for covered and uncovered slurry tanks in Denmark. Also for swine on deep bedding housing system is used a weighted value due to the residence time of manure in the barn. In Annex 3D, Table 3D-15, is given an overview of all national manure management systems and the MCF related to each system.

Slurry

During national studies in 2015-2016 with the purpose to develop a national MCF for anaerobically digested slurry (Kai et al., 2015 and Petersen et al., 2016), it became apparent that the IPCC 2006 MCF default for untreated cattle- and swine slurry seems to be underestimated. It was therefore decided to estimate a country specific MCF for both the biogas treated and untreated cattle and swine slurry.

The overall methodology for estimating the CH_4 emission from liquid animal manure and anaerobically digested biomass is based on the available amount of volatile substance (VS) in the biomass and the temperature dependent CH_4 formation function; Van't-Hoof/Arrhenius equation (Sommer et al., 2004). The estimation taken into account a 2-pooled concept for estimating the CH_4 emission from degradable VS (VSd) and from non-degradable VS (VSnd) (Sommer et al., 2004). A more detailed description can be found in Annex 3D Chapter 3D-1. However, the most important data used to calculate the CH_4 emission from untreated and anaerobically digested slurry is listed below:

- VS –The amount of excreted dry matter is taken from the Danish Normative System for animal manure (data included in IDA). The share of VS of dry matter is set as a default to 80 %.
- Temperature
  - inside the barns, based on 20 samples from swine slurry and 11 samples from cattle slurry (Petersen et al., 2016)
  - outdoor storage for untreated liquid manure, based on measurement for Danish and Swedish samples (Husted, 1994) and Rodhe et al. (2009, 2012 and 2015).
  - anaerobically digested manure, based on results from Hansen et al. (2006).
- Storage time for slurry in Danish barns, HRT (Hydraulic Retention Time) (Kai et al., 2015)
- The distribution between degradable VS (VSd) and non-degradable VS (VSnd) based on results from Petersen et al. (2016) and Møller & Moset (2015).
- ln*A* (g CH_4 kg-1 VS h-1) is the pre-exponential factor (methane production potential) and *Ea* (J mol-1) the activation energy of methanogenesis, and both are parameters of a so-called Arrhenius equation for the temperature

dependence of methane production. Data for ln*A* and *Ea* are based on results from Elsgaard et al. (2016) and Petersen et al. (2016).

The trend 1990–2021 for the national estimated MCF for cattle and swine slurry, both digested and not digested, is shown in Table 5.13. The MCF for not digested cattle slurry is changing slightly over time, form 14.21 in 1990 and 14.36 in 2021, while the MCF for not digested swine slurry is reduced from 19.48 in 1990 to 17.75 in 2021. The main reason for changing of MCF over time is caused by change in housing system, which affects the average HRT. The development from housing systems for swine with fully slatted floor towards systems with partly slatted floor, shorter the storage time for slurry and thus reduces the MCF.

The MCF for non digested cattle slurry in 2021 is estimated to 14.36 % and the MCF for digested cattle slurry is 7.14 %, which show a 50 % reduction for biogas treated cattle slurry. The MCF for not digested swine slurry in 2021 is estimated to 17.75 % and the MCF for digested swine slurry to 10.20 %, which corresponds to a 43 % reduction.

Table 5.13 Estimated methane conversion factor (MCF) for digested and not digested cattle and swine slurry from 1990 to 2021, %.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Cattle										
MCF for digested cattle slurry	6.47	6.42	7.33	7.24	7.37	7.60	7.34	7.28	7.24	7.14
MCF for not digested cattle slurry	14.21	14.07	14.91	14.75	14.77	14.80	14.60	14.51	14.47	14.36
Swine										
MCF for digested swine slurry	12.07	11.90	11.61	10.71	10.75	10.66	10.20	10.21	10.14	10.20
MCF for not digested swine slurry	19.48	19.36	19.13	18.38	18.29	18.05	17.78	17.75	17.71	17.75

For liquid systems for fur bearing animals, the MCF is a weighted value depended on the situation for covered and uncovered slurry tanks in Denmark. Due to legislation from 2003, all slurry tanks must be fully covered or have established a floating cover. However, it is difficult to achieve full floating cover all days of the year and some emission can take place during filling and mixing of manure in the tank. Therefore, it is assumed that floating/fixed covers are absent on 2 % in fur production. This results in a weighted MCF of 98% covered slurry (MCF=10 (IPCC, 2006)) and 2 % uncovered (MCF=17 (IPCC, 2006))), which gives a MCF of 10.1 in 2021 for fur slurry.

Deep bedding

The MCF for swine deep bedding depends on how long time the manure is stored in the barn and the emission is particularly higher for bedding stored more than one month. The bedding situation is based on information from SEGES and is different for the three swine subcategories. The lowest MCF at 8.2 % is seen for weaners because 70% of the bedding material is removed during the first month. The situation is opposite for sows where only 20 % of the bedding is removed during the first month, which lead to a higher MCF at 18.0 %.

Table 5.14 MCF factor for swine, deep bedding.

		DK condition, % of year		MCF - IPCC, 2006	
MCF, swine deep bedding	MCF, DK	> 1 month	< 1 month	> 1 month	< 1 month
Deep bedding weaners	8.23 %	30	70	21 %	2.75 %
Deep bedding fattening	13.70 %	60	40	21 %	2.75 %
Deep bedding sows	17.96 %	80	20	21 %	2.75 %

5.4.3 Emission factor

The implied emission factor depends on the VS content in manure, the use of straw, the number of days on grass, MCF and the manure type. The changes of IEFs during the years thus reflect changes in the variables mentioned above. For some livestock categories, which include subcategories, the IEF can also be affected by changes in allocation of animals on the different subcategories. For IEFs for all animal categories for all years, see Annex 3D Table 3D-17.

The IEF for poultry, ostriches, pheasants and deer are almost unaltered from 1990 – 2021 because of very few changes in feed intake and grazing days. A more detailed division in subcategories for goats is implemented from 2007 and for horses in 2003 and the distribution between subcategories are changed for horses in 2020, and explains the small changes in IEFs.

IEF for dairy cattle has increased as a result of increase in feed intake and manure excretion, but also because of changes in housing types (Annex 3D Table 3D-1). Old-style tethering systems with solid manure have been replaced by loose-housing with slurry-based systems, which has a higher MCF. Same pattern is seen for non-dairy cattle, but here the increasing IEF is mainly caused by a higher proportion of bull-calves reared in housings with deep litter, where the MCF is high. The decrease in the IEF for non-dairy cattle from 2012 to 2013 is due to decrease in the use of straw for bulls.

IEF for swine increases from 1990 to 2004 but decreases from 2004 to 2020. This is mainly due to change in housing systems, which affect the calculation of the MCF because of differences in storage time and HRT (Hydraulic Retention Time) in the barns for the different housing types, see Annex 3D Chapter 3D-1.

5.4.4 Activity data

Activity data include both the number of animals and the allocation of animal on different housing types, which determines the manure type. The livestock production is based on the agricultural statistics (Statistics Denmark), SEGES and CHR (see Chapter 5.2.1) and the numbers are given in Annex 3D Table 3D-2. The allocation of housing types is based on registration from the Danish Agricultural Agency (see Chapter 5.2.2 and Annex 3D Table 3D-1).

5.4.5 Biogas treated slurry – activity data

Data regarding the amount of slurry delivered to biogas plants is available for the years 2001, 2003, 2015 - 2021. Data for year 2001 and 2003 is based on a single investigation provided by the DEA – the Danish Energy Agency, while the data for year 2015 - 2021 is based on data registration covering the main part of all biogas plants, it is called the BIB – register (Biomass Input to Biogas production), managed by DEA. For the intervening years, 1990-1999, 2002 and 2004-2014, the data for amount of slurry delivered to the biogas production is based on an interpolation, by using the relation between the amount of slurry delivered and the total energy production produced at the biogas plants. The total energy production from biogas plants for all years is based on the Energy Statistics (DEA, 2022).

In 2021, manure based biogas plants account for 95 % of the total biogas production, which is produced by approximately 30 large-scale plants and 60 farm-level plants. The BIB register shows that manure accounts for around 54 % of the total biomass input. The remaining biomass input is from sewage sludge, residues from the meat production and biomass from crops. The majority of manure sent to anaerobic digestion is slurry, 89 % (mainly from the cattle- and swine production) in 2021. Deep litter to biogas treatment accounts for 11 % of the total amount of manure.

In 1990, the energy production produced at the manure based biogas plants is by DEA estimated to 266 TJ, and the amount of slurry used in biogas plant was estimated to 220 kt. In 2021, the energy production is increased to 24 787 TJ (DEA, 2022), and the amount of slurry delivered to the manure based biogas plants is estimated to 9 575 kt slurry. In 2021, around 25 % of the total amount of slurry is delivered to the biogas plants.

The estimation of the national MCF for biogas treated slurry is described in Annex 3D Chapter 3D-1.

5.4.6 Time series consistency

The overall CH_4 emission from manure management is increased by 21 % from 1990 to 2021. The emission from swine has increase from 1990 to 2004 and hereafter decreased until 2021. The emission is mainly determined by the production of fattening pigs and the emission development follows the same trend as the number of produced fattening pigs. Also, change in housing types influence the emission. The emission increases due to change to more slurry based housing systems but decreases again due to change to housing systems with a shorter storage time and HRT (Hydraulic Retention Time) for the manure in the barns.

The emission from dairy cattle is increased from 1990 to 2021, despite a decrease in number of dairy cattle, but is related to higher milk yield and thus higher feed intake and higher manure excretion.

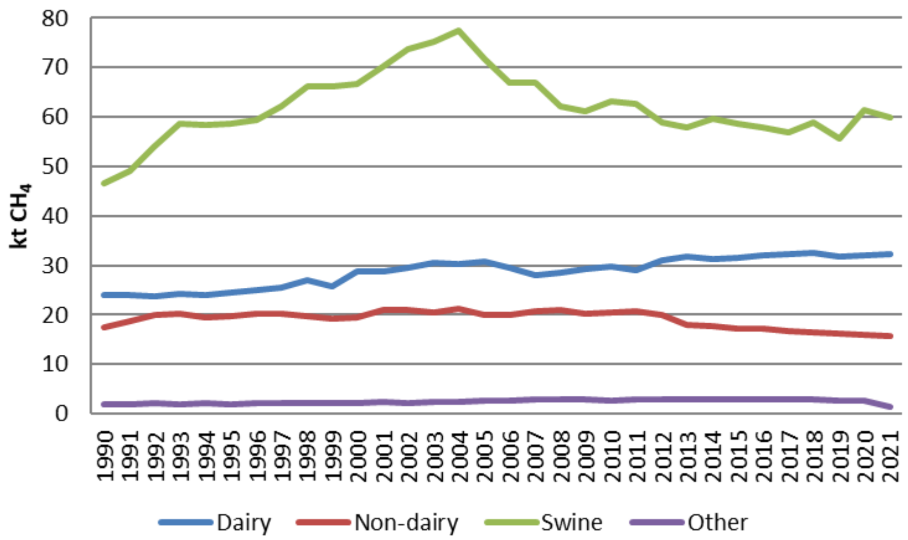

Figure 5.5 CH_4 emission from manure management, 1990 - 2021. For all numbers, see Annex 3D Table 3D-18.

5.5 Manure management – N_2O

5.5.1 Description

The N_2O emission related to CRF category 3B covers a direct and an indirect emission source. The direct emission includes emission from handling of manure in housing and storage and the indirect emission includes the N_2O emission estimated based on the emission of NH_3 and NO_x, which takes place in housing and storage.

The N_2O emission from manure management represents 5 % of the total GHG from the agricultural sector in 2021 and the major part (84 %) originates from the direct emission. Cattle- and swine production account for the largest contribution.

The emission only includes the emission from housing and storage, while the emission from manure deposited on grass is included in CRF category 3D.3 Urine and dung deposited by grazing animals.

5.5.2 Methodological issues

The emission is based on IPCC 2019 Guidelines Tier 2 approach and depends on the N-content in manure. National data is used for N-excretion for all livestock categories.

5.5.3 Emission factor

For the direct emission, a weighted emission factor for cattle and swine slurry with and without natural crust cover is estimated based on the IPCC default N_2O emission factors. For all other manure systems and livestock categories, the IPCC default N_2O emission factors are used. The following table shows the Danish housing system compared to the housing system given in the IPCC 2019 Guidelines Table 10.21 and the respective default emission factors. For cattle slurry, 2 % of the slurry are without crust cover and for swine slurry 5 % are without crust cover.

Table 5.15 Manure management system (MMS) - emission factors.

DK MMS	IPCC MMS	Emission factor, kg N_2O-N pr kg Nex
Cattle		
Liquid/Slurry	Liquid/Slurry, with natural crust cover	0.0049
Solid	Solid storage	0.005
Deep bedding	Cattle and Swine deep bedding, no mixing	0.01
Biogas treated slurry	Anaerobic digester	0.0006
Swine		
Liquid/Slurry	Liquid/Slurry, with natural crust cover	0.00475
Solid	Solid storage	0.005
Deep bedding	Cattle and Swine deep bedding, Active mixing	0.07
Biogas treated slurry	Anaerobic digester	0.0006
Poultry		
Housing with or without litter	Poultry manure with or without litter	0.001
Fur-bearing animals		
Slurry	Liquid/Slurry, with natural crust cover	0.005
Solid	Cattle and Swine deep bedding, no mixing	0.01
Sheep and goats		
Deep bedding	Cattle and Swine deep bedding, no mixing	0.01
Horses and ostrich		
Deep bedding	Cattle and Swine deep bedding, no mixing	0.01

N_2O emission factor for indirect emission is based on the IPCC default, i.e. 0.01 kg N_2O-N per kg NH_3-N and NO_x-N volatilized.

5.5.4 Activity data

Besides the number of animals, the activity data for direct emission also includes allocation to housing types and the N-excretion for each animal type.

The livestock production is based on the agricultural statistics (Statistics Denmark), SEGES and CHR (see Chapter 5.2.1) and the numbers are given in Annex 3D Table 3D-2. The allocation to housing types is based on registration from the Danish Agricultural Agency (see Chapter 5.2.2 and Annex 3D Table 3D-1).

The total amount of nitrogen in manure for each animal category is based on the standards given in the "Danish Normative System", which builds on data from the farmers fertilisers plans – see Chapter 5.2.3 for further details. It is important to point out that the nitrogen excretion rates shown in Table 5.16 are values weighted for the subcategories and thus reflects the nitrogen excreted per AAP. The variations in N-excretion during the time series reflect changes in feed intake, feed efficiency and allocation of animals between subcategories. The nitrogen excretion increases for dairy and non-dairy cattle as a result of higher feed intake. It also has to be noted that the average nitrogen excretion for swine has decreased significantly from 1990 to 2010 due to an improvement of feed efficiency; from 2010 to 2021, it is almost unaltered. For poultry, the average nitrogen excretion varies over time due to distribution of animals in subcategories. The trend for the average nitrogen excretion for fur farming follow the trend for feed intake and increases over time. The average nitrogen excretion for horses decreases from 1990 to 1995, but almost unaltered from 1995 to 2021.

Table 5.16 Nitrogen excretion, annual average 1990 – 2021, kg N per head per year (AAP).

CRF Table 3.B(b)	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Livestock category										
Dairy cattle	129.49	125.23	125.31	133.30	138.63	143.43	154.67	156.20	156.36	156.90
Non-dairy	35.57	35.93	35.70	40.66	42.90	43.09	42.33	42.82	42.45	42.33
Sheep	6.64	6.64	6.64	6.64	6.64	6.64	6.64	6.64	6.64	6.64
Goats	16.36	16.36	16.36	15.83	16.46	16.85	16.84	16.81	16.81	16.79
Swine	11.86	9.74	9.63	9.23	7.85	7.80	7.69	7.56	7.74	7.12
Poultry	0.63	0.62	0.55	0.73	0.60	0.56	0.49	0.46	0.48	0.47
Horses	44.15	39.56	39.56	39.56	39.56	39.56	39.56	39.56	43.81	43.81
Fur farming	4.90	4.65	4.62	5.38	5.82	5.31	5.11	5.47	5.47	0.00
Deer	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Ostrich	0.00	15.61	15.60	15.60	15.60	15.60	15.60	15.60	15.60	15.60
Pheasant	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
N-excretion, total, kt N per year	292	274	269	277	261	257	264	254	263	241
N-excretion, housing, kt N per year	258	239	235	252	239	236	243	233	241	220

Activity data for the indirect emission covers the volatilisation of NH_3 and NO_x, which takes place in housing and during storage of the manure. These are based on national data, for detailed information see Annual Danish Informative Inventory Report (Nielsen et al., 2022). Emission of NH_3 from housing and storage has decreased from 1990 to 2021 mainly due to implementation of a number of action plans to reduce nitrogen losses from the agricultural production. NO_X emission has also decreased over time, mainly due to changes from solid based systems to slurry-based systems for both the dairy cattle and the swine production. In 2021 the emission of NH_3 has decreased a lot due to abolition of mink production.

Table 5.17 Volatilization of NH_3-N and NO_x-N in housing and during storage, 1990-2021.

CRF Table 3.B(b)	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
NH_3-N, housing and storage	41 624	38 353	38 589	38 991	32 739	29 653	28 873	27 014	27 794	23 086
NO_x-N, housing and storage	304	317	309	246	224	198	216	236	229	231
Sum, tonnes N	41 928	38 669	38 899	39 237	32 963	29 852	29 090	27 249	28 023	23 317

5.5.5 Time series consistency

The N_2O emission from manure management is estimated to 2.25 kt in 2021 of which 0.36 kt is related to the indirect emission. The overall emission has decreased with 1.0 kt N_2O from 1990 – 2021 corresponding to 31 %. This decrease is mainly caused by a decreased emission from swine, which is driven by improvements in feed efficiency. The average nitrogen excretion per swine has decreased significantly (see Table 5.15) from 1990 due to the farmers' economic benefit of increased feed efficiency and due to environmental requirements.

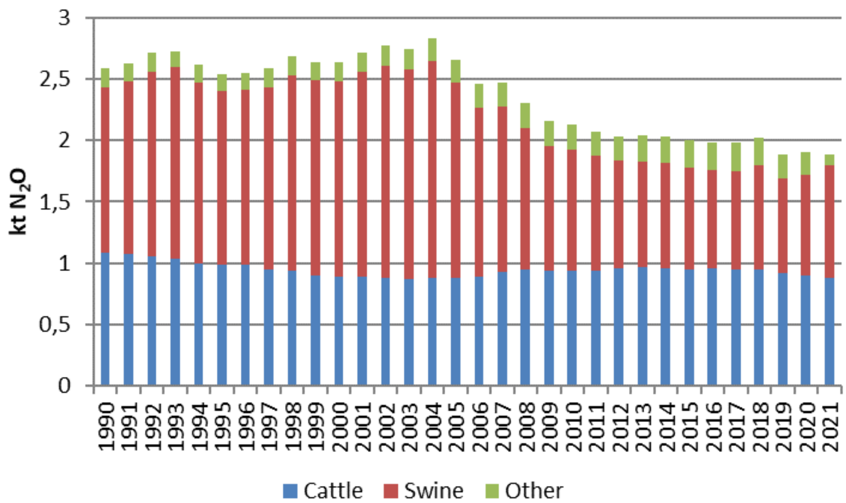

Figure 5.6 N_2O direct emission from manure management, 1990 - 2021.

5.6 Agricultural soils – direct N_2O emissions

5.6.1 Description

The emissions from agricultural soils – direct emissions, is emissions from inorganic N fertiliser, animal manure applied to soils, sewage sludge, other organic fertiliser applied to soils, urine and dung deposited by grazing animals, crop residues, mineralization/immobilization and organic soils. Emission from agricultural soils – direct emissions contribute, in 2021 with 72 % of the N_2O emission from the agricultural sector. The largest sources are manure and inorganic N fertiliser applied on agricultural soils. The emission has overall decreased 21 % from 1990 to 2021.

5.6.2 Methodological issues

To calculate the N_2O emission the IPCC Tier 1 methodology is used, except from animal manure applied to soils and grazing animals, where Tier 2 methodology is used.

Emissions of N_2O are closely related to the nitrogen balance and all data concerning the evaporation of NH_3 and data for manure condition is applied from the national NH_3 emission inventory. This is described in detail in Albrektsen et al. (2021) and Annual Danish Informative Inventory Report (Nielsen et al., 2022).

5.6.3 Activity data

Area of agricultural land is shown in Annex 3D Table 3D-19.

Inorganic N fertiliser applied to soils

The amount of nitrogen (N) applied to soil by use of inorganic N fertiliser is estimated from sales estimates managed by the Danish Agricultural Agency and from the Danish fertiliser N accounts controlled by The Danish Agricultural Agency. As a part of the QA/QC procedure the sale statistics and the actually consumption registered in the Danish fertiliser N accounts is compared. This indicate an increasing difference for a range of years and especially a significant difference for 2016. The difference is caused by the growing import of inorganic fertilisers. The farmer are allowed to import fertiliser, if the consumption is related to own fields, but not for onward sale. Because of the increasing import, the amount of N applied to soil by use of inorganic N fertiliser is based on Danish fertiliser N account from 2009 - 2016. For 2017, the sales estimates have been updated and sales information from more companies have been included (Danish Agricultural Agency, 2020). Therefore, the amount of N applied to soil by use of inorganic N fertiliser in 2017 and 2019-2021 is based on the sales estimates managed by the Danish Agricultural Agency (Danish Agricultural Agency, 2022). For 2018, a high uncertainty is indicated for the sales estimates (Skade, 2020, pers. Comm.) and therefore use of inorganic N fertiliser is based on the Danish fertiliser N accounts for 2018.

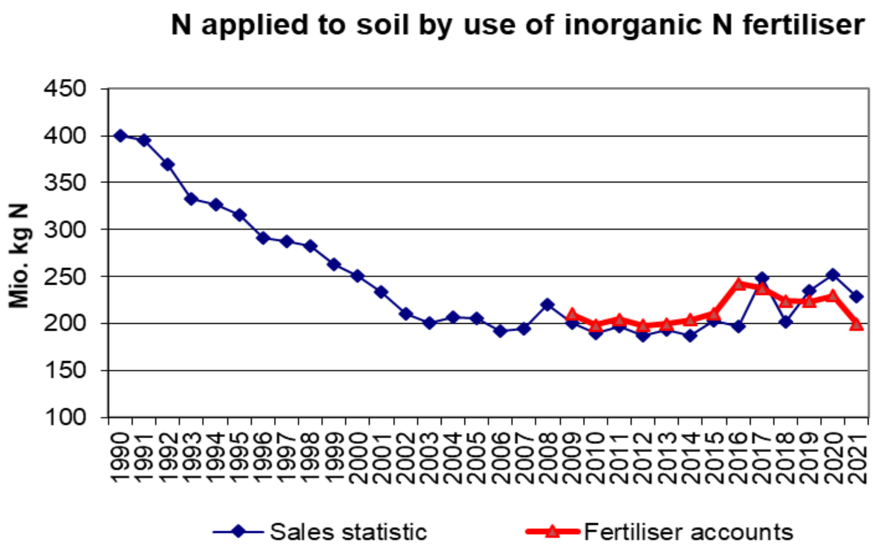

Figure 5.7 N applied from inorganic N fertiliser, sales statistic and N fertiliser account.

Table 5.18 shows the consumption of each fertiliser type for the inorganic fertiliser. The NH_3 emission factor for each fertiliser is given, based on the values from the EMEP/EEA Guidebook 2019. The emission factors are weighted values of EF for soil with normal pH (≤ 7) and high pH (> 7), in Denmark 79 % of the soils have a normal pH and 21 % have a high pH. The NH_3 emission depends on fertiliser type and the major part of the Danish emission is related to the use of ammonium nitrate and NPK fertiliser, where the emission factor is 0.019 and 0.059 kg NH_3-N per kg N, respectively. The Danish $Frac_{GASF}$ is low compared to the IPCC default value. This is due to the small consumption of urea (<1%), which has a high emission factor.

Table 5.18 Inorganic N fertiliser consumption 2021 and the NH_3 emission factors.

	NH_3 Emission factor[1] kg NH_3-N per kg N	Consumption[2] 1000 t N
Fertiliser type		
Pure ammonium nitrate	0.019	0.88
Ammonium nitrate with/without sulphur	0.019	116.77
Ammonium nitrate-urea solutions	0.097	11.72
Urea	0.157	0.74
Calcium ammonium nitrate	0.010	9.78
Calcium and boron calcium nitrate	0.012	0.16
Ammonium sulphate	0.106	6.98
Ammonium sulphate nitrate	0.106	7.32
Liquid ammonia	0.022	5.38
Liquid nitrogen	0.097	2.23
NPK-fertiliser	0.059	57.85
NK fertiliser	0.019	1.08
Other NP fertiliser types	0.059	7.00
Other fertiliser with N	0.019	0.72
Total consumption of N in inorganic N fertiliser		228.61
National emission of NH_3-N, kt	9.23	
Average NH_3-N emission	0.04	
$Frac_{GASF}$[3]	0.05	

[1]) EMEP/EEA (2019), cool climate, weighted 79 % normal pH and 21 % high pH.

[2]) The Danish Agricultural Agency (2022).

[3]) $Frac_{GASF}$ fraction of synthetic fertiliser N that volatilises as NH_3 and NOx, kg N volatilised (kg of N applied).

The use of inorganic N fertiliser includes fertiliser used in parks, golf courses and private gardens. One percent of the inorganic N fertiliser can be related to these uses outside the agricultural area (Knudsen, 2011).

As a result of increasing requirements for improved use of nitrogen in livestock manure and reduce the nitrogen loss to the environment, the consumption of nitrogen in inorganic N fertiliser has decreased from 1990 to 2005 (Table 5.19). From 2005 to 2015, only small variation is seen in the consumption of N and emission of N_2O. In 2016-2021 the consumption and emission increases caused by a political agreement on Food and Agricultural package, adopted in December 2015 (MEFD, 2017). The purpose of the agreement was to establish better framework conditions for the agricultural production, to ensure opportunities for economic growth and increased exports and increased employment in interaction with nature and the environment. This agreement made it legally possible to use more nitrogen for some areas.

Table 5.19 Nitrogen applied as fertiliser to agricultural soils 1990 – 2021.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
N content in inorganic N fertiliser, kt N	400	316	251	206	199	211	224	235	252	229
N_2O emission, kt N_2O	6.29	4.96	3.95	3.24	3.13	3.31	3.52	3.69	3.96	3.59

Animal manure applied to soils

The amount of nitrogen applied to soils is estimated as the N-excretion in housings which includes N from bedding. The total N-excretion in housings from 1990 to 2021 has decreased by 15 %.

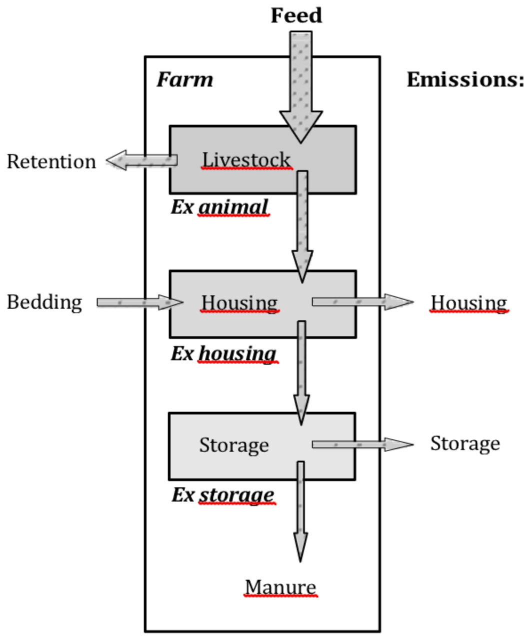

Figure 5.8 The flow dynamics of the Danish normative manure system, which quantifies nutrient content in livestock manure ex animal, ex housing and ex storage (Luostarinen and Kaasinen, 2016).

Table 5.20 Nitrogen applied as manure to agricultural soils 1990 – 2021.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
N-excretion, housing, kt N	258	239	235	252	239	236	243	233	241	220
N in manure applied on soil, kt N*	212	198	195	213	208	209	217	209	216	199
N_2O emission, kt N_2O	3.33	3.11	3.07	3.34	3.27	3.28	3.42	3.28	3.39	3.13

*Including N from bedding.

Sewage sludge applied to soils

Information regarding the amount of sewage sludge applied on agricultural soil as fertiliser is based on information from the Danish Environmental Protection Agency, and covers the years 1990-2002, 2005, 2008-2009, 2013-2020 (for 2020: EPA(a), 2022). For 2021, the amount of sewage sludge applied is based on an average of the years 2018-2020. The N-content varies from 4 to 6 kg N per kg dry matter for the years 1990-2021 (EPA, 2009, EPA(b), 2022).

Table 5.21 Emission from sewage sludge applied on agricultural soils 1990 – 2021.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Nitrogen in sewage sludge, t N	3 115	4 635	3 625	2 710	3 622	4 038	3 373	4 180	4 920	4 820
N_2O emission, kt N_2O	0.05	0.07	0.06	0.04	0.06	0.06	0.05	0.07	0.08	0.08

Other organic fertilisers applied to soils

The category, "Other", includes emission from sludge from industries, which is applied to agricultural soils as fertiliser and biomass other than manure treated in biogas plants.

Information about industrial waste applied on agricultural soils and the content of nitrogen is obtained from a series of reports published by the Danish Environmental Protection Agency, where recent official figures covering year

2001 (Petersen & Kielland, 2003). From 2005 and forward the amount of N from sludge from industries applied to soil, is based on the information registered in the Danish N fertiliser accounts controlled by the Danish Agricultural Agency. The N applied for years 2002- 2004 are interpolated.

Amount of nitrogen applied to soil from biomass treated in biogas plants (other than manure) are based on energy production in the biogas plants given in PJ and N per PJ were amount of N from NH_3 emission at the biogas plant are subtracted. Amount of NH_3 emission from feedstock at the biogas plants are reported in the waste sector in the Danish Informative Inventory Report (Nielsen et al., 2022). N per PJ are estimated to 7.5 tonnes N per PJ based on an average of N in feedstock and energy production in 2016-2019.

Table 5.22 Emission from sludge from industries applied on agricultural soils 1990 – 2021.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Nitrogen in industrial waste, t N	1 529	4 445	5 147	2 359	3 401	4 455	4 788	5 669	5 283	5 425
Nitrogen in other biomass, t N	5.3	9.8	16.8	24.0	29.4	44.6	96.2	119.3	153.6	190.5
N applied on soil	1 534	4 455	5 164	2 383	3 430	4 500	4 884	5 788	5 437	5 615
N_2O emission, kt N_2O	0.02	0.07	0.08	0.04	0.05	0.07	0.08	0.09	0.09	0.09

Urine and dung deposited by grazing animals

The amount of nitrogen deposited on grass is based on estimations from the NH_3 inventory (Nielsen et al., 2022). Information on grazing days is based on expert judgement from DCA and SEGES (Poulsen et al., 2001, Aaes, 2008, Clausen 2008). N-excretion on grass has decreased due to a reduction in the number of dairy cattle and days on grass. Emission factor from IPCC 2019 are used.

Table 5.23 Nitrogen excreted on grass 1990 – 2021.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
N-excretion, grass, kt N	34	35	34	26	22	21	21	21	22	21
N_2O emission, kt	1.00	1.04	0.98	0.72	0.61	0.59	0.59	0.58	0.60	0.59

$Frac_{GASM}$

The $Frac_{GASM}$ express the fraction of N applied from all organic N fertilisers and dung and urine deposited by grazing animals volatilised as NH_3 and NO_x emission. Emission factors for NH_3 from the housing unit and storage are given in Annex 3D Table 3D-3 and 3D-4. The $Frac_{GASM}$ has decreased from 0.18 in 1990 to 0.09 in 2021 (Table 5.24). This is the result of an active strategy to improve the utilisation of the nitrogen in manure.

Table 5.24 $Frac_{GASM}$ 1990 – 2021.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
N applied, kt N	250	242	238	243	237	239	247	240	248	231
NH_3-N and NO_x- N emission, kt N	46	35	29	23	22	20	21	20	21	20
$Frac_{GASM}$	0.18	0.15	0.12	0.09	0.09	0.09	0.08	0.09	0.09	0.09

Crop residues

The emission from crop residues is estimated based on the tier 1 methodology in the 2019 IPCC Guidelines. However, country specific estimates is used for crop yield and dry matter content. Default values for all parameters given in IPCC 2019 Table 11.2 are used. The default aggregated N_2O emission factor at 0.01 kg N_2O-N per kg N in crop residues is used.

The dry matter fraction in crops is based on a feedstuff table produced by SEGES, which has information for content of dry matter, fatty acid, protein, starch, sugar and energy for each crop type (SEGES, 2005). The total amount of dry matter in harvest product used to estimate the "Above-ground residue dry matter $AG_{DM(T)}$" is based on data from Statistics Denmark (DSt, 2022). The $AG_{DM(T)}$ varies from year to year depending on the climate conditions – refer to Annex 3D, Table 3D-20.

Besides the cultivated area registered in Statistics Denmark, the inventory also include N content in catch crops, which has increased significantly, from approximately 200 000 hectare in 2010 to 475 000 hectare in 2021, in relation to decrease the N surplus from the fields to the aquatic environment. The total N content in crop residue for catch crop is estimated to 45 kg N per hectare, which is based on a first estimate provided by Peter Sørensen (Sørensen, 2021).

The amount of straw harvested and used for feeding, bedding and bio fuel in power plants is taken into account, because this quantity is removed from the fields. The amount of harvested straw is based on data from Statistics Denmark (DSt, 2022).

The total amount of nitrogen in crop residues is calculated and then the N-content in harvested straw is deducted. The N content in crop residues has increased from 160 million kg N in 1990 to 214 million kg N in 2021, which is a result of both increased total N content in crop residue and a lower amount of N from straw is removed from the fields. In 2018, N in crop residues is significantly decreased, this is due to very dry weather conditions, which resulted in very low yields of the crops.

Table 5.25 N-content in crop residue, 1990-2021.

Million kg N	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Total N in crop residue	184.3	176.6	185.2	203.1	220.0	235.0	191.9	243.4	245.1	228.2
N-content in harvested straw	24.2	20.1	17.4	14.6	14.8	13.6	16.3	15.8	14.8	13.8
CRF Table 3.D.4 N in crop residue	160.1	156.5	167.9	188.5	205.2	221.4	175.5	227.6	230.3	214.3

The N_2O emission is proportional to the N-amount in crop residues. Figure 5.9 shows the total N-content in crop residues allocated on the main crop types. Increase in N-content for maize and grass-clover mixtures in rotation is a result of increase of cultivated area. Some variations are seen from one year to another due to the annual climate conditions e.g. in 1992 and 2018 the spring and summer was extremely dry.

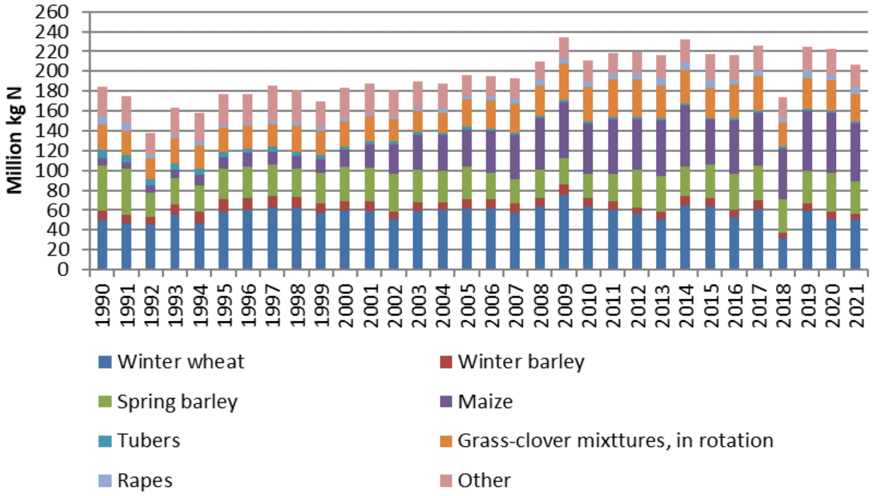

Figure 5.9 Total N in crop residue, 1990 – 2021.

Mineralization/immobilization associated with loss/gain of soil organic matter

The N mineralization from mineral soils associated with loss/gain of soil organic matter is estimated with a dynamical modelling tool - C-TOOL, which is used to estimate long-term changes in carbon from mineral soils. For a further description, see LULUCF, Section 6.3.1. Cropland and cropland management, mineral soils. C-TOOL is a 3-pooled dynamic model, where the approximate average half-live times for the three different pools, Fresh organic matter (FOM), Humified organic matter (HUM) and ROM (Resilient Organic Matter) are 0.6-0.7 years, 50 years and 600-800 years, respectively. The main part of biomass returned to soil each year is in the first and easiest degradable FOM pool. This pool consists of mainly fresh straw, fresh manure, root residues, fungi and small animals and fluctuates very much between years depending on the harvest yield and climatic conditions. The annual input to the FOM-pool is very close to the estimated annual amount of crop residues.

The estimated release of N_2O follows eq. equation 11.8, page 11.20 in the 2019 IPCC Guidelines. The N_2O formation is estimated from the annual changes in the HUM and ROM pool. Changes in the FOM pool is considered as being the same as crop residues incorporated in the soil and to avoid double-counting changes in the FOM is not included.

C-TOOL is subdivided into 44 combinations of regions and soil types. Within each subdivision are only losses included in the estimate. Only losses in soil carbon are included in the estimate. If a subdivision one year has an increase in the HUM and ROM pool the release of N_2O by default are zero as only losses are included, cf. eq. 11.8. A C:N-ratio of 10, which is common in the fertilized Danish agricultural soils are used for all soil types. The recommended default value in the 2019 IPCC Guidelines is 15.

Cultivation of organic soils

N_2O emissions from cultivation of organic soils are based on the area of organic soils of cropland, grassland and areas with no field identification, which are defined as grassland, shallow drained, nutrient-rich areas according to the 2013 Wetlands Supplement (IPCC, 2014). These areas are subdivided in areas with >12 % of soil organic carbon (SOC) and 6-12 % SOC. The Danish definition of organic soils are >10 % organic matter equivalent to app. 6 % SOC. It was defined in 1975 (Madsen et al., 1992). Agricultural soils in use under Danish conditions will normally have a carbon content of 1.5-3 % SOC (Taghizadeh-Toosi et al., 2014). This is the equilibrium state with a degradation condition and crop residue input. Drained land under agricultural use will therefore evidently approach a C content of 1.5-3 %. It is therefore assumed that the 6-12 % SOC soils will have losses of CO_2, N_2O and CH_4. Almost all measurements in the literature is performed on soils having >12 % OC. The areas with >12 % of SOC are multiplied by the default emission factor from Table 2.5 of the 2013 Wetland Supplement, IPCC (2014), which for >12 % SOC is 13 kg N_2O-N per ha cropland, 8.2 kg N_2O-N per ha deep-drained, nutrient-rich grassland and 1.6 kg N_2O-N per ha shallow-drained, nutrient-rich grassland. It has not been able to find any solid documentation for areas with 6-12 % SOC, so it is chosen to use 50 % of the values for soils having >12 % SOC, i.e. 6.5, 4.1 and 0.8 kg N_2O-N per ha, respectively.

EF is constant for all years 1990-2021. The area of organic soils is shown in Table 5.26. The area of organic soils has decreased from 1990 to 2021, see more in Chapter 6.3.1.

Table 5.26 Area of organic soils in ha, 1990-2021.

Year	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Cropland, >12 %**	54 082	50 967	47 851	44 736	40 718	33 518	31 060	31 339	30 348	29 992
Grassland, >12 %**	46 668	43 980	41 292	38 603	37 720	39 796	41 956	41 658	42 273	42 659
SN grassland*, >12 %**	0	0	0	0	0	1 461	1 438	1 415	1 442	1 453
Cropland, 6-12 %**	79 618	77 232	74 845	72 459	69 159	62 373	59 915	59 871	58 717	58 081
Grassland, 6-12 %**	34 922	33 875	32 829	31 782	32 839	35 240	37 106	36 980	37 649	38 050
SN grassland*, 6-12**	0	0	0	0	0	1 796	1 816	1 819	1 864	1 889

*SN grassland - shallow drained, nutrient-rich grassland.

** % SOC.

5.6.4 Emission factors

In the calculation of N_2O from agricultural soils, most of the N_2O emission factors are based on the default values given by the IPCC (IPCC, 2019). EF for cultivation of organic soils are based on the 2013 Wetlands Supplement (IPCC, 2014). A NH_3 and N_2O emission factor overview is presented in Table 5.27.

Table 5.27 Emission factors – NH_3 and N_2O from agricultural soils – direct emissions.

	NH_3 emission factor (national data) Kg NH_3-N per kg N	N_2O emission factor (IPCC default value) kg N_2O -N per kg N
Inorganic N fertilisers	0.04*	0.01[1]
Animal manure applied to soils	0.17**	0.01[1]
Sewage sludge applied to soils	0.11[3]	0.01[1]
Other organic fertilisers applied to soils	0.07[3]	0.01[1]
Urine and dung deposited by grazing animals	0.05-0.35[3]	0.003-0.004[1]
Crop residues		0.01[1]
Mineralization/immobilization associated with loss/gain of soil organic matter		0.01[1]
Cultivation of organic soils		0.8-13***[2]

*Varies from year to year.

**Varies from year to year, has decreased from 0.28 in 1990.

***Unit: kg N_2O-N per ha.

[1] IPCC (2019) Aggregated default.

[2] IPCC (2014).

[3] EMEP/EEA Guidebook (2019).

5.6.5 Time series consistency

Figure 5.10 shows the distribution and the development from 1990 to 2021 according to different N_2O sources. The yearly variations in emissions are mainly due to variations in the emission from inorganic N fertiliser and animal manure applied to soils. The main decrease is seen from 1990 to 2002 and is mainly due to the decrease in emission from inorganic N fertiliser, which is caused by increasing requirements for improved use of nitrogen in livestock manure and reduction of nitrogen loss to the environment. From 2003 to 2021 small yearly variations is seen, with increased emissions in 2008, 2016, 2017 and 2019 mainly due to increase in emission from inorganic N fertiliser. In 2018, the emission is decreased due to decrease in emission from inorganic N fertiliser and crop residues, which is due to the climate conditions were spring and summer was extremely dry.

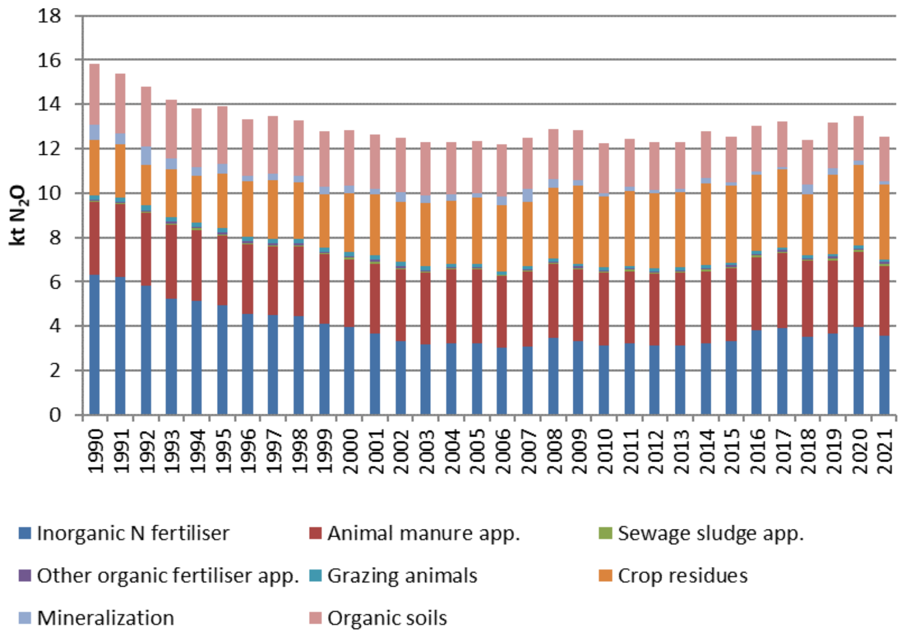

Figure 5.10 N_2O emissions from agricultural soils – direct emissions 1990 - 2021.

5.7 Agricultural soils –indirect N_2O emissions

5.7.1 Description

The emissions from agricultural soils – indirect emissions, are emissions from atmospheric deposition and from leaching and run-off. Agricultural soils – indirect emissions contribute, in 2021 with 15 % of the N_2O emission from the agricultural sector. The largest source is nitrogen leaching and run-off. The emission has decreased by 45 % from 1990 to 2021.

5.7.2 Methodological issues

To estimate the emission of N_2O from atmospheric deposition the Tier 2 methodology is applied. Principally same calculation methodology as IPCC 2019 guidelines is used, but based on national data for nitrogen leach to groundwater, watercourses and the sea. Due to atmospheric deposition, national data is used for the ammonia emission and the N-excretion.

The calculation of the N_2O emission from nitrogen leaching and runoff is based on IPCC model and a national model. Nitrogen, which is transported through the soil, can be transformed to N_2O. The IPCC 2019 recommends an

N_2O emission factor of 0.011 used, of which 0.006 is for leaching to groundwater, 0.0026 for transport to watercourses (in IPCC definition called rivers) and 0.0026 for transport out to sea (in IPCC definition called estuaries). The N_2O emission from nitrogen leaching is a sum of the emission for all three parts calculated as:

$$N_2O_{leaching} = \left(N_{leach\ ground} \cdot EF_{ground} + N_{leach\ rivers} \cdot EF_{rivers} + N_{leach\ estuaries} \cdot EF_{estuaries}\right) \cdot \frac{44}{28}$$

In the Action Plans for the Aquatic Environment, nitrogen leaching to groundwater, rivers and estuaries has been estimated, see Table 5.28. The calculation of N to the groundwater is based on two different models– SKEP/Daisy and N-LES (Børgesen & Grant, 2003) carried out by DCA and DCE, Aarhus University (see overview of model in Annex 3D Figure 3D-1). SKEP/DAISY is a dynamical crop growth model taking into account the growth factors, whereas N-LES is an empirical leaching model based on more than 1500 leaching studies performed in Denmark during the last 15 years. The models produce rather similar results for nitrogen leaching on a national basis (Waagepetersen et al., 2008).

5.7.3 Activity data

Atmospheric deposition

Atmospheric deposition includes all agricultural NH_3 and NO_x emission sources included in the Danish NH_3 emission inventory (Nielsen et al., 2022). Emission from atmospheric deposition from livestock manure, housing and storage, is reported in Sector 3B. Atmospheric deposition reported in Sector 3D includes the emission from livestock manure applied to soils and deposited during grazing, inorganic N fertiliser, growing crops, NH_3-treated straw used as feed, field burning of crop residues, sewage sludge and other organic fertiliser applied to agricultural soils.

The emission from atmospheric deposition has decreased from 1990 – 2021 because of the reduction in the total NH_3 and NO_X emission, from 80 275 tonnes of N in 1990 to 37 841 in 2021.

Table 5.28 NH_3 and NO_x emission 2021.

	t NH_3-N	t NO_x-N
Manure	16 935	2 424
Inorganic N fertilisers	9 228	2 783
Crops	5 225	
NH_3 treated straw	199	
Burning of agricultural residues	34	
Sewage sludge	516	59
Other organic fertiliser	370	68
Emission total	32 507	5 334
N_2O emission, kt		0.59

Nitrogen leaching and Run-off

For N-leaching for ground water the SKEP/Daisy model has estimated the total N leached from 2003-2011 to be 149-175 thousand tonnes N, whereas N-LES model has estimated the total N leached to be 161-170 thousand tonnes in the same period. An average of the results from the two models is used in the emission inventory. From 2012 to 2020, data from N-LES is used (Rolighed, 2022). For 2021 no model estimations are available therefore are the N-leaching from ground water based on an average for 2016-2020.

Data concerning the N-leaching to rivers and estuaries are based on data from NOVANA (National Monitoring program of the Water Environment and Nature) received from the Department of Ecoscience, Aarhus University (Windorf et al., 2011, Windorf, 2013, Tornbjerg, 2022). NOVANA is a monitoring program, which includes monitoring of the ecologic, physic and chemical condition of water areas and transport of water and a range of substances, including N, to lakes and the sea (Wiberg-Larsen et al., 2010). These studies include measurements from 223 monitoring stations in all parts of Denmark and they have been carried out since the early 1990's. No data for 2021 are available yet and values are based on an average for 2016-2020.

Table 5.29 N leaching to groundwater, rivers and estuaries in kt, 1990-2021.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Groundwater	267	235	179	162	167	153	160	152	149	150
Rivers	97	95	89	58	59	86	60	78	74	70
Estuaries	100	88	77	54	56	70	49	74	57	59

Figure 5.11 shows leaching from groundwater estimated in relation to the nitrogen applied to agricultural soils as livestock manure, inorganic N fertiliser, sludge, crop residue and mineralization. The average proportion of nitrogen leaching from groundwater has decreased from around 33 % in the middle of the nineties to around 22 % in 2021. The decline is due to implementation of measures to avoid the nitrogen surplus in the agricultural production by improved nitrogen in manure, to use catch crops during winter and ban application of manure in winter. The reduction in nitrogen applied is particularly due to the fall in the use of inorganic N fertiliser. The main decrease in applied N to soil is seen from 1990 to 2003 due to the decrease in emission from inorganic N fertiliser. From 2002 to 2020, small yearly variations is seen with increase in 2008, 2016, 2017, 2019 and 2020 due to increase in N from inorganic N fertiliser. In 2018 and 2020, a decreased is seen mainly due to decrease in N from inorganic N fertiliser and crop residues. In 2021 is also seen a decrease in N from manure applied to soil mainly due to closing of the mink production.

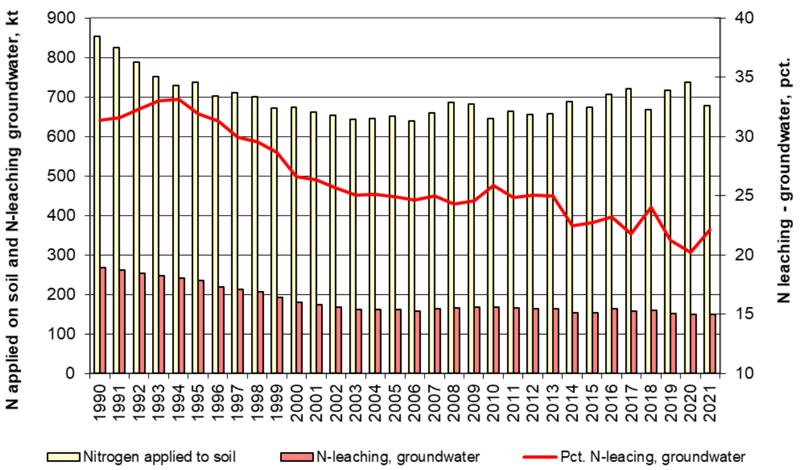

Figure 5.11 Nitrogen applied to agricultural soils and N-leaching, groundwater 1990-2021.

Frac$_{LEACH}$

The proportion of N input to soils lost through leaching and runoff (Frac$_{LEACH}$) is in the Danish emission inventory calculated as:

$$Frac_{LEACH} = {N_{leached}}/{N_{applied}}$$

Where:

$Frac_{LEACH}$ = proportion of N input to soils lost through leaching and runoff

$N_{leached}$ = amount of N leached to ground water based on SKEP/Daisy and N-Les model, kt N

$N_{applied}$ = N applied to agricultural soils from manure, inorganic N fertiliser, sludge, crop residue and mineralization, kt N

In 2021, the Danish $Frac_{LEACH}$ are 22 %; the default value of the IPCC is 24 %. $Frac_{LEACH}$ has decreased from 1990 and onwards. At the beginning of the 1990s, manure was often applied in autumn. Now, the main part of manure application takes place in the spring and early summer, where there is nearly no downward movement of soil water. The decrease in $Frac_{LEACH}$ over time is due to increasing environmental requirements and banning manure application after harvest.

5.7.4 Emission factors

In the calculation of indirect N_2O emissions from agricultural soils, the emission factors for both sources are based on the default values given by the IPCC (IPCC, 2019). See Table 5.30.

Table 5.30 Emission factors – N_2O from agricultural soils – indirect emissions.

	N_2O emission factor (IPCC default value)
	kg N_2O -N per kg N
Atmospheric Deposition	0.01
Nitrogen Leaching and Run-off	0.0112*

*Groundwater = 0.006, rivers = 0.0026 and estuaries = 0.0026.

5.7.5 Time series consistency

Figure 5.12 shows the emission of N_2O from agricultural soils – indirect emissions. Both emissions from atmospheric deposition and leaching ad run-off have decreased from 1990 to 2021. The dips and jumps are mainly due to change in emission from leaching and run-off.

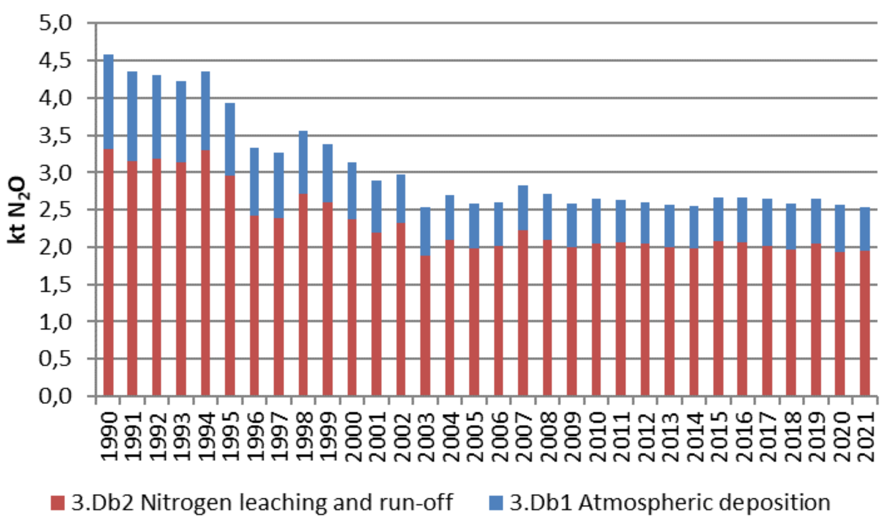

Figure 5.12 N_2O emissions from agricultural soils – indirect emissions 1990 – 2021.

5.8 Field burning of agricultural residues

5.8.1 Description

Field burning of agricultural residues in Denmark, has been prohibited since 1990 and may only take place in connection with production of grass seeds on fields with repeated production and in cases of wet or broken bales of straw. Field burning produces emissions of a wide variety of different pollutants and only the greenhouse gases are covered in this report. For emission of air pollutants, see the Danish Informative Inventory Report (Nielsen et al., 2022).

5.8.2 Methodological issues

Equation for calculating emissions:

$$E = BB \cdot \frac{EF}{1\ 000\ 000} \cdot FO$$

$$BB = CP \cdot FB \cdot FR_{DM}$$

Where:
E = emission of compounds, kt
BB = total burned biomass, kt DM
CP = crop production, t
FB = fraction burned in fields
FR_{DM} = dry matter fraction of residue
EF = emission factor, g per kg DM
FO = fraction oxidized

5.8.3 Activity data

The amount of burnt straw from the grass seed production is estimated as 15 % of the total amount produced. The amount of burnt bales of broken or wet bales of straw is estimated as 0.1 % of total amount of straw. Both estimates are based on an expert judgement by SEGES (Feidenhans'l, 2009, pers. comm.). The total amounts are based on data from Statistics Denmark.

5.8.4 Emission factor

Table 5.31 shows the emission factors used to estimate emissions of CH_4 and N_2O (Andreae, 2019).

Table 5.31 Factors for estimating emissions of CH_4 and N_2O, 2021.

		Crop production	Fraction burned in fields	Dry matter (dm) fraction of residue	Total Biomass burned	EF	Fraction oxidized	Emission
		t			kt dm	g per kg dm		kt
CH_4	Mixed cereals	5 657 900	0.001	0.85	4 809	5.7	0.90	0.025
CH_4	Straw from seeds of grass	478 500	0.15	0.20	14 355	5.7	0.90	0.074
N_2O	Mixed cereals	5 657 900	0.001	0.85	4 809	0.09	0.90	0.0004
N_2O	Straw from seeds of grass	478 500	0.15	0.20	14 355	0.09	0.90	0.001
Total CO_2 eqv								3.16

5.8.5 Time series consistency

The emission of CH_4, N_2O, NO_x, CO, CO_2, SO_2 and NMVOC from field burning contributes with less than 1 % of the national emission.

5.9 CO_2 from liming

5.9.1 Description

The emission of CO_2 from liming in Denmark occurs during liming with limestone. The emission of CO_2 from liming contributes with 98 % of the CO_2 emission from the agricultural sector.

5.9.2 Methodological issues

A Tier 1 method as given in the 2019/2006 IPCC Guidelines is used.

5.9.3 Activity data

The amount of limestone used is based on the sales statistics. The amount used on the agricultural soils is collected by SEGES (Hansen, 2022). The amount of limestone used in private gardens is based on expert judgement (Andersen, 2004, pers. comm.).

5.9.4 Emission factors

The emission factor is 0.44 kt CO_2 per kt limestone and is the same for all years 1990 to 2021. It is based on the molecular weight for $CaCO_3$ and CO_2.

$$EF=\frac{M_{CO_2}}{M_{CaCO_3}}$$

Where:

EF   Emission factor for CO_2 from liming

M_i Molecular weight for *i* molecule

5.9.5 Time series consistency

The emission of CO_2 from liming has overall decreased by 52 % from 1990 to 2021. As shown in Figure 5.13, the main decrease is occurring from 1990 to 1997, and is due to a change in fertiliser practice with increase in use of manure as fertiliser and decrease in use of inorganic N fertiliser. When ammonium nitrogen is used as fertiliser and a loss of nitrogen from the soil is occurring, it causes an acidification of the soil and use of liming could be necessary to even out pH in the soil (Knudsen, 2004).

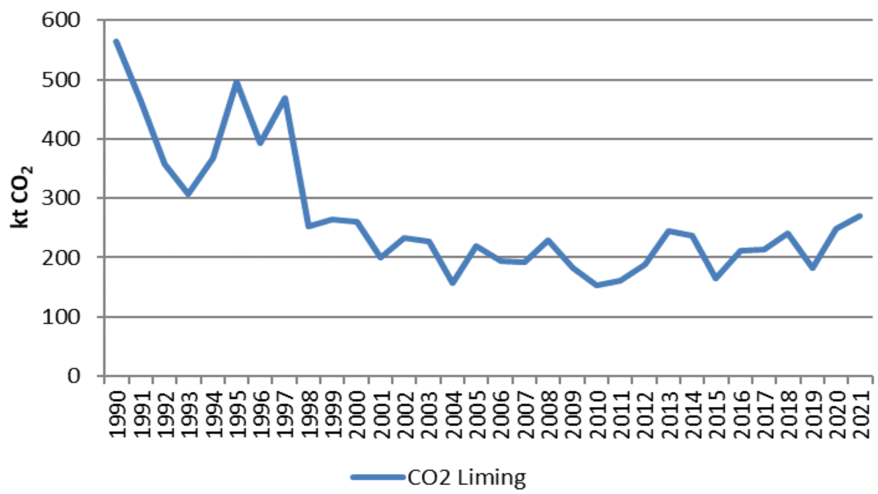

Figure 5.13 CO_2 emission from liming, 1990 to 2021.

5.10 CO_2 from urea

5.10.1 Description

Emission of CO_2 from use of urea contributes with less than 1 % of the CO_2 emission from the agricultural sector.

5.10.2 Methodological issues

A Tier 1 method as given in the 2019/2006 IPCC Guidelines is used.

5.10.3 Activity data

The amount of urea used on agricultural soils is based on sales estimates from the Danish Agricultural Agency (Danish Agricultural Agency, 2022).

5.10.4 Emission factors

The default emission factor of 0.20 kg C per kg urea given in the 2019/2006 IPCC Guidelines is used.

5.10.5 Time series consistency

Figure 5.14 shows the emission of CO_2 form use of urea. The emission has decreased with 92 % from 1990 to 2021, but the main decrease is occurring from 1990 to 2000. From 2003 to 2021, the emission is almost unaltered. The decrease is due to decrease in the use of urea.

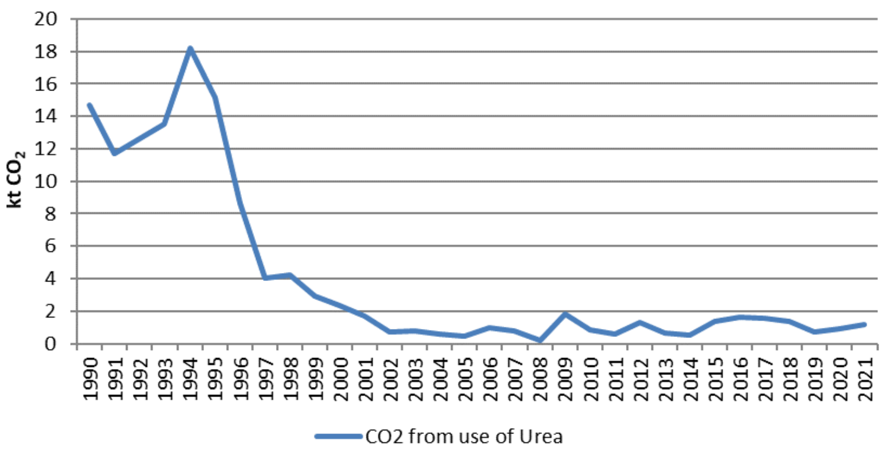

Figure 5.14 Emission of CO_2 from use of urea, 1990 to 2021.

5.11 CO_2 from other carbon-containing fertilisers

5.11.1 Description

Use of other carbon-containing fertilisers is in Denmark the use of calcium ammonium nitrate (CAN). The emission of CO_2 from CAN contributes with 2 % of the CO_2 emission from the agricultural sector.

5.11.2 Methodological issues

A Tier 1 method as given in the 2019/2006 IPCC Guidelines is used.

5.11.3 Activity data

The amount of CAN used on agricultural soils is based on sales estimates from the Danish Agricultural Agency (Danish Agricultural Agency, 2022).

5.11.4 Emission factors

The emission factor is 0.026 kg C per kg CAN and the same for all years 1990 to 2021. It is based on the molecular weight:

$$EF=\left(\frac{\text{kg CaCO}_3}{\text{kg CAN}}/100\right)/M_{CaCO_3}\cdot M_C$$

$$\frac{\text{kg CaCO}_3}{\text{kg CAN}}=\left(100-M_{NH_4NO_3}\right)/M_{CaMg(CO_3)_2}\cdot M_{CaCO_3}\cdot 2$$

Where:

EF Emission factor for CO_2 from CAN

M_i Molecular weight for *i* molecule

5.11.5 Time series consistency

Figure 5.15 shows the emission of CO_2 form use of CAN. The emission has decreased with 90 % from 1990 to 2021, but the main decrease is occurring from 1990 to 1999. From 2000 to 2021, the emission is almost unaltered except from in 2015 were an increase is seen. The change is due to change in the use of CAN.

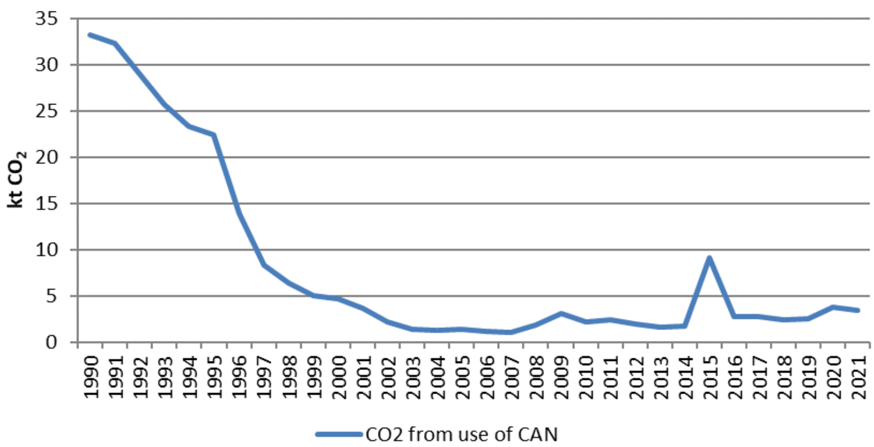

Figure 5.15 Emission of CO_2 from use of CAN, 1990 to 2021.

5.12 Uncertainties

Uncertainties are calculated using Approach 1.

5.12.1 Uncertainty values

The main part of the Danish emissions depends on the livestock production, and uncertainties, such as number of animals, feeding consumption, normative figures etc., are relatively low. The number of animals is estimated by Statistics Denmark and all cattle, sheep and goats have their own ID-number (ear tags), which is an important reason for a low uncertainty level. The uncertainties for the most important livestock categories are relatively low e.g. for swine and cattle the uncertainties is estimated to 1.3 % and 0.9 %, respectively (DSt, 2022). The uncertainty is higher for less important animal groups, e.g. fur bearing animals (3.2 %), poultry, horses and sheep (10.4 %) (DSt, 2022). The overall uncertainty for number of animals is estimated to 2 %.

The Danish Normative System for animal excretions is based on data from SEGES and DCA, Aarhus University. SEGES is the central office for all Danish agricultural advisory services and are participating in a great deal of research as well as the collection of efficacy reports from Danish farmers for dairy production, meat production, swine production, etc. to optimise productivity in Danish agriculture. In total, feeding plans from 15-18 % of Danish dairy production, 25-30 % of swine production, 80-90 % of poultry production and approximately 100 % of fur production are collected annually. These basic feeding plans are used to develop the standard values of the "Danish Normative System". However, due to the large number of farms included in the norm figures, the arithmetic mean can be assumed as a very good estimate with a low uncertainty. In the normative standards (Børsting & Hellwing, 2022) uncertainty values are indicated for emission measurements in housing and varies from 15 -25 %.

Data for hectares under cultivation is estimated by Statistics Denmark and the uncertainties are based on their estimates. For the most common crops, winter wheat the uncertainty are 1.1% estimated by DST (2022) and a less common crop type as spring wheat is estimated to 5.8%. The overall uncertainties for the total cultivated area are below 5 %.

For CH_4 emission from enteric fermentation, the uncertainty for activity data is the uncertainty for numbers of animals and the uncertainty for the emission factor is based on IPCC 2019. For the emission of CH_4 from manure management, the uncertainty for the activity data is the uncertainty for number of animals and the distribution of housing types. The uncertainty for the emission factor is based on uncertainty given in IPCC 2019.

For the N_2O emission uncertainties, the activity data uncertainty is based on the uncertainties for NH_3 emission due to the high correlation between the NH_3 and N_2O emission (Nielsen et al., 2022). Uncertainties related to the N_2O emission factor are based on the IPCC 2006. See Table 5.32 for uncertainty values for the agricultural sector.

Table 5.32 Uncertainties values for activity data and emission factors for CH_4, N_2O and CO_2.

CRF category	Emission factor	Uncertainties value for activity data, %	Uncertainties value for emission factor, %
3A Enteric Fermentation	CH_4	2	20
3B Manure Management			
	CH_4	5	20
	N_2O	20	100
3B5 Atmospheric Deposition	N_2O	15	100
3D Agricultural Soils			
3Da Direct soil emissions			
3Da1 Inorganic N fertiliser	N_2O	3	300
3Da2a Animal manure applied to soils	N_2O	25	300
3Da2b Sewage sludge applied to soils	N_2O	15	300
3Da2c Other organic fertiliser applied to soils	N_2O	20	300
3Da3 Urine and dung deposited by grazing animals	N_2O	10	300
3Da4 Crop Residues	N_2O	25	300
3Da5 Mineralization	N_2O	50	300
3Da6 Cultivation of organic soils		50	300
3Db Indirect soil emissions			
3Db1 Atmospheric deposition	N_2O	15	500
3Db2 Leaching	N_2O	20	300
3F Field Burning of Agricultural Residue			
	CH_4	25	50
	N_2O	25	50
3G Liming	CO_2	5	100
3H Urea application	CO_2	3	100
3I Other carbon-containing fertilisers	CO_2	3	100

5.12.2 Result of the uncertainty calculation

Table 5.33 shows the result of Approach 1 uncertainty calculation for 2021. The overall uncertainty calculation for the agricultural sector based on Approach 1 is estimated to ±44 %.

The lowest uncertainties are seen for CH_4 emission from enteric fermentation and manure management and the highest for emission form atmospheric deposition.

Table 5.33 Uncertainty calculation, 2021.

Uncertainty		Emission, kt CO_2 eqv.	Uncertainty, % Lower and upper (±)
3 Agriculture total	CH_4, N_2O and CO_2	12 074	44
3A Enteric Fermentation	CH_4	4 142	20
3B Manure Management	CH_4 and N_2O	3 660	22
	CH_4	3 064	21
	N_2O	499	102
3B5 Atmospheric deposition	N_2O	97	101
3D Agricultural Soils	N_2O	3 993	112
3Da Direct soil emissions	N_2O	3 321	148
3Da1 Inorganic N fertiliser	N_2O	952	300
3Da2a Animal manure applied to soils	N_2O	829	301
3Da2b Sewage sludge applied to soils	N_2O	20	300
3Da2c Other organic fertiliser applied to soils	N_2O	23	301
3Da3 Urine and dung deposited by grazing animals	N_2O	33	300
3Da4 Crop Residues	N_2O	893	301
3Da5 Mineralization	N_2O	39	304
3Da6 Cultivation of organic soils	N_2O	532	304
3Db Indirect soil emissions	N_2O	672	258
3Db1 Atmospheric deposition	N_2O	158	500
3Db2 Leaching	N_2O	515	301
3F Field Burning of Agricultural Residues	CH_4 and N_2O	3	49
	CH_4	9	56
	N_2O	0.4	56
3G Liming	CO_2	271	100
3H Urea application	CO_2	1	100
3I Other carbon-containing fertilisers	CO_2	3	100

5.13 Quality assurance and quality control (QA/QC)

5.13.1 Verification

Enteric fermentation

Tier 2/Country Specific compared to IPCC Tier 2 method

A comparison between the IPCC Tier 2 methodology and Denmark's Tier 2/Country Specific (CS) calculation method for enteric fermentation is made. In the IPCC Guidelines default values are given for dairy cattle and non-dairy cattle, therefore a comparison is made for these groups.

Calculations of IEFs are made by IPCC Tier 2, with both default and national values for Y_m, and Denmark's Tier 2/CS method. A comparison between IEFs (Table 5.34) shows that the Danish method gives a value for dairy cattle, which is 14 % higher than the IPCC Tier 2 method and for non-dairy cattle, the Danish method gives a value which is 5 % higher than the IPCC Tier 2.

Table 5.34 IEFs for enteric fermentation calculated by different methods, 2021.

kg CH_4 per animal per year	Tier 2 (IPCC Y_m)	Tier 2 (DK Y_m)	Tier 2/CS
Dairy cattle	141.8	143.4	161.6
Non-dairy cattle	38.0	38.0	39.7

The three different Tier 2 calculations for non-dairy cattle all show an IEF between 38.0-39.7 kg per head per year, which indicates that the Tier 2/CS used in the Danish inventory is reasonable. However, these values are lower compared to the Tier 1 default value at 52 kg per head per year given in the IPCC 2019, Table 10.11, which can be explained by a lower animal weight/lower feed intake.

The higher value for the IEF for dairy cattle is mainly due to higher GE in Danish method (Table 5.35). The Danish values for feed consumption are based on the Danish normative figures, the normative data are based on actual efficacy feeding controls or actual feeding plans at farm level. The national Y_m have been lowered in 2018 and 2020 due to change in feeding composition and fodder practice for Danish dairy cattle. More info on GE calculations and Y_m is included in Chapter 5.3.2.

Table 5.35 GE for dairy cattle calculated by different methods, 2021.

MJ per animal per day	Tier 2 (IPCC Y_m)	Tier 2/CS
Dairy cattle	379.3	426.5

Manure management

Nitrogen excretion rates compared to the IPCC defaults

For non-dairy cattle, horses, poultry and mink (have no bearing on mink in 2021) nitrogen excretion rates given by 2019 IPCC Guidelines and the Danish nitrogen excretion rates are at the same level. For dairy cattle Denmark has a higher nitrogen excretion rate than given in 2019 IPCC Guidelines, this is due to a high feed consumption to give high milk production per cow at Danish dairy cattle. The nitrogen excretion rate for swine reported in the CRF is an average for the subcategories sows, weaners and fattening pigs, 7.1 kg N per animal per year in 2021. For sows the nitrogen excretion rates given by 2019 IPCC Guidelines and the Danish nitrogen excretion rates are at the same level. However, the Danish nitrogen excretion rate is lower than the default given in the 2019 IPCC Guidelines for fattening pigs and this is due to the high feed efficiency in Danish swine and the high share of weaners.

The animal weights are not used directly for estimating emissions because excretion rates are given in the Danish normative figures per animal (Børsting & Hellwing, 2022). The weights for animals given in the CRF Tables are mainly for the most dominating subcategory.

Table 5.36 Nitrogen excretion rates from the 2019 IPCC Guidelines and for Denmark, 2021.

IPCC	kg N per 1000 kg animal per day	Weight kg (DK)	kg N per animal per year	Denmark	kg N per animal per year
Dairy cattle	0.5	580	105.9	Dairy cattle	156.9
Other cattle	0.42	320[1]	49.1	Non-dairy cattle	42.3
Swine - market	0.76	115[2]	31.9	Swine – weighted fattening pigs and weaners	5.7
				Swine - fattening pigs	9.9
				Swine - weaners	2.1
Swine - breeding	0.38	140	19.4	Swine - sows	23.5
Sheep	0.36	70[3]	9.2	Sheep – weighted	6.6
				Sheep - mother	12.8
				Sheep - lambs	2.5
Goats	0.46	60[4]	10.1	Goats	16.8
Horses	0.26	600[5]	56.9		
- average weight		504[5]	47.8	Horses – weighted	43.8
Hens	0.87	2	0.6	Hens	1.1
Pullets	0.58	1.4	0.3	Pullets	0.1
Broilers	1.14	2	0.8	Broilers	0.4
Turkeys	0.74	14	3.8	Turkeys	2.6
Ducks	0.83	3.7	1.1	Ducks	1.0
Mink			4.59	Mink	5.5
Fox			12.09		

[1] Weight of heifers.

[2] Weight of fattening pigs. Weaners weigh 6.7-31 kg (Børsting et al, 2021).

[3] Weight of mother sheep including 1.5 lambs (Børsting et al, 2021).

[4] Weight of mother goat including 1.5 kid (Børsting et al, 2021).

[5] 600 kg is the weight of the most dominating group of horses, while 504 kg are the average weight for all horses.

Nitrogen excretion compared to DCA numbers

DCA, who estimates the normative figures for nitrogen excretions per animal, also estimate the total amount of nitrogen excreted for the years 2005-2016 (Blicher-Mathiesen et al., 2018).

A comparison of the total nitrogen excretion estimated by DCE for the emission inventory and that estimated by DCA is made, see Figure 5.16. It is seen that the trend for the total nitrogen excretion almost follow the same pattern for both estimations. The nitrogen excretion estimated by DCE are a bit higher than the nitrogen excretion estimated by DCA and this is probably due to the number of animals. The inventory includes animals on small farms, which are not included in numbers from DSt (horses, sheep and goats) and also some animal categories, which are not included in the normative system (deer, pheasants and ostriches). Another reason for the difference between the two estimations could be differences in definitions for grazing – e.g. days on grass vs. days in housings.

The comparison between the total N-excretion estimated by DCE and DCA, shows the same trend, and based on this, it is concluded that the total N-excretion estimated by DCE for all years 1985-2021 used in the national inventory, seems reliable.

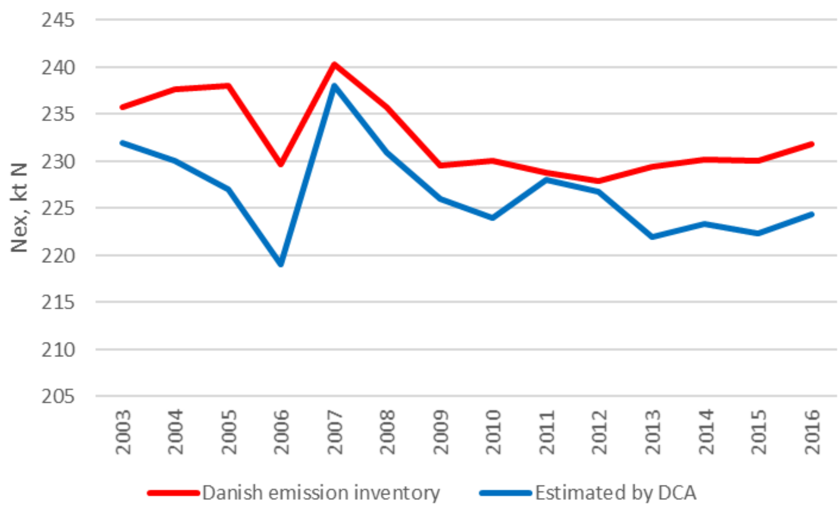

Figure 5.16 Comparison of nitrogen excretion estimated by DCE and DCA.

MCF compared to IPCC default

The comparison of MCF given in IPCC 2019 and the MCF used in the Danish inventory are shown in Annex 3D, Table 3D-15. For liquid untreated and biogas treated manure for cattle and swine, a national estimated MCF is used (see Annex 3D Chapter 3D-1). For other animal categories and manure types, the MCF is based on values from the 2019 IPCC Guidelines.

Distribution of animals on housing types

Table 5.37 shows the distribution of animals on different manure management systems given in IPCC 2019 and the Danish national distribution. The main part of Danish dairy cattle is housed in systems with liquid/slurry manure whereas the distribution given by IPCC, for a great part, is housed in systems with solid manure. IPCC has a great part of non-dairy cattle on systems with solid manure, whereas this part of non-dairy cattle in the Denmark is in systems with deep litter that is the manure management system other. For swine, the main part of the animals in Denmark is housed in systems with liquid/slurry, as it is also the case in the IPCC distribution, but here are also a great part in systems with pit > 1 month which is not commonly in Denmark.

Table 5.37 Distribution of animals on manure management systems IPCC 2019 vs. national.

	IPCC 2019			DK 2021		
	Dairy cattle	Other cattle	Swine	Dairy cattle	Non-dairy cattle	Swine
Lagoon	0	0	6	0	0	0
Liquid/slurry	43	22	51	58.9	31.3	86.9
Solid storage	29	26	14	0.7	0.3	0.1
Drylot	0	0	0	0	0	0
Pasture, range and paddock	26	48	0	4.9	28.8	0.4
Daily spread	2	4	1	0	0	0
Digester	0	0	0	27.2	0	9.4
Burned for fuel	0	0	-	0	0	0
Other	0	0	-	8.3	39.6	3.2
Pit < 1 month	-	-	2	0	0	0
Pit > 1 month	-	-	26	0	0	0

Calculation of VS based on GE and DM

Figure 5.17, 5.18 and 5.19 show a comparison of the calculation of VS based on gross energy (GE) and manure. In the Danish inventory, the calculation of

VS is based on manure. For dairy cattle, the two calculations follow the same trend, but the VS based on manure are higher than the one based on GE. This is mainly due to the inclusion of bedding.

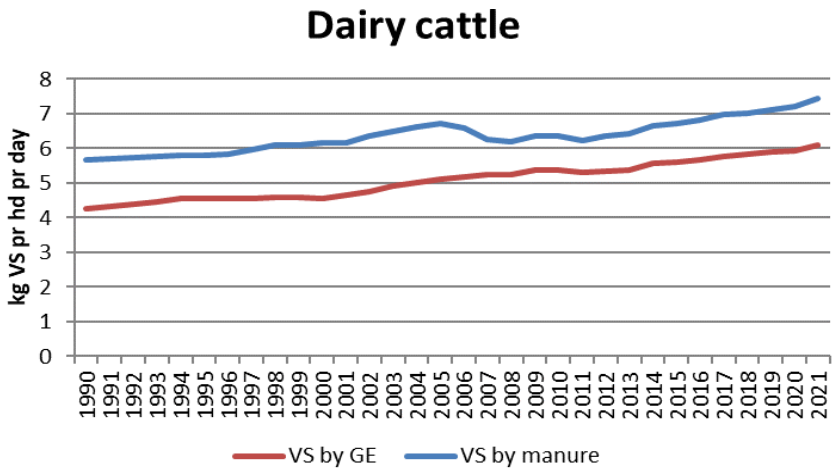

Figure 5.17 VS for dairy cattle based on GE and on manure.

For all non-dairy cattle, VS based on manure are higher than the one based on GE and this is mainly due to the inclusion of bedding. For bulls, VS based on manure, increase in 2001-2011 due to increase in the share of animals in housings with deep litter. From 2012 to 2013, the VS for bulls decrease due to reduction of bedding per animal per day given in the normative figures. VS based on manure for suckling cattle change due to increase in amount of manure per animal and decrease in dry matter (DM) in the manure for animals on some housing types. The decrease from 2006 to 2007 is due to division of suckling cattle in three wait classes with different amount of bedding per animal per day.

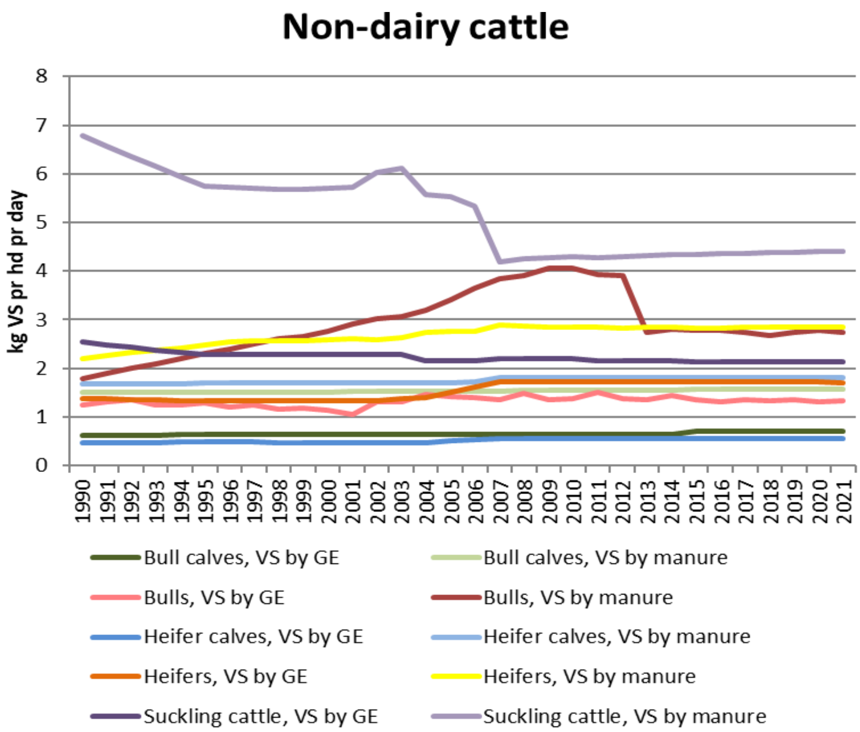

Figure 5.18 VS for non-dairy cattle based on GE and manure.

VS for weaners and fattening pigs based on both GE and manure follow the same trend, but the VS based on GE are a bit higher than VS based on manure.

This is mainly due to high feed efficiency in Danish swine. The decrease in VS based on manure for sows in 2004-2007 is due to decrease in the share of animals in housings with bedding.

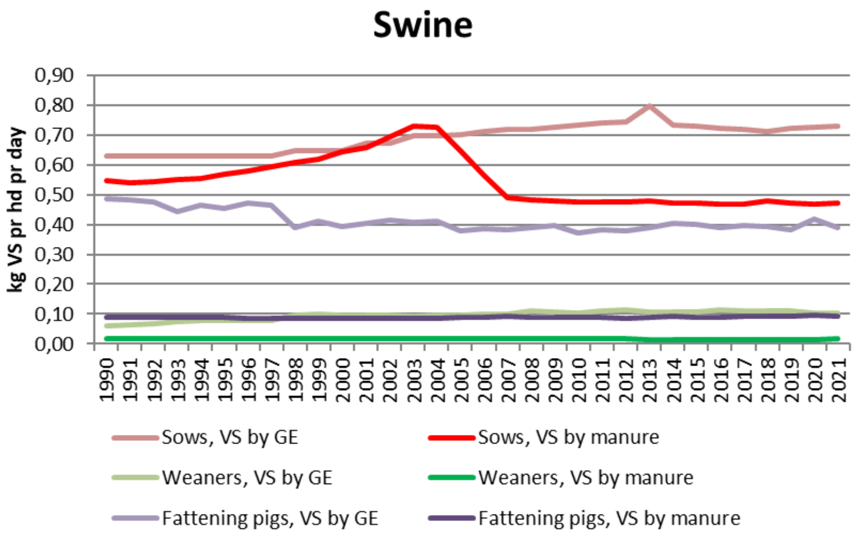

Figure 5.19 VS for swine based on GE and manure.

5.13.2 QA/QC plan

A first step of development and implementation of a general QA/QC plan for all sectors started in 2004 which is described in a publicised manual (Sørensen et al., 2005). The manual describes the concepts of quality work and how to handle quality management by using Critical Control Points and a list of Point of Measurements (Nielsen et al., 2013). For more detailed information of the structure in the general QA/QC plan, please refer to Chapter 1.6 for QA/QC.

A complete list Points of Measures (PM) are given in Table 1.2. PM related to the agricultural inventory is listed below in Chapter 5.13.3 and are primarily connected to data storage and data processing level 1. For PM not mentioned below please refer to Chapter 1.6.

The QA/QC work specific for the agricultural sector is still improved. The overall framework regarding a QA/QC plan for agriculture are constructed in form of six stages and each stage focus on quality assurance and quality check in different part of the inventory process. A more detailed set up for stage I, II and III are developed – refer to Annex 3D Table 3D-21.

The QA/QC procedure is divided in six stages as listed below:

Table 5.38 Stages of QA/QC procedure.

Stage I	**Check of input data** - check of data input in IDA are consistent with data from external data suppliers
Stage II	**Check of IDA data – overall** - check of recalculations for total emissions compared with the latest submission - check of total emissions for the total CO_2 eqv. and for each compound
Stage III	**Check of IDA data – specific** - check of annual changes of activity data, emission factors, IEF and other important variables as GE, Nex, housing system distribution, grazing days
Stage IV	**Check by comparing calculation with estimates from other institutions** - the total Nex for all livestock production estimated by DCA - the Register for fertilization controlled by the Danish Agricultural Agency
Stage V	**Check of data registered in CRF** - compare data in CRF with data from IDA
Stage VI	**Check of the inventory in general (external review)** - check that data is used correctly - check the methodology and the calculations

Stage I: Check of input data

At stage I, it is checked that all input data in IDA are consistent with data from the external data suppliers. Data from the Statistics Denmark have to be checked for the livestock production, slaughter data for poultry and pigs, check of land use and crop yield. Data input from the DCA have to be checked for feed intake, N-excretion, manure production, dry matter content and grazing days. Data from the Danish Agricultural Agency: distribution of housing systems and the use of nitrogen in inorganic N fertiliser.

Stage II: Check of IDA data - overall

Stage II includes check of the overall calculations in IDA, where the first step is to compare the inventory with the last reported emission inventory - submission 2022. In the case where an error covers the whole time series, it can be difficult to identify this error by checking the changes in inter-annual values. Therefore, a check of recalculations is needed.

Next step in stage II is a check of total emissions of CH_4, N_2O, NMVOC and the other compounds, which are related to the field burning of agricultural residues. For each compound, a check of trends of time series 1990-2021 and inter-annual changes is provided. Significant jumps or dips from one year to another could indicate an error - otherwise it has to be explained.

Stage III: Check of IDA data - specific

At stage III, a check of specific variables in IDA is provided for both inter-annual changes and trends for the entire time series. Variables includes activity data, emission factors, IEFs and other important key variables such as feed intake, GE, Nex and housing system distribution.

Stage IV: Check by comparing calculation with estimates from other institutions

The purpose of stage IV is to verify the calculations in IDA, as far as external data estimations are available. For other purposes DCA for some years calculate the overall N excretion from the total livestock production in DK, this is compared with the estimated in the emission inventory, see Chapter 5.13.1.

Another possibility to check some of the IDA estimations is the information in the fertiliser accounts controlled by The Danish Agricultural Agency. Farmers with more than 10 animal units is registered and have to keep accounts of the N content in manure, received manure or other organic fertiliser. These comparisons will properly show some differences, which not necessarily indicate an error, but the most important cause of the difference has to be identified.

Stage V: Check of data registered in CRF

Stage V primarily focuses on the last reported year 2021 and the base year (1990), where all activity data, emissions and IEFs are checked. Furthermore, CRF sum emissions are checked with sum emissions in IDA. If an error is detected a more detailed check is done to find the reason for the error.

Stage VI: Check of the inventory in general

A detailed description of the methodology used to calculate the Danish agricultural emissions is published as a sectorial report for agriculture (Albrektsen et al., 2021). General checks of the inventory include considerations of which data input is used, how they are used in the calculations and whether more accurate data are available. The review of the sectorial report addresses these issues and is a most valuable part of the QA of the agricultural sector.

Status for the QA/QC plan

The framework for working out a specific QA/QC plan for the agricultural sector is complete. Stage I-III is done as part of the process of inventory preparation, which has reduced the number of errors in the CRF and in this way meet the ERT recommendations. A more detailed list showing the checked variables of stage I – III is provided in Annex 3D Table 3D-21.

Concerning the stage IV we have provide some random checks but need to provide a more systematic check. We are aware of some external calculations, which can be compared with the estimations in IDA – e.g. some comparisons with the Register of Fertilisation administrated by the Danish Agricultural Agency can be provided.

Stage VI is implemented. Five reports describing the methodology in calculation of agricultural emissions in details are published (Mikkelsen et al., 2006, Mikkelsen et al., 2011, Mikkelsen et al., 2014, Albrektsen et al., 2017 and Albrektsen et al., 2021). All reports have been reviewed by experts not involved with the preparation of the emission inventory. The 2021 report was reviewed by Anders Peter Adamsen, Aarhus University, DCA – National Centre for Food and Agriculture. The reviewer have reviewed all sections of the report.

5.13.3 QA/QC plan expressed in Critical Control Points and Point of Measurements

Data storage level 1

Data Storage level 1	3. Completeness	DS.1.3.1	Documentation showing that all possible national data sources are included by setting down the reasoning behind the selection of datasets.

The following external data are in used in the agricultural sector, in more details see Table 5.3:

- Data from the annual agricultural census made by Statistics Denmark.
- DCA, Aarhus University.
- The Danish Agricultural Agency
- SEGES
- The Danish Energy Agency.
- Danish Environmental Protection Agency.

The emission factors come from various sources:

- IPCC guidelines.
- DCA, Aarhus University: NH_3 emission, CH_4 emission from enteric fermentation and manure management.

Statistics Denmark

The agricultural census made by Statistics Denmark is the main supply of basic agricultural data. In Denmark, all cattle, sheep and goats have to be registered individually and hence the uncertainty in the data is negligible. For all other animal types, farms having more than 10 animal units are registered.

DCA

The DCA is responsible for the delivery of N-excretion data for all animal and housing types. Data on feeding consumption on commercial farms are collected annually by SEGES from on-farm efficacy controls. For dairy cattle, data is collected from 15-20 % of all farms, for pigs, 25-30 % and for poultry and mink, 90-100 % of all farms. The farm data are used to calculate average N-excretion from different animal and housing types. Due to the large amount of farm data involved in the dataset, N-excretion is seen as a very good estimate for average N-excretion at the Danish livestock production.

Danish Agricultural Agency

Total area with the various agricultural crops is provided to the Danish Agricultural Agency via the agricultural subsidy system. For every parcel of land (via a vector-based field map with a resolution of >0.01 ha), the area planted with different crops is reported. If the total crop area within a parcel is larger than the parcel area, a manual control of the information is performed by the Agency. The area with different crops, therefore, represents a very precise estimate.

All farmers are obligated to do N-fertiliser accounting on a farm and field level based on the Danish normative data provided by DCA. Data at farm level is reported annually to the Danish Agricultural Agency. The N figures also include the quantities of inorganic N fertilisers applied to agricultural soils. Suppliers of inorganic N fertilisers are required to report all N sales to commercial farmers to the Danish Agricultural Agency, which is registered and published in a sales statistic annually. Comparison between the sales statistics and the N fertiliser account, shows a higher consumption of N in inorganic fertilisers from 2005, which is caused be an import from the farmers them self. Therefore, the consumption of N in use of inorganic fertiliser registered in the n fertiliser account seems to be the most reliably reference.

The Danish Agricultural Agency, as the controlling authority, performs analysis of feed sold to farmers. On average, 1600 to 2000 samples are analysed every year. Uncertainty in the data is seen as negligible. The data are used when estimating average energy in feedstuffs for pigs, poultry, fur animals, etc.

From 2005, the Danish Agricultural Agency provides data for distribution of housing type based on registration from farmers to the Danish fertiliser N accounts.

SEGES

SEGES is the central office for all Danish agricultural advisory services. SEGES carries out a considerable amount of research itself, as well as collecting efficacy reports from the Danish farmers for dairy production, meat production, pig production, etc., to optimise productivity in Danish agriculture. From SEGES data on housing type until 2004, grazing situation and information on application of manure is received.

The Danish Energy Agency

The amount of slurry treated in biogas plants is received from the Danish Energy Agency.

Danish Environmental Protection Agency

Information on the sludge from wastewater treatment and the manufacturing industry and the amount applied on agricultural soil is obtained from the Danish Environmental Protection Agency.

Data Storage level 1	1. Accuracy	DS.1.1.1	General level of uncertainty for every dataset including the reasoning for the specific values

The most important emission source is related to the animal production. Uncertainty for the animal data is very low due to the very strict environmental laws in Denmark. Standard deviation regarding the numbers of cattle and pigs has been estimated to <0.7 %. For poultry the standard deviation is <2.1 %. For all years, 25-35 % of all holdings are included in the census. The standard deviation for N-excretion between farms is reported as 25 % for dairy cattle and pigs, but due to the large numbers involved in the estimation of the average N-excretion, the average is assumed a precise estimate for the Danish agricultural efficacy level.

Regarding uncertainties for the remaining emission sources, see Chapter 5.12.

Data Storage level 1	1. Accuracy	DS.1.1.2	Quantification of the uncertainty level of every single data value including the reasoning for the specific values.

Please, refer to Chapter 5.12 and Table 5.31.

Data Storage level 1	1. Comparability	DS.1.2.1	Comparability of the data values with similar data from other countries, which are comparable with Denmark, and evaluation of discrepancy.

The Danish N-excretion levels are generally lower than IPCC default values. This is due to the highly skilled, professional and trained farmers in Denmark, with access to a highly competent advisory system.

The feed consumption per animal is in line with similar data from Sweden, although they are not quite comparable because Denmark is using feeding units (FE) which cannot easily be converted to energy content. Earlier, one feeding unit was defined as one kg of barley. Today, the calculations are more complicated and depend on animal type.

Data Storage level 1	4. Consistency	DS.1.4.1	The origin of external data has to be preserved whenever possible without explicit arguments (referring to other PMs).

External data received are stored in the original format in the quality management database system.

Data Storage level 1	6. Robustness	DS.1.6.1	Explicit agreements between the external institution holding the data and DCE about the conditions of delivery.

DCE has established formal data agreements with all institutes and organisations, which deliver data, to assure that the necessary data is available to prepare the inventory on time.

Data Storage level 1	6. Robustness	DS.1.6.2	At least two employees must have a detailed insight into the gathering of every external data set.

Please refer to Chapter 1.6.

Data Storage level 1	7. Transparency	DS.1.7.1	Summary of each dataset including the reasoning for selecting the specific dataset.

Please refer to DS 1.1.1.

Data Storage level 1	7. Transparency	DS.1.7.2	The archiving of data sets needs to be easy accessible for any person in the emission inventory.

Please refer to Chapter 1.6.

Data Storage level 1	7. Transparency	DS.1.7.3	References for citation for any external data set have to be available for any single value in any dataset.

A great deal of documentation already exists in the literature list, and is also achieved in the quality management database system.

Data Storage level 1	7. Transparency	DS.1.7.4	Listing of external contacts for every dataset.

Statistics Denmark:

Mrs. Mona Larsen (mla@dst.dk)
Mr. Karsten K. Larsen (kkl@dst.dk)

DCA (Aarhus University):

Mr. Christian Friis Børsting (cfb@anis.au.dk)
Mr. Peter Lund (peter.lund@anis.au.dk)
Mr. Christen Duus Børgesen (christen.Borgesen@agro.au.dk)
Mrs. Gitte Blicher-Mathisen (gbm@bios.au.dk)
Mr. Henrik Tornbjerg (hto@bios.au.dk)

SEGES:

Mr. Torkild Birkmose (tsb@seges.dk)

Danish Agricultural Agency:

Mrs. Mette Skade (mail@lbst.dk)

The Danish Energy Agency:

Mr. Christian Bloch (cnbh@ens.dk)
Mr. Søren Tafdrup (st@ens.dk)

Data processing level 1

Data Processing level 1	1. Accuracy	DP.1.1.1	Uncertainty assessment for every data source as input to Data Storage level 2 in relation to type of variability. (Distribution as: normal, log normal or other type of variability).

The Approach 1 methodology is used to calculate the uncertainties for the agricultural sector. The uncertainties are based on a combination of IPCC guidelines and expert judgement (Olesen et al., 2001, Poulsen et al., 2001) and a normal distribution is assumed.

Data Processing level 1	1. Accuracy	DP.1.1.2	Uncertainty assessment for every data source as input to Data Storage level 2 in relation to scale of variability (size of variation intervals).

Please refer to DP 1.1.1.

Data Processing level 1	1. Accuracy	DP.1.1.3	Evaluation of the methodological approach using international guidelines.

Denmark has worked out a report with a more detailed description of the methodological inventory approach in Mikkelsen et al. (2006), Mikkelsen et al. (2011), Mikkelsen et al. (2014), Albrektsen et al. (2017) and an updated version in Albrektsen et al. (2021). The first report has been reviewed by the Statistics Sweden, who is responsible for the Swedish agricultural inventory; the second was reviewed of qualified persons with comprehensive agricultural knowledge; Nicholas J. Hutchings from the DCA, Aarhus University and Johnny M. Andersen from the Faculty of Life Sciences, University of Copenhagen. The third was reviewed by MST. The fourth was reviewed by Peter Lund, from Department of Animal Science, Aarhus University and the latest was reviewed by Anders Peter Adamsen, Aarhus University, DCA – National

Centre for Food and Agriculture. None of the reviewers is involved in the preparation of the annual inventory.

Furthermore, data sources and calculation methodology developments are continuously discussed in cooperation with specialists and researchers in different institutes and research sections. Consequently, both the data and methods are evaluated continually according to the latest knowledge and information.

Data Processing level 1	1. Accuracy	DP.1.1.4	Verification of calculation results using guideline values

The methodological approach is consistent with the IPCC 2006 Guidelines and IPCC 2019 Refinement. See Chapter 5.13.1.

Data Processing level 1	2. Comparability	DP.1.2.1	The inventory calculation has to follow the international guidelines suggested by UNFCCC and IPCC.

The methodological approach is consistent with the IPCC 2006 Guidelines and IPCC 2019 Refinement.

Data Processing level 1	3. Completeness	DP.1.3.1	Assessment of the most important quantitative knowledge, which is lacking.

Regarding the reduction potential for biogas treated slurry, more information and investigation would be preferred. There is on-going work to increase the accuracy of this emission source.

Data Processing level 1	3. Completeness	DP.1.3.2	Assessment of the most important missing accessibility to critical data sources

All known major sources are included in the inventory. In Denmark, only very few data are restricted. Accessibility is not a key issue; it is more lack of data.

Data Processing level 1	4. Consistency	DP.1.4.1	In order to keep consistency at a high level, an explicit description of the activities needs to accompany any change in the calculation procedure

The calculation procedure is consistent for all years.

Data Processing level 1	4. Consistency	DP.1.4.2	Identification of parameters (e.g. activity data, constants) that are common to multiple source categories and confirmation that there is consistency in the values used for these parameters in the emission calculations

Please refer to Chapter 1.6.

Data Processing level 1	5. Correctness	DP.1.5.1	Show at least once, by independent calculation, the correctness of every data manipulation.

During the development of the model, thorough checks have been made by all persons involved in preparation of the agricultural section.

Data Processing level 1	5. Correctness	DP.1.5.2	Verification of calculation results using time series.

Time series for activity data, emission factors and national emission are performed to check consistency in the methodology, to avoid errors, to identify and explain considerable year-to-year variations.

Data Processing level 1	5. Correctness	DP.1.5.3	Verification of calculation results using other measures.

A comparison between IPCC Tier 2 method for enteric fermentation and Denmark's Tier 2/CS is made, see Chapter 5.13.1.

Data Processing level 1	5. Correctness	DP.1.5.4	Show one-to-one correctness between external data sources and the databases at Data Storage level 2

In the database key ids is used to identify the unique data. The data on DS level 1 is linked to the key id used in the database so a clear reference from DS level 1 to higher levels of both DP and DS is secured.

Data Processing level 1	6. Robustness	DP.1.6.1	Any calculation must be anchored to two responsible persons that can replace each other in the technical issue of performing the calculations.

Please refer to Chapter 1.6.

Data Processing level 1	7. Transparency	DP.1.7.1	The calculation principle and equations used must be described.

All calculation principles are described in the NIR and the documentation report (Albrektsen et al., 2021).

Data Processing level 1	7. Transparency	DP.1.7.2	The theoretical reasoning for all methods must be described.

All theoretical reasoning is described in the NIR and the documentation report (Albrektsen et al., 2021).

Data Processing level 1	7. Transparency	DP.1.7.3	Explicit listing of assumptions behind methods.

All theoretical reasoning is described in the NIR and the documentation report (Albrektsen et al., 2021).

Data Processing level 1	7. Transparency	DP.1.7.4	Clear reference to dataset at Data Storage level 1.

In the database key ids is used to identify the unique data. The data on DS level 1 is linked to the key id used in the database so a clear reference from DS level 1 to higher levels of both DP and DS is secured.

Data Processing level 1	7. Transparency	DP.1.7.5	A manual log to collect information about recalculations.

Changes compared with the last emissions report are described in the NIR and the national emission changes is given in a table under the section, "Recalculation". The text describes whether the change is caused by changes in the dataset or changes in the methodology used. Furthermore, a log table is filled in when data are updated or adjusted continuously.

Data storage and processing level 2

For point of measurements not mentioned below, please refer to Chapter 1.6.

Data Storage level 2	5. Correctness	DS.2.5.1	Documentation of a correct connection between all data types at level 2 to data at level 1.

A manual checklist is under development for correct connection between all data types at level 1 and 2.

Data Processing level 2	5. Correctness	DS.2.5.2	Check if a correct data import to level 2 has been made.

A manual checklist is under development for correctness of data import to level 2.

5.14 Recalculations

Below an overview of improvements and recalculations implemented since the 2022 submission.

A range of changes in calculation of agricultural emissions 1990-2020 has taken place. A range of the changes is due to change in emission factors because of transition from IPCC 2006 to IPCC 2019 Refinement. The recalculation has contributed to an increase in the total agricultural emissions for the years 1990-2020 of 5-9 % and given in CO_2 equivalent (Table 5.39).

Table 5.39 Changes in GHG emission in the agricultural sector compared with the CRF reported last year.

	1990	1995	2000	2005	2010	2015	2018	2019	2020
Previous inventory									
3.A Ent. Ferm., kt CH_4	161.6	158.7	145.2	139.3	145.2	146.7	149.8	147.8	147.2
3.B Man. Man., kt CH_4	74.2	85.8	95.1	100.9	93.6	89.2	89.5	85.9	87.9
3.B Man. Man., kt N_2O	3.2	3.1	3.2	3.2	2.6	2.4	2.5	2.3	2.3
3.D Agri. Soils, kt N_2O	19.7	17.3	15.6	14.3	14.0	14.4	14.1	15.0	15.0
3.Da1 Inorganic N fertilizer	6.3	5.0	4.0	3.2	3.1	3.3	3.5	3.7	4.0
3.Da2a Animal manure	3.3	3.1	3.1	3.3	3.3	3.3	3.4	3.3	3.3
3.Da2b Sewage sludge	0.05	0.07	0.06	0.04	0.06	0.06	0.05	0.07	0.06
3.Da2c Other organic	0.02	0.07	0.08	0.04	0.05	0.07	0.08	0.09	0.09
3.Da3 Grazing animals	1.0	1.0	1.0	0.7	0.6	0.6	0.6	0.6	0.6
3.Da4 Crop residues	2.5	2.3	2.5	2.6	2.8	3.1	2.3	3.2	3.0
3.Da5 Mineralization	0.7	0.4	0.4	0.2	0.1	0.1	0.4	0.3	0.2
3.Da6 Organic soils	2.7	2.6	2.5	2.4	2.2	2.1	2.0	2.0	2.0
3.Db1 Atmo. Depo.	1.3	1.0	0.8	0.6	0.6	0.6	0.6	0.6	0.6
3.Db2 Nitrogen leaching	1.8	1.7	1.4	1.1	1.1	1.2	1.1	1.2	1.1
3.F Field Burning, kt CH_4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
3.F Field Burning, kt N_2O	0.002	0.003	0.003	0.004	0.003	0.003	0.004	0.004	0.004
3.G Liming, kt CO_2	565.5	496.0	260.6	219.7	152.8	165.6	239.9	181.4	249.6
3.H-I Urea and CAN, kt CO_2	48.0	37.6	7.0	1.9	3.1	10.5	3.9	3.3	4.8
Total in CO_2 eqv., M. t	**13.29**	**12.78**	**11.97**	**11.59**	**11.24**	**11.24**	**11.33**	**11.31**	**11.41**
Current inventory									
3.A Ent. Ferm., kt CH_4	160.3	157.4	144.1	138.4	144.2	145.6	148.8	146.8	147.0
3.B Man. Man., kt CH_4	90.1	105.1	117.1	125.1	116.0	110.4	110.9	106.2	112.1
3.B Man. Man., kt N_2O	3.2	3.1	3.2	3.3	2.6	2.5	2.5	2.3	2.3
3.D Agri. Soils, kt N_2O	20.4	17.9	16.0	15.0	14.9	15.2	15.0	15.8	16.1
3.Da1 Inorganic N fertilizer	6.3	5.0	4.0	3.2	3.1	3.3	3.5	3.7	4.0
3.Da2a Animal manure	3.3	3.1	3.1	3.3	3.3	3.3	3.4	3.3	3.4
3.Da2b Sewage sludge	0.05	0.07	0.06	0.04	0.06	0.06	0.05	0.07	0.08
3.Da2c Other organic	0.02	0.07	0.08	0.04	0.05	0.07	0.08	0.09	0.09
3.Da3 Grazing animals	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
3.Da4 Crop residues	2.5	2.5	2.6	3.0	3.2	3.5	2.8	3.6	3.6
3.Da5 Mineralization	0.7	0.4	0.4	0.2	0.1	0.1	0.4	0.3	0.2
3.Da6 Organic soils	2.7	2.6	2.5	2.4	2.2	2.1	2.0	2.0	2.0
3.Db1 Atmo. Depo.	1.3	1.0	0.8	0.6	0.6	0.6	0.6	0.6	0.6
3.Db2 Nitrogen leaching	3.3	3.0	2.4	2.0	2.0	2.1	2.0	2.1	1.9
3.F Field Burning, kt CH_4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
3.F Field Burning, kt N_2O	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002
3.G Liming, kt CO_2	565.5	496.0	260.6	219.7	152.8	165.6	239.9	181.4	249.6
3.H-I Urea and CAN, kt CO_2	48.0	37.6	7.0	1.9	3.1	10.5	3.9	3.3	4.8
Total in CO_2-eqv., M. t	**13.90**	**13.45**	**12.67**	**12.43**	**12.08**	**12.03**	**12.15**	**12.08**	**12.39**
Change									
3.A Ent. Ferm., kt CH_4	-1.27	-1.25	-1.15	-0.97	-1.03	-1.08	-1.00	-0.97	-0.16
3.B Man. Man., kt CH_4	15.85	19.29	21.94	24.18	22.49	21.22	21.40	20.25	24.15
3.B Man. Man., kt N_2O	0.0008	0.04	0.09	0.07	0.02	0.02	0.02	0.03	0.09
3.D Agri. Soils, kt N_2O	0.75	0.60	0.37	0.68	0.91	0.82	0.92	0.83	1.10
3.Da1 Inorganic N fertilizer	0	0	0	0	0	0	0	0	0
3.Da2a Animal manure	0	0.003	0.008	0.006	0.004	0.002	0.003	0.003	0.08
3.Da2b Sewage sludge	0	0	0	0	0	0	0	0	0.02
3.Da2c Other organic	0	0	0	0	0	0	<-0.001	<-0.001	<-0.001
3.Da3 Grazing animals	-0.79	-0.83	-0.80	-0.58	-0.48	-0.47	-0.46	-0.46	-0.47
3.Da4 Crop residues	0.06	0.12	0.16	0.35	0.46	0.42	0.48	0.42	0.63
3.Da5 Mineralization	0	0	0	0	0	0	-0.01	-0.002	-0.01

3.Da6 Organic soils	0	0	0	0	0	0	0	0	0
3.Db1 Atmo. Depo.	0	-0.002	-0.002	0.002	0.004	0.010	0.010	0.010	0.021
3.Db2 Nitrogen leaching	1.49	1.31	1.00	0.90	0.93	0.86	0.90	0.86	0.82
3.F Field Burning, kt CH_4	0	0	0	0	0	-0.03	-0.05	-0.06	-0.06
3.F Field Burning, kt N_2O	0	0	0	0	0	-0.002	-0.002	-0.002	-0.002
3.G Liming, kt CO_2	0	0	0	0	0	0	0	0	0
3.H-I Urea and CAN, kt CO_2	0	0	0	0	0	0	0	0	0
Total in CO_2-eqv., M. t	**0.61**	**0.67**	**0.70**	**0.84**	**0.85**	**0.78**	**0.82**	**0.77**	**0.98**
Change in pct.									
3.A Ent. Ferm., kt CH_4	-0.78	-0.79	-0.79	-0.70	-0.71	-0.73	-0.67	-0.66	-0.11
3.B Man. Man., kt CH_4	21.36	22.48	23.06	23.96	24.04	23.78	23.91	23.57	27.48
3.B Man. Man., kt N_2O	0.02	1.19	2.82	2.06	0.73	0.75	0.93	1.18	3.97
3.D Agri. Soils, kt N_2O	3.82	3.48	2.35	4.74	6.53	5.71	6.54	5.55	7.33
3.Da1 Inorganic N fertilizer	0	0	0	0	0	0	0	0	0
3.Da2a Animal manure	0	0.11	0.27	0.17	0.11	0.07	0.08	0.09	2.43
3.Da2b Sewage sludge	0	0	0	0	0	0	0	0	32
3.Da2c Other organic	0	0	0	0	0	0	-0.01	-0.02	-0.03
3.Da3 Grazing animals	-79.32	-79.58	-79.75	-79.28	-78.98	-78.85	-78.75	-78.70	-78.62
3.Da4 Crop residues	2.29	5.11	6.54	13.34	16.49	13.59	21.13	13.38	21.01
3.Da5 Mineralization	0.00	0.00	0.00	0.00	-0.03	-0.01	-1.61	-0.63	-2.51
3.Da6 Organic soils	0	0	0	0	0	0	0	0	0
3.Db1 Atmo. Depo.	0	-0.16	-0.21	0.28	0.74	1.73	1.57	1.65	3.47
3.Db2 Nitrogen leaching	81.26	79.34	73.22	83.30	83.77	70.46	84.34	71.40	73.44
3.F Field Burning, kt CH_4	-23.33	-30.50	-34.40	-37.43	-32.02	-30.11	-39.41	-37.05	-37.32
3.F Field Burning, kt N_2O	-53.30	-57.67	-60.05	-61.89	-58.60	-57.44	-63.10	-61.66	-61.83
3.G Liming, kt CO_2	0	0	0	0	0	0	0	0	0
3.H-I Urea and CAN, kt CO_2	0	0	0	0	0	0	0	0	0
Total in pct.	**4.57**	**5.27**	**5.85**	**7.29**	**7.53**	**6.98**	**7.23**	**6.76**	**8.63**

The most significant inventory changes are mentioned below.

5.14.1 Enteric fermentation

A decrease of around 0.7-0.8 % are seen for the years 1990-2019 and a decrease of 0.1 % in 2020. The main reason for the recalculation is change in Ym which for heifers, suckling cattle, sheep and goats has been changed to Ym given in IPCC 2019 Refinement.

Number of sows has been recalculated for the years 2010-2020 due to an inconsistency. Number of weaners, fattening pigs and hens has been recalculated for 2020 due to updated data from Statistics Denmark.

5.14.2 Manure management

Recalculations have been made for CH_4, N_2O, NOx and NMVOC.

CH_4

An increase in CH_4 from manure management of 21-28 % for the years 1990-2020 is seen. This is mainly due to change in the national estimated MCF for cattle and swine slurry. For deep litter and pasture, range and paddock are MCF changed to MCF given in IPCC 2019 Refinement.

A review of the model estimating the national MCF for cattle and swine slurry have shown an error in some parameters, which has increased the MCF for untreated and biogas treated slurry. Furthermore has MCF for biogas treated slurry been changed due to a correction of input data for amount of biogas treated slurry.

Number of sows has been recalculated for the years 2010-2020 due to an inconsistency. Number of weaners, fattening pigs and hens has been recalculated for 2020 due to updated data from Statistics Denmark.

N_2O

Change from emission factors in IPCC 2006 to IPCC 2019 Refinement is the main reason for change in N_2O from manure management because the emission factor for biogas treated slurry in IPCC 2019 Refinement is increased. Furthermore are there changes in N-excretion for sows in 1991-2020 and number of sows in 2010-2020 due to an inconsistency and number of weaners, fattening pigs and hens has been recalculated for 2020 due to updated data from Statistics Denmark. This increases the emission of N_2O from manure management with up to 4 % in the years 1990-2020.

For N_2O emission from indirect emission from manure management the emission has changed up to 3 % in 1990-2020 due to the changes in N-excretion and number of animals mentioned above, but also updating of emission factors and updated data for acidification in housings for NH_3.

NMVOC

The emission of NMVOC decreases with less than 0.1 % for the years 1990-2019 and increases 0.3 % in 2020. The changes in 1990-2019 is mainly due to updating of emission factors for NH_3, because the calculation of emission of NMVOC is depending on the proportion of emissions of NH_3 from housing and storage, while the change in 2020 mainly is due to changes in number of animals.

NO_x

Changes in the number of animals mentioned above increase the emission of NO_X with up to 0.3 % in the years 2010-2020.

5.14.3 Agricultural soils

Recalculation of N_2O emission from agricultural soils increases the overall emission for all the years 1990-2020 with 2-7 % mainly due to increase in emission from crop residue and leaching. The emission of NMVOC and NO_x has also been recalculated. Changes for all subcategories a mentioned below.

3Da1 Inorganic fertiliser: No recalculations of emission from inorganic fertiliser.

3Da2a Animal manure applied to soil: Emission of N_2O and NO_x increases with up to 2 % for the years 1991-2020 and this is due to changes in N-excretion, number of animals and updated data for acidification in housings for NH_3.

Emission of NMVOC from manure applied to soil decreases with up to 3 % for all years 1990-2020. This is due to update of NH_3 emission factors because the calculation of emission of NMVOC from manure applied to soil is depending on the proportion of emissions of NH_3 from housing and application.

3Da2b Sewage sludge applied to soil: Data is now available for 2020 for N from sewage sludge applied to soil, so recalculations of emission of N_2O and NO_x from sewage sludge has been made for 2020.

3Da2c Other organic fertilizer applied to soil: Recalculations of N_2O and NO_x is made for all years 2017-2020, which decrease the emission with up to 2 %. The decrease is due to updated data from The Danish Energy Agency for energy produced in biogas plants.

No recalculations of emission from sludge from industries.

3Da3 Urine and dung deposited by grazing animals: Change from emission factors in IPCC 2006 to IPCC 2019 Refinement is the main reason for change in N_2O from grazing animals. The emission is decreased with around 79 % for all years 1990-2020.

For NMVOC no recalculation.

3Da4 Crop residues: Dry matter content in crop residues has been re-evaluate and this lead to change in dry matter content for maize, non-fixing forages, perennial grass and grass-clover mixtures in and outside rotation. The main reason for change in the emissions of N_2O is the changes for maize.

The emission of N_2O from crop residue has increased with 2-21 % for the years 1990-2020.

3Da5 Mineralization: Due to recalculation of number of animals mentioned above, emission of N_2O from mineralization has been recalculated for the years 2010-2020. The emission is decreased with up to 2.5 %.

3Da6 Cultivation of organic soils: No recalculations of emission from organic soils.

3Db1 Atmospheric deposition: Emission of N_2O from atmospheric deposition has been recalculated for all years 1990-2020 due to updated emission of NH_3 and NO_X from field burning, growing crops, manure applied to soil and other biomass applied to soil. Emission of NH_3 and NO_X from field burning has been recalculated due change in dry matter content in grass seeds for the years 1990-2020. Emission of NH_3 from growing crops has been recalculated for the years 2000-2020 due to including of NH_3 from catch crops. Emission of NH_3 and NO_X from manure applied to soil is recalculated for the years 1991-2020 due to change in N-excretion from sows and change in number of animals. Emission of NH_3 and NO_X from other organic fertiliser (other biomass from biogas plants) is recalculated for the years 2017-2020 due to updated data from The Danish Energy Agency for energy produced in biogas plants.

The emission from of N_2O from atmospheric deposition has decreased with less than 0.4 % in the years 1990-2001, but increased with up to 3 % in the years 2002-2020.

3Db2 Nitrogen leaching and run-off: Change from emission factors in IPCC 2006 to IPCC 2019 Refinement is the main reason for change in N_2O from nitrogen leaching and run-off. The emission is increased with around 68-100 % for all years 1990-2020. Furthermore has N-leaching to rivers and estuaries been updated due to updated data from NOVANA.

5.14.4 Field burning of agricultural residue

Recalculations have been made for the years 1990-2020 due to change in dry matter content in grass seeds and updating in emission factors for N_2O and CH_4 so the emission factors are based on Andreae (2019). For the years 1990-2020 is the emission of N_2O decreased with 53-62 % and emission of CH_4 decreased with 23-39 %.

5.14.5 Liming

No recalculations.

5.14.6 Urea and other C-containing fertilisers

No recalculations.

5.15 Category-specific improvements

5.15.1 Response to the review process

A review of the Danish 2022 submission took place in September 2022. At the time of preparing this report, Denmark had not yet received a final review report. Therefore, the table below represents the latest available report.

Table 5.40 Response to the review process.

Para.	CRF	ERT Comment	Denmark's response	Reference
2021 submission (Review report: https://unfccc.int/sites/default/files/resource/arr2021_DNK.pdf)				
A.3	3.B Manure management – N2O	CH4 from enteric fermentation is not reported for fur-bearing animals in CRF table 3.As1, but number of fur_bearing animals was estimated for manure management and reported in CRF table 3.B (a)s1, with a population of 2,809,980 animals. Page 399 of the NIR notes that CH_4 emissions from enteric fermentation from fur farming were considered to be negligible. The ERT recommends that the Party report in CRF table 3.As1 the number of mink an report "NE" in the corresponding column, while including its reasoning in the NIR	The number of mink is included in CRF table 3.As1 and in corresponding columns are reported NA because the emission is considered to be non-applicable based on country-specific information.	CRF table 3.As1 and 5.3.2
A.4	3.A.1 Cattle – CH4	The Party reported in its NIR (p.402) that its estimation of the national Ym value for dairy cattle was based on the Karoline model developed by Danish C entre for Food and Agriculture. The Ym value in NIR table 5.6 ia a constant of 6.00 for 2002-2019, while the measurements reported of Hellwing, Weisbjerg and Lund (2014) ranged between 5.98 and 6.13. However, there is no justification in the NIR for the Party's selection of the Ym value. The ERT recommends that the Party to include in the NIR a justification of the Ym value used.	Th Ym values in Hellwing , Weisbjerg and Lund (2014) are from a range of feeding tests, with different feeding practice and the results are in range of the result from the "Karoline" model. The authors of the article have been contacted to define which Ym would best reflect the feeding of Danish dairy cattle and the co-author Peter Lund recommended an Ym of 6.0 when uncertainties and variation in feeding practice is taken into account. No data is available for providing an annual Ym factor between 2002-2019. Chapter 5.3.2 Methane conversion factor (Ym) is updated.	Chapter 5.3.2
A.5	3.B Manure management – N2O	CRF table 3.B (b) and the NIR (Table 5.36, p.432) contain inconsistent values for typical animal mass for sheep (70 and 48.5 kg, respectively), goats (60 and 38.5 kg, respectively) and horses (600 and 438 kg, respectively). The ERT recommends that the Party ensure consistency between the NIR and CRF table 3.B (b) and provide documentation showing how the typical animal mass values for sheep, goats and horses reported in NIR Table 5.36 were derived.	Table 5.36 is updated. The animal weights are not used for estimating emissions because excretion rates are given in the Danish normative figures per animal.	Chapter 5.13, Table 5.36
A.6	3.B Manure management – N2O	The Party reported in its NIR (p.446) that EF for NOx from manure management has been updated to the EF given in EMEP/EEA Guidebook 2019. This increases the emission with 109-262 % in the years 1990-2018, and no justification was provided. The ERT encourages the Party to supplement details justifying the increases in EF for NOx from manure management in the NIR of next submission.	Recalculations of NOx emissions are now described in Chapter 5.14 recalculations	Chapter 5.14
A.7	3.B.2 Sheep – N2O	The Party reported in its NIR (p.432) that the Danish nitrogen excretion rate for mother sheep is 12.8 kg N per animal per year in 2019 while in table 5-36 of its NIR the party mentioned that the Danish nitrogen excretion rate for mother sheep is 6.6 kg N per animal per year in 2019. The ERT recommends that the Party include correct values and name of categories for the nitrogen excretion rate from sheep in the next NIR submission.	In Table 5.36 an error in the naming for animal category has occurred. In Table 5.36 the nitrogen excretion rate are now given for the average for all sheep, mother sheep and lambs.	Chapter 5.13, Table 5.36

5.16 Planned improvements

Caused by the requirements to continued focus on the possibilities to reduce the agricultural ammonia emission, a still increasing part of the farmers choose ammonia reducing technologies as for example air scrubbers, slurry acidification and slurry cooling, where the last two technologies mention also leads to a reduction in CH_4 emission. However, reduction of CH_4 are not yet included due to lack of verified reduction potential. Ammonia reduction from air scrubbers are not yet included either. However, a further work is ongoing to include effect of reduced CH_4 in the future emission inventories, as well as the ammonia reduction from air scrubbers.

The national Y_m factor for dairy cattle has been updated in 2020 due to change in the fodder practice. However, a lot of scientific work is still going on about new feeding strategies with e.g. supply of fatty acids and other feed additives to reduce the CH_4 emission from enteric fermentation. This work will be followed an included in the inventory when it is implemented by farmers in Danish cattle production.

The Danish normative system for N-excretion and NH_3 emission is planned to be extended to also include carbon and CH_4 emission, by means of a range of scientific projects covering methane emission from livestock, housing and storage facilities. This project include comparison and quality check of a range of variables used in the inventory calculations and in the normative systems. The normative system are the basic for the farmer´s fertilizer accounts, so these will be included in the checks as well. This work is planned for the years 2021-2024. When results are available, they will be incorporated in the Danish emission inventory as far as possible.

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6 LULUCF

This chapter covers only the territory of Denmark without Greenland and the Faroe Islands. Greenland is submitting a separate NIR as well as the corresponding CRF tables for the Greenlandic territory to UNFCCC. This can be found as Chapter 11. The Faroe Islands is submitting a separate NIR as well as the corresponding CRF tables for the Faroese Island. This can be found as Chapter 12 of the NIR.

Chapter 6 is structured as follows: Section 6.1 presents an overview of the sector, emissions and CRF tables and overall emission estimates, next an overview and introduction to the methodology, key category analysis and the tier levels applied. Section 6.2 goes on to explain the categorisation and mapping of land area along with information on the data input sources and soil type categorisation. Sections 6.3 – 6.7 goes into detail and unfolds the calculations, activity data and emission factors for each of the land use categories and subcategories. Sections 6.9 - 6.13 contains information on the smaller emissions source categories such as methane (CH_4) and nitrous oxide (N_2O), biomass burning and Harvested Wood Products. Sections 6.14-6.15 holds descriptions on the quality assessment and quality controls (QA/QC) and improvements. Finally, Section 6.16 provides the references.

Annex 3E with supporting information include further information and can be found here: Annex 3E LULUCF

6.1 Overview of the sector

The LULUCF sector covers the emissions related to Land Use, Land Use Change and Forestry, reporting on the impact from the big carbon streams from the land use and from changes in the land use. This includes carbon from both living and dead biomass, aboveground and belowground and carbon stock in the soils. Following the 2006 IPCC guidelines, all land area is classified into the six IPCC land categories: Forest land, Cropland, Grassland, Wetlands, Settlements or Other land. Together, the land categories form the basis of the LULUCF inventory methodology. When the land use of an area changes, it is registered as 'land converted to/from' in the following 30 years. Land which has been reported in the same land category for more than 30 years are reported in the category 'land remaining'. A couple of related emissions sources are included in the LULUCF; Harvested wood products and biomass burning.

The sector correlates to the CRF 4 tables, and contain the emissions from the following main sources and their corresponding specific CRF categories and table numbers:

- Forest land (4.A)
- Cropland (4.B)
- Grassland (4.C)
- Wetlands (4.D)
- Settlements (4.E)
- Other land (4.F)
- Harvested wood products (4.G)

Emissions from land use related activities is reported under the respective sector. Direct and indirect N_2O from all forms of nitrogen input to the managed soils e.g. in Forest land and Cropland are reported with Agriculture in Chapter 5 and not in CRF Table 4(I) and 4(IV). Minor nitrous oxide (N_2O) emissions from mineralisation/immobilisation related to organic matter degradation in Forest soils and from peat extraction areas is included in LULUCF (CRF Table 4(III) as well as methane (CH_4) and N_2O from management of organic soils (peat extraction and drainage and rewetting) (CRF Table 4(II)). Biomass burning (CRF Table 4(V)) is reported with the relevant land use (4.A-4.F).

Denmark is situated around 56°N and 13°E and covers 43 051 km^2. According to 2006 IPCC Guidelines, the climate is cold and wet. No permanent ice is occurring and only very small insignificant areas with rocks. Savannas and rice cultivation do not occur. Denmark is an intensively cultivated country where most of the area is affected by agriculture and almost all land is managed in one way or the other. The average temperature in the latest standard 30-year period, 1991-2020 was 8.7°C, which was the exact mean of 2021 as well (DMI, 2022). The warmest year ever reported, since the Danish measurements began in 1884, was 2014 with an average temperature of 10.0°C.

6.1.1 Abbreviations

FL: Forest land
CL: Cropland
GL: Grassland
SE: Settlements
WL: Wetlands
OL: Other land

ABG: Above Ground Biomass
BGB: Below Ground Biomass
C: Carbon
DEM: Digital Elevation Model
DM: Dry matter
DTM: Digital Terrain Model
DSM: Digital Surface Model
NFI: National Forest Inventory
LULC: Land Use, Land Cover
LPIS: Land Parcel Information System
N: Nitrogen
PSU: Primary Sampling Unit (National Forest Inventory)
SSU: Secondary Sampling Unit (National Forest Inventory)
TSU: Tertiary Sampling Units (National Forest Inventory)
OC: Organic Carbon
SOC: Soil Organic Carbon
$SINK_S$: Specific group of research projects covering LULUCF
FOM: Fresh Organic Matter
HUM: Humified Organic Matter
ROM: Resilient Organic Matter
HWP: Harvested Wood Products

6.1.2 Overall emission estimates

In 2021, total emissions from LULUCF were estimated to be a net source of 2420 kt CO_2 eqv. or 5.2 % of the national emissions (incl. LULUCF). Table 6.3 gives an overview of the emission from the LULUCF sector in Denmark from

1990 to 2021. The LULUCF sector differs from the other sectors in that it contains both sources and sinks of carbon dioxide. In the inventory, removals are given as negative figures and emissions are reported as positive figures according to the guidelines[1].

The average net emission in the last five years from 2017-2021 was 2828 kt CO_2 eqv., which corresponds to close to 59 % reduction from the base year of 1990, but there are large yearly variations in the sector, since it is highly impacted by e.g. varying climatic conditions affecting the biological factors of growth, decomposition, yield etc. The majority of all emissions are CO_2 as N_2O and CH_4 combined make up around 13.7 % of the 2021 emissions. This is also the case historically, but the share of emissions from CH_4 and N_2O range from 5 – 38 % between 1990 and 2021.

The Danish forests have been estimated to be a net sink of 2921 kt CO_2 eqv. in 2021. The forests have been a sink of around 3000 kt CO_2 eqv annually in the last 10 years. Cultivation and drainage of organic soils within Cropland and Grassland is the main source of emissions in the sector, amounting to 4792 kt CO_2 eqv. (CRF Table 4.B, 4.C, 4(II)) in 2021. Emissions from organic soils is almost double the net emissions of the entire sector, where you count in the sink effect of the forests, and equal about 10% of national emissions incl. LULUCF. The LULUCF sector contributes to a large extend to the total estimated Danish uncertainty.

Table 6.1 Overall emission in kt CO_2 equivalents from the LULUCF sector, 1990 - 2021.

CRF	Category	1990	2000	2010	2015	2018	2019	2020	2021
4.	Total LULUCF	6896.7	5168.2	2516.9	848.9	3784.6	2953.4	3101.7	2420.1
4.A	Forest Land (FL)	-1231.6	-1320.5	-2247.2	-3988.2	-2105.8	-2471.5	-2154.1	-2920.7
4.B	Cropland (CL)	5314.3	4046.1	2574.5	2586.1	3376.9	3057.2	2829.8	2759.1
4.C	Grassland (GL)	2244.0	1994.9	1892.7	2130.3	2249,9	2166,4	2192,9	2315,2
4.D	Wetlands (WL)	105.0	78.5	82.1	70.0	78.7	74.3	110.6	89.7
4.E	Settlements (SE)	467.4	343.5	239.8	222.3	231.0	211.7	240.1	232.6
4.F	Other Land (OL)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.G	Harvested Wood Products (HWP)	-2.4	25.8	-25.1	-171.6	-46.2	-84.6	-117.6	-55.9

Cropland is ranging from being a net source of 5314 kt CO_2 eqv. in 1990 to a net source of 2759 kt CO_2 eqv. in 2021. From 1990 and onwards, a general decrease in the emission from Cropland is estimated due to the following reasons:

- A higher incorporation of straw (ban on field burning)
- Requirements on growing of catch crops in the autumn
- A switch from low yielding spring barley to high yielding winter wheat
- An increased carbon stock in hedgerows due to an increased area both in length and width
- A continuously smaller area with cultivation of organic soils.

Fluctuations in the emission from Cropland between years are mainly related to the crop yield that year and the climatic conditions because the emission estimate is based on a dynamic Tier 3 modelling. Low crop yields combined with high temperatures reduce the total amount of carbon in agricultural soils,

[1] In the CRF tables it is opposite; here C stock gains (removals) are reported as positive figures and C stock losses (emissions) are reported as negative figures.

because low yield also means low biomass production/input on the field and in the soil and because the higher temperatures increase biological activity and the decomposition rate. A year with a high yield and low temperatures increase the carbon stock in soil, due to a higher biomass production and a lower decomposition rate.

Grassland emissions have stayed relatively stable since 1990 and in 2021 contribute with emissions of 2315 kt CO_2 eqv due to the large area with drained organic permanent grassland.

The area with restored wetlands has increased and the area with peat excavation has been reduced since 1990, leading to a lower emission from wetlands.

In Figure 6.1 the time series for the aggregated source categories is visualised along with a black line that represents the total LULUCF emissions. Cropland and Grassland stand out as the main emission sources. The forest net sink is pictured as negative bars.

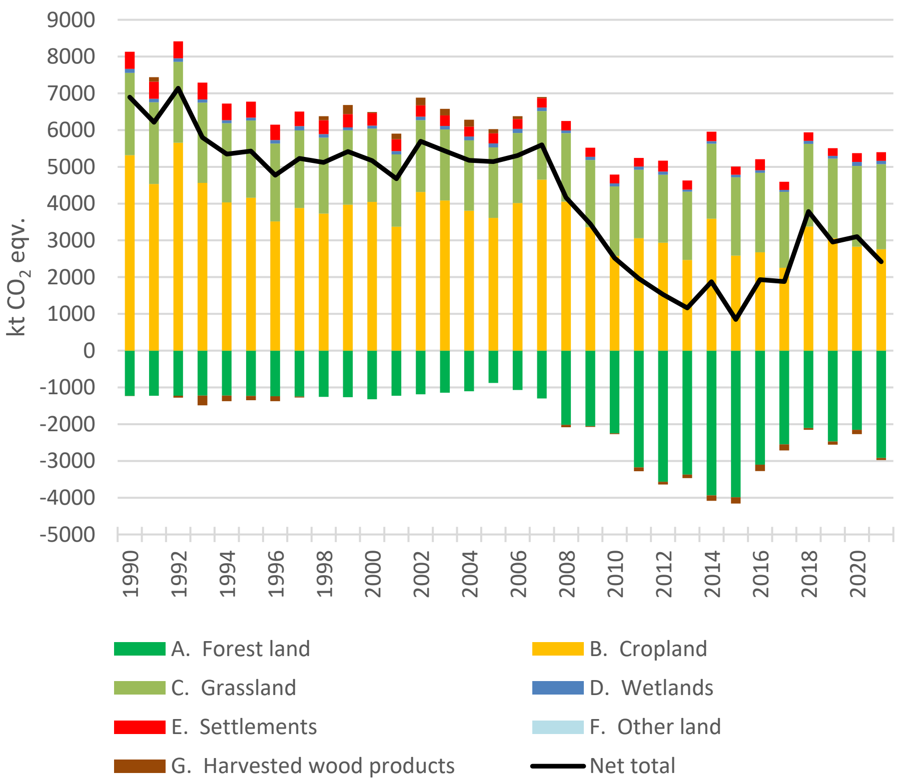

Figure 6.1. Overview of the land use categories' contribution to total emissions and sinks in the LULUCF sector in the period 1990 to 2021.

6.1.3 Key category analysis

Key Category Analysis (KCA) highlights the most significant emission sources, either due to their emission level in 1990, in 2021 or due to significance in the historical trend of the emission source. KCA analysis for approach 1 and 2 for level in year 1990, 2021 and trend for Denmark has been carried out in accordance with the 2006 IPCC Guidelines. Table 6.2 shows which of the LULUCF categories are identified as key categories by the respective approaches. Detailed KCA is explained and shown in NIR Chapter 1.5 and Annex 1.

The major key categories in LULUCF are the CO_2 emissions from forests remaining forest on both the level and the trend. For Cropland, both mineral and organic soils are major key sources.

Table 6.2 Key categories, LULUCF (analysed including LULUCF).

CRF Category	GHG	Approach 1			Approach 2		
		1990	2021	1990-2021	1990	2021	1990-2021
4.A.1 Forest land remaining, Living biomass	CO_2	Level	Level	Trend		Level	Trend
4.A.1 Forest land remaining, Dead organic matter	CO_2		Level	Trend			
4.A.1 Forest land remaining, Organic soils	CO_2		Level				
4.A.2 Land converted to forest land	CO_2	Level	Level	Trend	Level	Level	Trend
4.B.1 Cropland remaining, Living biomass	CO_2		Level	Trend		Level	Trend
4.B.1 Cropland remaining, Mineral soils	CO_2	Level	Level	Trend	Level	Level	Trend
4.B.1 Cropland remaining, Organic soils	CO_2	Level	Level	Trend	Level	Level	Trend
4.B.2 Forest land converted to cropland	CO_2			Trend			Trend
4.B.2 Other land uses converted to cropland	CO_2						Trend
4.C.1 Grassland, Organic soils	CO_2	Level	Level	Trend	Level	Level	Trend
4.C.2 Other land uses converted to grassland	CO_2		Level	Trend			Trend
4.E.2 Other land uses converted to settlements	CO_2	Level	Level		Level	Level	Trend
4.G Harvested Wood Products	CO_2						Trend
4(II) Cropland on organic soils, Drainage and rewetting	CH_4				Level	Level	
4(II) Grassland on organic soils, Drainage and rewetting	CH_4		Level			Level	Trend

6.1.4 Overall methodology and tier levels

The current submission is based on the 2006 IPCC Guidelines combined with the emission factors from the 2013 Wetlands Supplement (IPCC, 2014) Chapter 2 and 3 for CO_2, N_2O and CH_4 combined with national derived emission factors.

Activity data for reporting in the LULUCF sector is the size of the area within the individual land-use categories, determined by the land presentation. Within each land-use category there can be several subcategories. In a Danish context, subcategories include soil type (mineral or organic) and management practice (e.g. drainage conditions). Emission factors will depend on the specific land-use category and its subcategories. For example, estimating the emissions for drained organic soils requires a different emission factor if the land use is Cropland compared to Grassland and a third for Wetland. The activity data and emission factors are explained in each land category section.

Tier

The type of emission factor and the applied tier level for each key category emission source are shown in Table 6.3 below. The tier level has been determined based on the 2006 IPCC Guidelines (IPCC, 2006). The tier level definitions were interpreted as follows:

- Tier 1: The emission factor is an IPCC default tier 1 value, some of which are country specific.
- Tier 2: The emission factors are country specific and based on either a few emission measurements or IPCC tier 2 emission factors.
- Tier 3: Based on models, which include carbon stock changes methodologies.

Table 6.3 Tier level and type of emission factor for emission sources defined as key categories. Most of the categories involve multiple emission sources which is why multiple tier levels are applied in many cases.

CRF	Category	GHG	Tier level	EF [a]
4.A.1	Forest land, living biomass	CO_2	Tier 1, 2, 3	CS
4	Forest land, dead organic matter	CO_2	Tier 2, 3	CS
	Forest land, organic soils	CO_2	Tier 1	D
4.A.2	Other land uses converted to forest	CO_2	Tier 1, 2	CS, D
4.B.1	Cropland, Living biomass	CO_2	Tier 2	CS
	Cropland, Mineral soils	CO_2	Tier 1, 3	CS, D
	Cropland, Organic soils	CO_2	Tier 2	CS, D
4.B.2	Forest land converted to Cropland	CO_2	Tier 1, 2, 3	CS
	Other land uses converted to Cropland	CO_2	Tier 1, 2, 3	CS, D
4.C.1	Grassland, Organic soils	CO_2	Tier 2	CS
4.C.2	Other land uses converted to Grassland	CO_2	Tier 1, 2, 3	CS
4.E.2	Other land uses converted to Settlements	CO_2	Tier 1	CS, D
4.G	Harvested Wood Products	CO_2	Tier 2, 3	CS, D
4(II)	Drainage and Rewetting	CH_4	Tier 1	D

[a] CS= Country Specific value. D= Default value.

6.1.5 Main data sources

The main data source is a complete wall-to-wall mapping of Denmark at 25*25 m pixel level (the land use matrix). The inventory uses many detailed and available data to supplement and subdivide the emissions, such as:

- various spatially explicit data sources, such as detailed map information on housing and road construction
- digital maps for subsidy schemes on afforestation on Cropland and Grassland with the exact position of the afforested areas
- a National Forest Inventory (NFI) starting in 2002 based on 2*2 km grid square
- EU subsidy related annual digital registration of farmers' own crops on field level, for dynamic modelling of carbon stock in agricultural soils based on the exact position of every agricultural field
- map of the organic soils, in a GIS overlay combined with the annual field position
- the Danish topographical maps (digital elevation model) for predicting biomass in hedges and other biotopes not qualified as forest
- digital maps with exact position where wetland restoration is taking place, etc.

In total this gives an advanced and dynamic inventory.

6.2 Assessment of land categories and C stock change

Categorisation of the Danish land area into the six IPCC land categories forms the basis of the activity data for the LULUCF sector. A method for mapping land categories and changes in land categories has been constructed for the purpose, called the Land Use Matrix. The Land Use Matrix, which is briefly described in the next sections, compiles spatially explicit data from various sources to identify and map land use and land cover (LULC) categories and continuously monitor changes between the categories. Detailed documentations of the applied data and methodology for the Land Use Matrix can be found in Levin et al. (2014) and Levin and Gyldenkærne (2022).

The emissions from Forest land specifically is e.g. based on updates from the yearly National Forest Inventory (NFI), and the overall methodology for the Forest inventory is described in 6.3 Forest land.

Emissions from the soils are dependent on the categorisation into soil types. For mineral Forest soils is the no-source principle and default EF for organic soils. For agricultural soils in Cropland and Grassland, the soil type categories applied in the inventory is restricted to mineral soils, organic soils <6 % SOC and organic soils >6% SOC. The emission calculations for the organic matter are mainly achieved by utilizing a 3-pooled dynamic soil carbon model called C-TOOL, further described in Section 6.2.4 and in more detail in Section 6.4.6.

6.2.1 Land category definitions and data sources

The assessment of LULC changes is based on a combination of various spatially explicit data sources. The assessment was first elaborated for the years 1990, 2005 and 2011 (Levin et al., 2014) and since 2011 at an annual basis (Levin and Gyldenkærne, 2022). The mapping is elaborated in raster format with a cell size of 25x25 metres.

The terrestrial area forms the physical frame for the estimation of land use changes and is defined as the inland land area above the highest tidal limit. For the Danish inventory, the terrestrial area is derived from the administrative delineation of regions from 2011 (SDFI, 2011) and covers 43 056 km² in the rasterised version. Although minor changes in the terrestrial area take place as a consequence of both land reclamation and coastal erosion, for the Danish inventory, it has been decided, to keep the terrestrial area constant at the 2011 level.

Settlement is defined as developed land including transportation infrastructure and human settlements.

Cropland includes arable and tillage land, and agroforestry systems, where vegetation falls below the thresholds used for the forestland category, consistent with the selection of national definitions. For the Danish inventory, cropland is defined as land intensively utilised for agricultural purposes. Grassland, which is part of a frequent agricultural rotation cycle, is included in the Cropland category.

Grassland includes rangelands and pastureland that is not considered as cropland. It also includes systems with vegetation that fall below the threshold used in the forestland category and are not expected to exceed, without human intervention, the threshold used in the forestland category. The category also includes all grassland from wild lands to recreational areas as well as agricultural and silvopastoral systems, subdivided into managed and unmanaged consistent with national definitions. For the Danish inventory, grassland is defined as land with grass and herb vegetation, which is used for grazing and other areas where the vegetation is maintained at a state, which implies that it does not hold trees with a crown cover of at least 10 percent. In this case, it would meet the definition for forestland. For the Danish inventory, Grassland includes extensively managed grassland, dry grassland and heathland.

Wetland is sub-divided into flooded wetland (permanently water covered) and periodically water covered wetland. Flooded area is defined as permanent water bodies, which are saturated by water throughout the year, such as lakes. For the Danish inventory, areas of open sea are not included. Periodically water covered wetland is defined as land that is covered or saturated by water part of the year, in IPCC terms also classified as 'Other wetlands'. For the Danish inventory, periodically water covered area includes freshwater meadows, coastal meadows, mires, bogs and areas used for peat excavation.

Forest land is defined as woody vegetation having a minimum tree crown cover of 10 %, a minimum area of 0.5 ha, a minimum width of 20 meter and a minimum value for tree height, which must be able to reach a minimum height of 5 m at the site. In addition, the forest area includes temporarily unstocked areas, smaller open areas in the forest needed for management purposes and fire breaks. Conifers for production of Christmas trees as well as forest for energy production, except willow plantations, are also included in the Forestland category. Woody vegetation not meeting the forest definition, such as shelter belts and fruit plantations for commercial purposes, orchards, gardens etc., which might be able to reach the forest definition, are reported under the Cropland category. Woody vegetation located within the Settlement category, such as trees in urban parks or gardens are included in the Settlement category.

Other land is defined as land with little or no vegetation and consequently no or very limited carbon stocks, both as living or dead biomass or as carbon in the soil. For the Danish inventory, Other land includes beaches, sand dunes and rocks.

Table 6.4 provides an overview of the applied data for the six land categories for the baseline period from 1990 to 2011 and for the annual updates since 2011. Compared to the baseline period, for the annual updates, fewer data sources are applied. Annual updates for the categories Cropland, Grassland and Forest land are based on field parcel maps (Danish Agricultural Agency, 2023). The categories Settlement and Wetland, permanently water covered are based on the topographical database (SDFI, 2023) and the category Wetland, periodically water covered is based on Wetland restauration designations (Danish Agricultural Agency, 2010 - 2021) and on field parcel maps (Danish Agricultural Agency, 2022).

Table 6.4 Applied data sources for land categories for the period from 1990 to 2011 and for annual updates after 2011.

IPCC Land area category	Definition	Data sources	
		Mapping 1990-2005 and 2005 - 2011	Annual updates since 2011
Forest land	Woody vegetation having a minimum tree crown cover of 10 %, a minimum area of 0.5 ha, a minimum width of 20 meter and a minimum value for tree height, which must be able to reach a minimum height of 5 m at the site This includes Christmas trees	Field parcel map 2011 (Danish Agricultural Agency, 2022a) Field block maps 1998 – 2010 (Danish Agricultural Agency, 2022b) Agricultural registers (GLR) 1998 – 2010 (Danish Agricultural Agency, 2022c) Landsat 5 Thematic Mapper scenes from 1989-90 and 2005-06 and SPOT XS (Eurimage, USGS EROS Data Center, and Image2006)	Field parcel maps 2011-2021 (Danish Agricultural Agency, 2022a)
Cropland	Land intensively utilised for agricultural purposes This includes grassland, which is part of a frequent rotation cycle	Field parcel map 2011 (Danish Agricultural Agency, 2022a) Field block maps 1998 – 2010 (Danish Agricultural Agency, 2022b) Agricultural registers (GLR) 1998 – 2010 (Danish Agricultural Agency, 2022c)	Field parcel maps 2011-2021 (Danish Agricultural Agency, 2022a)
Grassland	Rangelands and pastureland that is not considered Cropland and other open areas in the landscape representing more permanent Grasslands	Field parcel map 2011 (Danish Agricultural Agency, 2022a) Field block maps 1998 – 2010 (Danish Agricultural Agency, 2022b) Agricultural registers (GLR) 1998 – 2010 (Danish Agricultural Agency, 2022c) Registration of protected habitat types (Danish Environmental Agency, 2011a) Management plans for state forests (Danish Nature Agency, 2011) Management plans for defence holdings (Danish Defence, 2011) Registration of habitat types within Natura2000 designations (Danish Environmental Agency, 2011b)	Field parcel maps 2011-2021 (Danish Agricultural Agency, 2022a)
Settlement	Developed land including transportation infrastructure and human settlements	Topographical database 2005 and 2011 (SDFI, 2023) The Danish Areal Information System (AIS) (Danish Ministry of Environment, 2022) The national cadastre map 2012 (Danish Geodata Agency, 2012) The Danish Building Register (BBR) (Danish Ministry of the interior and Housing, 2011)	Topographical database 2012 – 2021 (SDFI, 2022)
Wetlands	Flooded areas include permanent water bodies, which are saturated by water throughout the year, such as lakes and other permanent water bodies except open sea	Topographical database 2005 and 2011 (SDFI, 2023) The Danish Areal Information System (AIS) (Danish Ministry of Environment, 2022)	Topographical database 2012 – 2021 (SDFI, 2022)
	Other wetlands include periodically water covered land that is covered or saturated by water part of the year, such as freshwater meadows, coastal meadows, mires, bogs and peat excavation sites	Field parcel map 2011 (Danish Agricultural Agency, 2022a) Field block maps 1998 – 2010 (Danish Agricultural Agency, 2022b) Registration of protected habitat types (Danish Environmental Agency, 2011a) Registration of habitat types within Natura2000 designations (Danish Environmental Agency, 2011b) Management plans for state forests (Danish Nature Agency, 2011) Management plans for defence holdings (Danish Defence, 2011) Wetland restauration designations until 2011 (Danish Agricultural Agency, 2022c)	Field parcel maps 2011-2021 (Danish Agricultural Agency 2022a) Wetland restauration designations until 2021 (Danish Agricultural Agency, 2022c)

Continued			
Other Land	Land with limited or without vegetation and limited carbon stocks, such as beaches and sand dunes	Topographical database 2011 (SDFI, 2022) Registration of habitat types within Natura2000 designations (Danish Environmental Agency, 2011b) Management plans for state forests (Danish Nature Agency, 2011) Management plans for defence holdings (Danish Defence, 2011)	Other land is assumed not to change significantly and therefore kept constant over the whole assessment period

6.2.2 Methodology for land category change assessment

The assessment of LULC changes is divided into an assessment of changes from 1990 to 2011 with elaborated maps for the years 1990, 2005 and 2011 and an annual change assessment after the year 2011.

Assessment from 1990 – 2011

The assessment of LULC changes for the period from 1990 to 2011 is based on a baseline mapping of land categories for the year 2011 and subsequent backward mapping for the years 2005 and 1990. For the 2011 baseline map, existing datasets are applied to map the six land categories and the categories are subsequently overlaid. Where land categories overlap (i.e., areas, which are contained in more than one category), the categories with higher spatial and thematic accuracies are prioritised over categories with lower accuracies. E.g., the categories Cropland and Grassland, which are derived from the field parcel maps, are prioritised over Forest land, which is derived from Satellite images.

In the next step, a backward mapping was done, first for the year 2005 and then for the year 1990. Since field parcel maps and topographic data are not available for the years 1990 and 2005, the assessment of land categories for these years are based on various other datasets. Mapping of the Forest land category is based on classification of Landsat images, Cropland and Grassland categories are based on agricultural information at field block scale and the Settlement category is based on a combination of cadastre maps and the Danish Building register and on the Danish Areal Information System (AIS). The applied data and methods are described in detail in Levin et al. (2014)

Annual assessments after 2011

Due to a significant increase in the availability of spatially explicit information, since the year 2011, the assessment of annual changes is based on annually updated countrywide datasets. The categories Settlement and flooded-Wetland, permanently water covered are based on data from topographical databases. Even though updated versions of the topographical database are continuously available, the information contained in this database is not necessarily updated annually and time lags of up to four year can occur. The Cropland, Grassland and Forest land categories are based on annually updated field parcel maps.

Introducing annual updates also entails fluctuations, particularly between the categories Cropland, Grassland and Forest land. E.g., a field parcel can change from Cropland to Grassland in one year and then change back to Grassland in the year after. To reduce fluctuations between land categories for the Danish inventory, two rules are applied for the annual assessment:

- A change from non-forest to Forest land is only mapped, if the cell contains Forest land in the field parcel maps in at least two successive years. Therefore, afforestation is registered with a delay of one year.
- A change form from Cropland to Grassland is only mapped, if the cell contains Grassland in the field parcel maps in at least five successive years. Therefore, changes from Cropland to Grassland are registered with a delay of four years.

Furthermore, in order to keep the annual update of LULC changes consistent, following general rules are applied:

- For cells, where Forest land changes to Settlement, the forest layer from the topographical database is applied to qualify, if the cell is forest. I.e., if the forest layer from the topographical database contains forest, the cell is kept as Forest land. Otherwise, the cell is mapped as Settlement.
- For cells, which change from any land category to undefined, i.e., are not contained in any of the applied layers for the subsequent year, the cell is kept in the category of the previous year.
- No changes from Settlement to other land use categories are mapped. I.e., once a cell is mapped as Settlement, it is kept in the Settlement category in all subsequent years.

A considerable proportion of the annual changes, especially those including agricultural land uses, only contain few cells. These changes are most probably the result of imprecise mapping of input datasets (particularly for the field parcel maps), rather than actual changes. Therefore, regions, which change and have a size of ≤ 8 cells or 0.5 ha, are not accepted. This is in accordance with the 2006 IPCC Guidelines (IPCC, 2006) and the elected Danish minimum forest definition (IRR, 2007). These regions are identified and the land use category for the previous year is copied to the new map as well. In 2018, a validation of the methodology was performed and reported in Johannsen et al. (2018). Results indicate that a reasonably high accuracy of mapped land use categories for the assessed years. For a detailed description of the applied data and methods for the annual assessment see Levin and Gyldenkærne (2022).

6.2.3 Overall LULC changes

Figure 6.2 visualises the geographical distribution of the various land use categories in Denmark as of 2021.

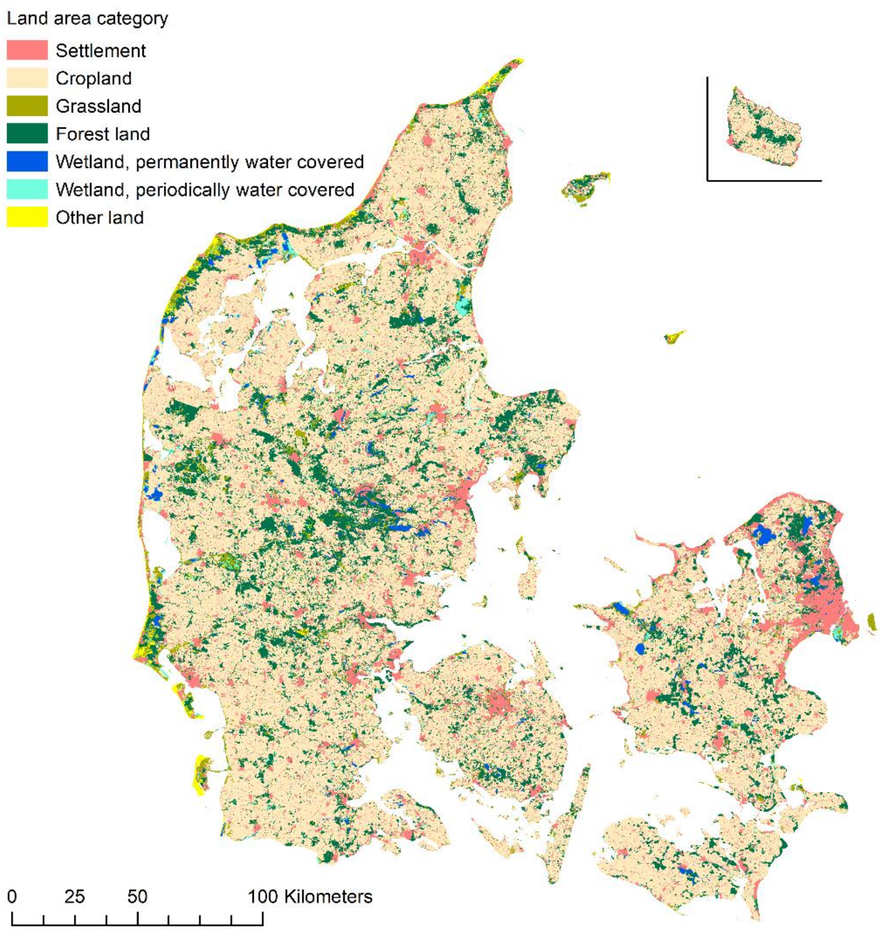

Figure 6.2 Land use in Denmark 2021, according to IPCC land use categories (Levin & Gyldenkærne, 2022).

Figure 6.2 shows the mapped land categories for the year 2021. It is apparent from the map that the Danish land use is dominated by Cropland, which in 2021 accounted for approx. 65 % of the Danish terrestrial area. Forest land accounted for 15 % and almost 13 % was covered by Settlement. Between 1990 and 2021, the dominant land use change has been a decrease in Cropland, which has mainly been converted to Forest land, Grassland, Wetland and Settlement. Table 6.5 summarises the matrix changes between land categories from 1990 to 2021. The rows note e.g. for Forest land that 527 642 ha that were forest in 1990 are still forest today in 2021, whereas 9 363 ha of the 1990 forest have been changed to Cropland. The columns note e.g. for Grassland that 4 404 ha of 2021 Grassland are in conversion from previous Forest land and 103 858 from Cropland.

Table 6.5 Registered changes in land categories in hectares from January 1st 1990 to December 31st 2021[2].

1990/2021	Forest land	Cropland	Grassland	Wetlands, periodically water covered	Wetlands, flooded	Settlement	Other land	Total, 1990	Proportion, 1990 (%)
Forest land	527 642	9 363	4 404	728	252	2149	0	544 538	12.6
Cropland	109 345	2 721 496	103 858	11 864	4 108	47 485	0	2 998 155	69.6
Grassland	7 445	47 862	73 059	11 211	2 314	5 109	0	146 999	3.4
Wetlands, periodically water covered (other wetlands)	1 558	687	9	46 777	717	108	0	49 856	1.2
Wetlands, flooded	0	0	0	0	52 951	8	0	52 958	1.2
Settlement	0	0	0	0	0	486 614	0	486 614	11.3
Other land	0	0	0	0	0	0	26 433	26 433	0.6
Total, 2021	645 990	2 779 408	181 329	70 579	60 342	541 472	26 433	4 305 552	100.0
Proportion, 2021 (%)	15.0	64.6	4.2	1.6	1.4	12.6	0.6	100.0	

Annex 3E provides further visualisation of the development in land use in Denmark and the main land use changes occurring since 1960. This historical data dating back before the base year of 1990 is necessary to include in order to apply a 30-year transition period for all land conversion categories. Such data has been collected from Statistics Denmark where we have gone back to the earliest available data. That includes the forest census from 1881, 1888, 1896, 1907, 1923, 1931, 1951, 1965 and 1976. Combined with other statistical land use data from Statistics Denmark, the 30-year transition period has been constructed allowing a linear interpolation for years between the data points.

6.2.4 Conversion between land-use categories

When the land use of an area changes, it is registered as 'land converted to' instead of 'land remaining', and all related emissions of the change are registered in the 'land converted to' category.

When the land-use of an area changes from one land-use category to another, the area will be under conversion for a defined number of years before reaching the 'land remaining' classification. The IPCC standard is a conversion period of 20 years; however, this was determined not to be applicable to the colder Danish condition with an average annual temperature of 8.7°C. According to the soil C model C-TOOL and its degradation rates of soil organic carbon, approximately 50 % of the soil organic matter has half-lives of > 40 years, adding to the argument of a longer conversion period. Therefore, the conversion period in the Danish inventory is set to 30 years except for cases of afforestation. For afforestation a 100 years transition period is used as research has shown it takes a long time to reach the new equilibrium state in the forest. The conversion period is applied to all calculations on the more slow or long-term impacts of the land use changes. The full conversion period applies to carbon stocks of soils. It is thereby assumed theoretically that the soil C will have reached its equilibrium state after this and that no changes in either of the C pools take place after this.

[2] The matrix data is from 1st January 1990. The figures are therefore not identical with figures given in the CRF tables, which are end of year 1990 data.

6.2.5 Carbon stock and change assessments

The estimation of the carbon stock as well as the emissions and/or removals of carbon (C) as CO_2 in the LULUCF is based on changes in the ecosystem C stocks within five defined C pools: above ground biomass (AGB), below ground biomass (BGB), deadwood, litter and soil organic carbon (SOC). AGB and BGB constitute the reported living biomass, while deadwood and litter constitute the reported dead organic matter (DOM) pool. DOM is only reported for Forest land.

In the inventory, the pools are referred to as living biomass, dead organic matter and soil. Land use conversions can result in a net gain of C or net losses of C. Whether or not a change from one land use type to another results in emissions or removals of C depends on the difference between the specific factors applied for the C pool, dependent on the involved land use categories and soil type. All changes in C pools are reported in the new land-use category ('land converted to'). If the C pools of the previous land use type was lower than the new one, the change will be a positive gain of C and removal/sink effect on the total emissions. If the C pools of the former land use category was higher the change will result in a negative loss of C and act as an emission source, and opposite if the new land use category has higher default amounts of C in the various C pools. Following conversions, the living biomass of the previous land use category and potential DOM (in cases of deforestation), is lost as instant oxidation, and the C loss is reported in the new land use category, only in the first year of conversion. Living biomass gain from the new land use category is reported annually. Soil C changes follow the longer land use conversion periods.

Gains in a land use category thus reflects biomass growth (removal of CO_2 from the atmosphere) or a transfer of C from the 'converted from' category. Losses reflect emissions of CO_2 due to decay, harvest or transfer of C to another land use C pool. The specific values used for estimating the C stock in the different C pools and stock changes between the pool and land uses are presented in Table 6.15 and with each land use category along the chapter.

For carbon changes in mineral soils with agricultural crops (areas in Cropland and Grassland), a 3-pooled dynamic soil model called C-TOOL, is used (Taghizadeh-Toosi et al., 2014b). The outcome from C-TOOL is reported under Cropland, although it also includes Grassland. C-TOOL is run on a regional level with further differentiation of soil types, based on the Danish JB soil classification system from 1975 (dca.au.dk – den danske jordklassifikation, 2023), and is further explained in the literature and in Section 6.4.6.

Estimation of carbon stock changes in the Danish forests for the entire period of 1990 – 2021 is based on a combination of previous forest surveys (1990 – 2006) and the present National Forest Inventory (NFI) (2006 – now). See next section on Forest land for calculations on forest carbon stock changes.

In addition to the carbon pools mentioned above, burning of biomass and harvested wood products (HWP) are reported separately. HWP represents C stored in wood products for different amounts of time, depending on the product (IPCC, 2006). The methodology is presented in Section 6.13 on HWP.

Soil type classification

For inventory purposes, soils are divided into mineral and organic soils. The IPCC guidelines define organic soils as soils having > 12 % organic carbon

(OC) in the topsoil. This definition is used in the forest sector (Section 6.3). For Cropland (CL) and Grassland (GL) the definition from the Danish soil classification system from 1975 is applied (dca.au.dk – den danske jordklassificering, 2023). Here organic soils are defined as soils having > 6 % OC in the topsoil (0-30 cm), classified as JB11. For the emission calculation for CL and GL the organic soils are divided into two categories: 6-12 % OC and soils > 12 % OC. This division is based on a mapping of the organic soils in Denmark prepared for inventory purposes in Greve et al. (2014). In the inventory it is assumed that the soils with 6-12 % OC contain half of the soil carbon content and hence will emit half of the emissions compared to organic soils with more than 12% OC, which is the definition used for the default values in the 2006 IPCC Guidelines (20 % OM).

The specific values used for estimating the C stock in the soils are presented with each land use category along the chapter.

6.3 Forest Land

Forest land emissions and removals are covered by CRF Table 4A. Table 6.6 shows the total area reported under Forest land. The area with Forest land has increased since 1990 due to an intensive afforestation programme. In the beginning of the 1990's, approximately 3000 ha were afforested every year. In recent years, approximately 1500 ha are afforested per year. Mineral soils are a small sink due to the afforestation. The CO_2 emission from organic soils is slightly reduced over time due to rewetting of the organic soils in the forests.

Table 6.6 Total area and annual emissions 1990 to 2021 from Forest land.

	1990	2000	2010	2015	2017	2018	2019	2020	2021
Area, 1000 ha	548.7	590.8	627.7	637.5	638.6	639.1	640.1	641.3	646.0
Living and dead biomass, kt C	-311.1	-335.4	-592.7	-820.2	-435.4	-308.7	-396.6	-370.3	-612.7
Litter, kt C	-68.6	-63.9	-44.7	-287.1	-270.6	-272.8	-284.6	-224.5	-199.1
Dead wood, kt C	-5.0	-5.1	-15.4	-22.7	-33.3	-37.0	-37.7	-38.1	-30.6
Mineral soils, kt C	-11.7	-16.6	-19.4	-17.9	-16.8	-16.3	-15.7	-15.3	-15.3
Organic soils, kt C	52.6	50.2	45.7	47.3	47.5	47.6	47.7	47.9	48.5
Total, kt C	-343.8	-370.9	-626.5	-1100.7	-708.6	-587.2	-686.9	-600.2	-809.2
CH_4, kt CH_4	0.2	0.6	1.0	0.9	0.9	0.9	0.9	0.9	0.9
N_2O, kt N_2O	0.0904	0.1	0.1	0.1	0.080	0.080	0.081	0.081	0.082
C, kt CO_2 equivalents	-1260.8	-1360.0	-2297.0	-4035.8	-2598.2	-2153.0	-2518.5	-2200.8	-2966.9
CH_4, kt CO_2 equivalents	5.2	17.0	29.3	26.4	26.0	25.9	25.6	25.2	24.4
N_2O, kt CO_2 equivalents	24.0	22.5	20.5	21.2	21.3	21.3	21.4	21.5	21.7
Total, kt CO_2 equivalents	-1231.6	-1320.5	-2247.2	-3988.2	-2550.9	-2105.8	-2471.5	-2154.1	-2920.7

The forest definition adopted in the NFI is identical to the definition used by the Food and Agriculture Organization (FAO, 2010, Annex 2). It includes "wooded areas larger than 0.5 ha, that *in situ* are able to form a forest with a height of at least 5 m and crown cover of at least 10 %. The minimum width is 20 m." Temporarily non-wooded areas, firebreaks and other small open areas, that are an integrated part of the forest, are also included. The temporarily un-stocked areas make up 3 % and auxiliary areas 2 % of the total forest area. The temporarily un-stocked areas are caused by e.g. clear cutting and wind throw and are generally required to be reforested within a 10-year period according to the Forest Act. It is part of standard forest management in Danish Forestry to perform clear cuttings. The forest area has consistently included these unstocked areas, ensuring consistency over time for the stock change method.

6.3.1 Forest census 1881 – 2000

From 1881 to 2000, a National Forest Census was carried out roughly every 10 years based on questionnaires sent to forest owners (e.g. Larsen and Johannsen, 2002). Since the data were based on questionnaires and not field observations, the actual forest definition may have varied. The basic definition was that the tree-covered area should be minimum 0.5 ha to be a forest. There were no specific guidelines as to crown cover or the potential height of the trees. Open woodlands and open areas within the forest (temporarily unstocked areas excepted) were generally not included. All estimates of growing stock, biomass or carbon pools for this period were based on data from the National Forest Census (reference year 2010) and the distribution of the forest area with reference to the census to main species, age classes and growth regions (Jutland and the Islands). In this way, the carbon stocks back in time for the Forest Census in 1951, 1965, 1976, 1990 and 2000 were estimated applying similar procedures as applied in current reporting and in estimation of reference levels for Danish forests (Johannsen et al. 2019). In this way the carbon stocks for each year, species and species groups (broadleaved and conifers) and age classes were calculated. In some cases areas from minor forests were not as detailed, but the overall estimates were re-scaled to include the full forest area with crown cover. The estimation also included the forest area mapping described in Section 6.2.3 for the years 1990 and 2000, expecting the additionally found forest area to be of lower stocking density than the area reported in the forest census. A detailed description of the recalculation is soon available (Johannsen & Stupak, 2023).

The overall development is given in Figure 6.3.

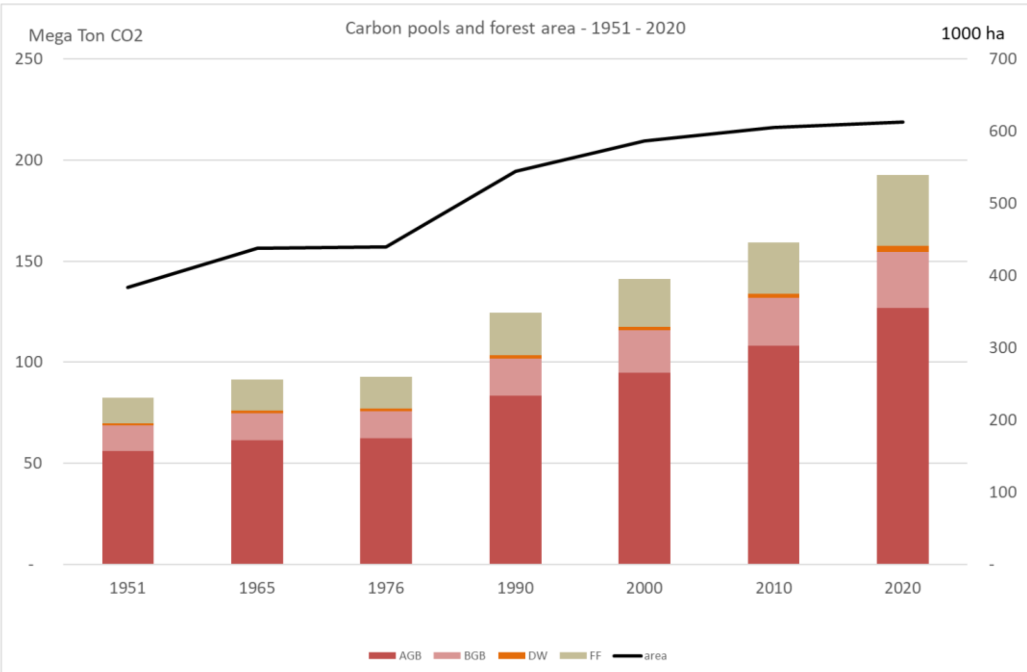

Figure 6.3 Forest carbon stock (in Mt $CO2_2$-eq, left y-axis) and forest area (in ha, right y-axis) from 1951 – 2020. Based on forest census data for 1951 – 2000 and NFI data for 2006 – 2020. AGB = Above ground live biomass, BGB = Below ground live biomass, DW = dead wood, FF = forest floor.

6.3.2 National Forest Inventory (NFI) 2002-

In 2002, the current sample-based National Forest Inventory (NFI) was initiated (Nord-Larsen and Johannsen, 2016). The design of the inventory is very similar to inventories used in other countries such as Sweden or Norway. The NFI has replaced the National Forest Census.

The Danish NFI is a continuous sample-based inventory with partial replacement of sample plots based on a 2 x 2 km grid covering the Danish land surface. In each grid cell, a cluster of four circular plots (primary sampling unit, PSU) for measuring forest factors (e.g. wood volume) are placed in the corners of a 200 x 200 m square. Each circular plot (secondary sampling unit, SSU) has a radius of 15 meters. When plots are intersected by different land-use classes or different forest stands, the individual plot is divided into tertiary sampling units (TSU).

About one third of the plots is assigned as permanent. These plots are re-measured in subsequent inventories every five years. Two thirds of the plots are temporary and are selected randomly among the particular 2 x 2 km grid cell with forest cover in subsequent inventories. The sample of permanent and temporary field plots from the 2 x 2 grid has been systematically divided into five non-overlapping, interpenetrating panels, which are each measured annually and constitute a systematic sample of the forest land of the entire country. Hence, all the plots are measured in a five-year cycle.

A detailed description of the Danish NFI is presented in Nord-Larsen and Johannsen (2016).

In the most recent five-year rotation of the NFI (2017-2021), the number of clusters (PSU) and measured sample plots (SSU) containing forest were 4 370 and 9 551 respectively; see Table 6.7. In the reporting, estimation of area and carbon pools in the period with the forest census (1954 – 2000) have been harmonized with the results of the NFI. The estimates of all forest carbon pools are based on direct NFI measurements from 2002 and onwards, with no usage of yield tables. The area and species distribution have been compared and reported in previous publications, e.g. Nord-Larsen et al. (2021).

Table 6.7 Number of clusters and total and measured sample plots in the five-year rotation 2017-2021.

Year	Clusters		Sample plots	
	Total	Forest	Total	Measured
2017	2 212	853	8 652	1 899
2018	2 191	902	8 586	2 014
2019	2 186	844	8 597	1 896
2020	2 190	887	8 569	1 886
2021	2.175	883	8.528	1.951
Total	10 954	4 370	42 933	9 551

6.3.3 Forest area mapping

Due to differences in methodologies, major inconsistencies in forest areas and other forest variables are observed between the different forest inventories (i.e. the 1990 and 2000 Forest Census and the National Forest Inventory (NFI) from 2002). With the objective to obtain time consistent and accurate estimates of forest areas to report to the UNFCCC, two projects have been carried out aimed at mapping the forest area in Denmark based on satellite images for the years 1990, 2005 and 2011.

A land use/land cover map was produced for the base year 1990 and for the year 2005 based on Earth Observations from EO Data Science (23 August 1990) and other data collected from 1992-2005 and for 2005 using NFI *in situ* data. Forest maps were developed using satellite imagery – mainly Landsat 5 (Thematic Mapper) and 7 (ETM+) data – to classify and estimate the area of different forest cover types in Denmark. Portions of seven scenes covering the whole country were classified into forest and non-forest classes. The approach involved the integration of sampling, image processing and estimation. A detailed QA/QC process was conducted in 2011/2012. Maps for 2011 were produced in 2012. In order to map the forest cover, multi-spectral and multi-temporal Landsat data of June 2010 and April 2011 with a spatial pixel resolution of 30 m were used. Except for the island of Bornholm, none of the scenes were cloud-free. So, to obtain a national forest cover map without gaps, the forest cover map of some minor areas is solely based on one image.

The product is specified by a Minimum Mapping Unit of 0.5 ha, a geometric accuracy of < 15 m RMS and a thematic accuracy of 90 % +/- 5 % for the land use class Forest.

In combination with the Forest Census back to 1881 it is possible to characterise the forest area into Forest remaining forest and afforestation younger than 30 years. This gives a development as shown in the figure below, where significant afforestation have been performed throughout the described period (1960-2019). Further details will be given in Johannsen & Stupak (2023).

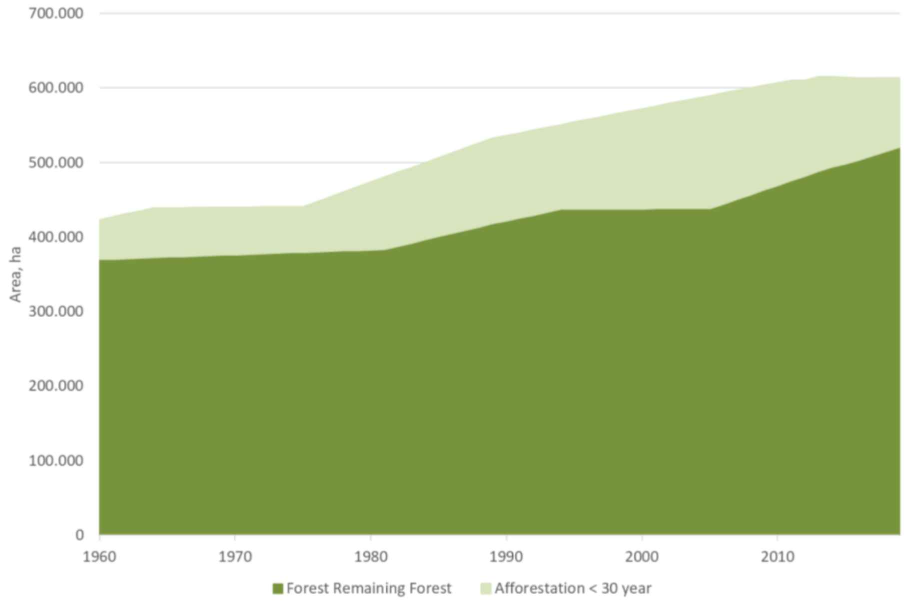

Figure 6.4 Forest area development from 1960-2019. Forest remaining forest = >30 years. Afforestation = forest < 30 years, in conversion from other land uses.

The updated land use matrix now includes increased afforestation in areas without support from public funds as well as establishment of minor forests areas, to improve hunting options and to produce biomass. Some forest areas have been established through natural succession, a method now approved by the Forest Act (from 2005). The area of Christmas trees is handled as a specific part of the forest land use and the dynamics therein are handled directly in the estimation of the carbon pools.

6.3.4 Estimation of forest carbon pools

In the following, procedures for estimating forest carbon pools are described in general. For a more detailed description of the calculations and the specific formulas used, readers are referred to Nord-Larsen and Johannsen (2016).

Estimation of forest area – for carbon pool estimates

Based on an analysis of the most recent aerial photos (Kortforsyningen, 2020), each NFI sample plot (SSU) is allocated to one of three forest status categories, reflecting the likelihood of forest or other wooded land in the plot: (0) Unlikely to be covered by forest or other wooded land, (1) Likely to be covered by forest, and (2) Likely to be covered by other wooded land. All NFI sample plots within clusters (PSU) with one or more SSU belonging to (1) or (2) are inventoried in the field.

Overall forest cover fraction is calculated as the sum of the forest covered plot area divided by the total sample plot area. In this calculation, the forest area in plots belonging to (0) is assumed to be 0 (zero). In the early years of the NFI, not all sample plots were inventoried due to insufficient resources. Furthermore, every year some plots are inaccessible due to infrastructure, water, or dangerous conditions on the site (e.g. leaning trees after wind throw). The estimated forest area in un-inventoried plots belonging to 1 or 2 was assumed to equal the average forest area in inventoried plots belonging to 1 or 2.

The overall forest area is calculated as the overall average forest cover fraction in the sample plots with status categories (0), (1) and (2) times the total land area.

The fraction of forest area with a specific characteristic, such as forest established before or after 1990, is estimated as the forested plot area with the particular characteristic divided by the total forested plot area. The total forest area with a particular characteristic is subsequently found as the fraction of forest area with the particular characteristic times the total forest area.

Area of forests with special treatment, incl. clear cuts and other areas temporarily without crown cover, are also inventoried in the sample plots. They are still included in the estimates of both area and carbon pools, but naturally with low values for living biomass. All assessments are conducted according to the instructions for the NFI. According to the Danish Forest Act, clear cut areas must be re-established with crown cover within 10 years. A permanent change of land-use will be reported in the overall land use matrix. With rotation ages of 50-200 years of the Danish tree species, an average of approx. 1 pct. (around 6000 ha) of the forest area will be regenerated each year, either as clear cuts or as removal of large trees in continuous cover forestry. This is directly included in the estimates of carbon stocks and hence in the estimation of change over time.

Estimation of volume, biomass and carbon pools

Growing stock is calculated using species-specific individual tree volume functions developed for the most common Danish forest tree species (e.g. Madsen, 1987; Madsen, 1987; Madsen & Heusèrr, 1993). The functions use individual tree diameter and height as well as quadratic mean diameter of the forest stand as independent variables.

The general form of the volume functions can be found in the report on NFI design and calculations (Danish_National_Forest_Inventory.pdf). For trees lacking volume functions, volumes are calculated using functions for trees with a similar phenology.

Biomass (dry mass) and carbon stocks are calculated using species specific individual tree biomass models developed for the most common forest tree species in Denmark with tree diameter and height as input (Nord-Larsen et al., 2017). For species where no biomass function is available, above ground biomass is calculated as the stem volume times the basic density, see Table 6.8 (e.g. Skovsgaard et al., 2011, Skovsgaard & Nord-Larsen, 2012, Moltesen, 1988). Finally, total biomass (below and above ground) is estimated using expansion factors for tree species with similar phenology (Skovsgaard et al., 2011, Skovsgaard & Nord-Larsen, 2012, Nord-Larsen & Nielsen, 2015). For calculation of forest biomass and carbon pools, national individual tree volume and biomass functions are available for beech, oak, ash, silver fir, Norway spruce, grand fir, Douglas fir, Sitka spruce and Japanese larch. This means that species-specific biomass models are applied for 57 % of the area and 73 % of the total standing volume. Only for the remaining species, the generic models for beech (Skovsgaard & Nord-Larsen, 2012) and Norway spruce (Skovsgaard et al., 2011) are applied. It has not been tested systematically, but they are expected not to be biased in terms of biomass or carbon estimates. Total growing stock, biomass and carbon stocks are estimated by obtaining an estimate of average stocks per hectare on inventoried NFI plots times the overall forest area. The total growing stock, biomass or carbon stocks with a given characteristic are estimated as the sum of the stocks with the particular characteristic divided by the inventoried plot area, times the total forest area. Biomass is converted to carbon using a concentration of 0.47 g C per g. Full documentation of the estimation and calculations of biomass and carbon pools are given in (Nord-Larsen & Johannsen, 2016). For further info on areas and volume for the specific species, see (Nord-Larsen et al., 2021).

Table 6.8 Basic density for different tree species used in estimation of biomass and carbon (Moltesen, 1988). *Basic density of beech and Norway spruce are estimated using functions from Skovsgaard and Nord-Larsen (2012).

Broadleaves	Basic density, tonnes per m^3	Conifers	Basic density, tonnes per m^3
Beech*	0.56	Norway spruce*	0.38
Oak	0.57	Sitka spruce	0.37
Ash	0.56	Other fir sp.	0.38
Sycamore	0.49	Other pine sp.	0.43
Other	0.56	Mountain pine	0.48
		Contorta fir	0.37
		Scots pine	0.43
		Nordmann fir	0.38
		Noble fir	0.38
		Other	0.38
		Douglas fir	0.41
		Larch sp.	0.45

Dead wood volume, biomass and carbon content

The volumes of standing dead trees and lying dead trees with their base inside the sample plots are calculated using individual tree volume functions, similarly to the calculations for live trees. The volume of lying dead tree parts (e.g. broken off branches, but excluding lying dead trees with their base outside the sample plot), within the sample plot is calculated as the length of the dead wood times the horizontal cross sectional area at the middle of the dead wood piece. Biomass of the dead wood is calculated as the volume multiplied with species specific basic densities (Moltesen, 1988) and a reduction factor of the density according to the structural decay of the wood (decay class). Biomass is converted to carbon using a concentration of 0.47 g C per g.

Similar to live biomass, total dead wood biomass and carbon stocks are estimated by obtaining an estimate of average stocks per hectare on inventoried NFI plots times the overall forest area.

The carbon pool in living and dead biomass estimated for the most recent rotation of the NFI (2016-2020) is 43 million tonnes C (Figure 6.2). The largest pool is living aboveground biomass carbon makes up 81 % of the carbon in total biomass, while the smallest pool is dead wood carbon that makes up only 1 % of the carbon in total biomass. Carbon in biomass in forests established after 1990 makes up 4 % of the total carbon in forests established before and after 1990.

For the reporting to the Convention the forest remaining forest area are for all the years focusing on the area with more than 30 years of forest cover. The afforested area and carbon pools related to this of the age class of 30 year, is transferred each year to the forest remaining forest reporting. This is conducted as described in Section 6.2.8 on the Stock change method.

Forest floor

Forest floor depth is measured on all NFI plots in the annual census by the method described in the NFI protocol (Knudsen et al., 2019). Carbon stocks are subsequently calculated by multiplying the forest floor depth with species-specific forest floor basic densities and C concentrations, see Table 6.9 (Vesterdal & Raulund-Rasmussen, 1998).

Table 6.9 Litter layer density in forest stands of different tree species (Vesterdal and Raulund-Rasmussen, 1998).

Broadleaves	Basic density, tonnes per m^3	Conifers	Basic density, tonnes per m^3
Beech	0.55	Norway spruce	1.09
Oak	0.36	Sitka spruce	0.86
Ash	0.55	Other fir sp.	1.09
Sycamore	0.55	Pine sp.	0.79
Other	0.55	Nordmann fir	1.09
		Noble fir	1.09
		Other	0.94

Christmas trees

Christmas trees are recorded as forest, as the areas fulfil the forest definition applied. The Christmas tree plantations occur on both traditional Forest Land (FL) and on areas formerly used for Cropland (CR). The Christmas trees are managed intensively compared to forest in many cases. Carbon stock in aboveground living biomass, based on the NFI data for Christmas trees, is estimated to 0.01 kt C per ha and 0.002 kt C per ha in the belowground biomass. No dead wood or litter layer of significance is present in these stands and their carbon stocks is therefore set to 0 (zero).

6.3.5 Emission from soils

Forest mineral soil and organic soil

The forest soil inventory aims to document that forest soils are not a source for emissions of CO_2, i.e. that there is no detectable depletion of soil carbon. According to the 2006 IPCC Guidelines (IPCC, 2006), the necessary documentation may come from various information sources such as:

- Representative and verifiable sampling and data analysis to show that the pool has not decreased.
- Reasoning based on sound knowledge of likely system responses.
- Surveys of peer-reviewed literature for the activity, ecosystem type, region and pool in question.
- Combined methods.

Based on a survey of literature and reasoning based on sound knowledge there is little evidence to support that the soil C pool in forest remaining forest would currently be changing to an extent that would be detectable by sampling with decadal frequency.

As supplement to the NFI monitoring, a representative and verifiable forest soil inventory has been implemented in order to provide further documentation that forest soils are not an overlooked source for CO_2 emissions and to be able to distinguish the area with mineral soils from area with organic soils, with the latter being defined by a topsoil carbon concentration of 12 % organic carbon (OC) in the 0-25 cm soil layer below the O-horizon. Based on this definition, organic forest soils have been estimated from the first inventory from 2007-2010 to represent 5 % of the forest area. This fraction is consistent with the map classification of organic soils using the Digital Geological Map of Denmark (1:25.000 and 1:200.000). For organic soils, the default carbon source emission factor of 2.6 t C per ha per year from the 2013 Wetlands Supplement was used (IPCC, 2014). The forest soil inventory does not provide separate estimates on emissions for forest soils with 6-12 % OC as for Cropland (CL) and Grassland (GL). Hence only emissions from organic forest soils > 12 % OC are reported.

Since the reporting in 2009 for years 1990-2007, quantitative information has gradually become available; the project "SINKS", initiated in 2007, has delivered data from 125 plots for estimation of soil pool C change based on repeated sampling of soils in forests remaining forests for two points in time, 1990 and 2007-2010. Data on soil pool C change from additional ca. 285 resampled plots will soon be available from the project "SINKS2", with the first sampling in 2009-2010 and first resampling in 2020.

The sampling is taking place in two grids, the so-called "Kvadratnet" (Agricultural network, 7 x 7 km, 126 plots) and the NFI grid (2 x 2 km, 285 plots). The "Kvadratnet" made it possible to estimate soil C pools in 1990 based on C concentration measurements of soil samples archived from sampling around 1989-1990 and test if they differ from soil C pools based on soil sampling during 2007-2010. The analysis of the data from these 108 re-measured sites (sampled in six depth sections: forest floor, 0-10, 10-25, 25-50, 50-75 and 75-100 cm, with some variation for historical reasons) suggested that mineral forest soil C pools are not a source of CO_2 and thus supported that more accurate estimates of soil C pool removals/emissions do not need to be included in the reporting (Callesen et al., 2015). The methodology of the 2007-2010 survey is described in Callesen et al. (2015).

Considering the forest structure in Denmark with many small forests (about 70 % of the forest estates are of less than five hectares) the "Kvadratnet" is a very coarse grid. Even if the grid was fully sampled, it is therefore unlikely that the 108 plots represent the Danish area of forests remaining forest of approximately 500 000 ha. Based on power analyses, it was evaluated in 2007 that further sampling is necessary for future monitoring and a randomly selected subset of the permanent plots of NFI was included for this purpose. In 2007-2010, in total 277 plots were sampled in six depth sections: forest floor, 0-10, 10-25, 25-50, 50-75 and 75-100 cm. The samples were processed as described in Callesen et al. (2015). A re-sampling of these plots took place in 2019-2020, together with the "Kvadratnet" plots. This will provide further documentation if forest soils are a sink or a source of carbon, which can potentially be included in the next inventory of 2022 emissions.

Soil carbon stock changes in forest remaining forest

Mineral soil C stocks in forest remaining forest are estimated at an average of 155 t C per ha to 1 m depth for soils with < 12 % C in the 0-25 cm layer (Callesen et al. 2015). For organic soils > 12 %, it is estimated at 500 t C per ha. These estimates are based on the full sampling from the "SINKS"-forest soil project. No overall changes in Soil Organic Carbon (SOC) stock were detectable in mineral soils in a depth of 0-100 cm between 1990 and 2007-2009.

Emissions from wet and drained forest soils

The 2013 Wetlands Supplement (IPCC, 2014), has introduced new soil categories including 'Mineral wet soils' and 'Mineral drained soils' (inland or coastal) as soil categories in addition to the formerly used 'Dry mineral soils'(IPCC, 2006). These categories are small and knowledge is uncertain with respect to activity data and emission factors. A range has been indicated in the reporting, but we are aware of the need for better assessment of SOC levels and effects of rewetting on non-CO_2 greenhouse gases. The peat definition of the soil map used for activity data category FT – ferskvandstørv is 'peat formed by accumulation of dead organic plant material in lakes, near streams or in moorlands' – a limit of at least 12 % C applies to this definition.

A large proportion of the Danish forest area may be considered as drained in the sense that the natural hydrology has been modified by establishment of ditches. Large forest areas have been drained in order to enable establishment of Norway spruce in depressions, fens and pond areas. As an example, a major state forest, Gribskov in Northern Zealand, by 1850 had an estimated wetland area 400 % larger than that of 1988 (Naturstyrelsen.dk, 2023). During recent years, there has been an effort to restore wetland habitats in the state forests and several drained areas have been restored by filling up ditches; and in many areas of the state forests ditches are no longer maintained and will be gradually more and more ineffective over time. This is a direct consequence of the strategic plan for the state forests to convert to more Close to Nature Forest Management with a specific aim to restore natural hydrology in as many places as possible.

The temporal change in shares of drained and rewetted soils has been assessed based on trends in forest management (Table 6.10) focusing on the period with most pronounced change 1990-2008, and based on expert assessment of observed trends in the past 20-30 years of active maintenance of preexisting ditches in forests. Before 1990 and after 2008 the share of drained soils is considered constant in the reporting, while the forest area is still changing due to afforestation and deforestation.

Table 6.10 Outline of assumptions on drainage changes over time for mineral and organic soils in forest.

Share, %	Mineral soil		Organic soil	
	Drained (ditched)	Undrained (not ditched)	Drained (ditched)	Undrained (not ditched)
1990–- 2008	65% - > 55% (0.5% points per year)	35%->45% (0.5 % points per year)	75%	25%
After 2008	55%	45%	50%	50%

The area of rewetted mineral and organic soil following the previously reported area shares of ditched/not ditched is calculated for each year. For each year the area of drained forest area is compared to the maximum drained area previously reported. There is assumed an equal share of rich and poor soils being rewetted and the average of the two emission factors is applied. The calculations only include emissions from rewetting of organic soils, since there is no emission factor for rewetting of mineral soils.

Organic soils constituted 5 % of the forest area based on information on presence of peat from the NFI. The area of rewetted organic forest soils remains under the Forest land category instead of converting the land to Wetlands, since the actual changes in water level are unknown. However, we assume that the CO_2 emissions have ceased and been replaced by CH_4 emissions.

Reporting of nitrous oxide emissions

The only soil category for which nitrous oxide emissions apply is 'organic soils, drained', and default emission values have been used. Measurements of nitrous oxide emissions from conditions applying for organic drained soils in Denmark are scarce or lacking. Danish measurements that apply to a hydromorphic, loamy soil were 0.4 – 0.6 kg N_2O-N per ha per year (Christiansen et al., 2012b), which is similar to the low end of the uncertainty range given in the 2013 Wetlands Supplement value, Table 2.5 (IPCC 2014).

Organic soils, drained: 2.8 (range 0.57 – 6.1) kg N_2O-N per ha per year (Table 2.5 in IPCC 2014, p. 2.33). Remaining soil categories do not apply, since they are either too dry or too wet to produce nitrous oxide.

For the rewetted area, this is calculated each year (see section on emissions from wet and drained forest soils).

Reporting of methane emissions

The following emission factors for methane were identified (Table 6.11); we note that units vary between chapters in 2013 Wetlands Supplement (IPCC 2014). A default area of 2.5 % ditches was assumed. Table numbers refer to the 2013 Wetland Supplement (IPCC 2014).

Table 6.11 Identified emission factors for methane and nitrous oxide in 2013 Wetlands Supplement (IPCC 2014) used in methane emission calculations.

CH_4 EF for organic drained soils	Table 2.3	kg CH_4/ha/yr	2.5
CH_4 EF for ditches on organic drained soils	Table 2.4	kg CH_4/ha/yr	217.0
CH_4 EF for organic rewetted poor soils	Table 3.3	kg CH_4-C/ha/yr	92.0
CH_4 EF for organic rewetted rich soils	Table 3.3	kg CH_4-C/ha/yr	216.0
CH_4 EF rewetted Inland Mineral Wetland Soils	Table 5.4	kg CH_4/ha/yr	235.0
N_2O EF for organic drained soils	Table 2.5	kg N_2O-N/ha/yr	2.8
N_2O EF for ditches on organic drained soils		NO	
N_2O EF for organic rewetted poor soils		p.3.19 'negligible'	
N_2O EF for organic rewetted rich soils		p.3.19 'negligible'	
N_2O EF rewetted Inland Mineral Wetland Soils	No info in WS chap 5 IWMS	Assumed negligible	

In a Danish study of three forests in eastern Denmark on hydromorphic soils, the reported methane emissions were -0.08 – -3.2 kg CH_4 per ha per year (Christiansen et al. 2012a; Christiansen et al. 2012b). The default value for drained organic soils seems to be reasonable until national estimates are better founded by representative measurements. Since no water level measurements in ditches and rewetted soils are available, it is not possible to judge whether the 2013 Wetland Supplement (IPCC, 2014) default values for methane emissions apply to Danish conditions.

For the rewetted area, this is calculated each year (see section on emissions from wet and drained forest soils).

6.3.6 Stock change methodology

Stock change method

The stock change method is based on actual assessment of carbon stock at two given points in time and provides estimates of change over time as given by the difference between the two consecutive inventories of carbon stocks.

A special issue arises when the area changes over time because afforestation area of a certain age is transferred to the forest remaining forest category. In these situations, there needs to be a special focus on the area and associated carbon stock that is transferred from the afforestation category to the forest remaining forest land category. This is required in order to assign the actual change to the afforestation including the growth/harvest/mortality of the last year, before transferring the carbon stock of the age class to the forest land carbon stock. Therefore, the stock of the age class to be transferred remains in the afforestation until the end of the year (December 31) and is transferred by the beginning of the next year (January 1). This is done on an annual basis. The principle is illustrated in Table 6.12 by the following example for time T1 and T2, one year apart. Age X indicates the age of transition from afforestation to forest remaining forest land, i.e. 30 years.

Table 6.12 Principle for handling transfer of area from afforestation to forest remaining forest. X representing age 30 years.

Area (ha) by 1.1 of:	T1	T2	Stock density t CO_2
Forest remaining forest	100	100	75
Afforestation of age X-2	7	2	10
Afforestation of age X-1	10	7	11
Afforestation of age X	14	10	12
Afforestation of age X+1	8	14	13
Afforestation of age X+2		8	14
Total forest area	122	132	

The area development and stock density leads to the following development in stocks, Table 6.13 (note equilibrium stock is assumed on the remaining forest land area).

Table 6.13 Principle for handling transfer of stock from afforestation to forest land. X representing age 30 years.

Stock (t CO_2 eqv.) by 1.1	T1	T2
Forest Remaining Forest (FRF)	7.500	7.500
Afforestation of age X-2	70	20
Afforestation of age X-1	110	77
Afforestation of age X	168	120
Afforestation of age X+1	104	182
Afforestation of age X+2	0	112
Forest Remaining Forest (bold figures)	7.772	7.914
Stock in the full area	7.952	8.011

A raw estimate of stock change T1-T2 would be 7914-7722=142, but the transfer of carbon stock from afforestation of age 30 =120 needs to be deducted, as this has only just been included in the FRF pool and the growth occurred before the transfer. This results in a real stock change on the area already in the FRF pool of 142-120=22. This equals the change in carbon stock of the forest-land (=0), and the afforestation of age 30+1 and 30+2 (182+112-168-104) =22.

For the afforestation area the raw estimate of stock change T1-T2 would be (20+77-70-110) =-83. Again the stock of the afforestation of age 30 = 120 needs to be taken into account, this time added, as the growth occurred before the transfer to the FRL pool. This results in a real stock change for the afforestation of -83+120= 37.

The overall change of the stock T1-T2 in the full forest area is 59, which is the sum of changes in the pool under forest land and under afforestation and hence ensuring consistency.

This principle is applied in the reporting of the Danish forest carbon pools to address the significant influence of the afforestation on the overall stock change in the Danish forest area.

Annual change estimates

The reporting is based on two subsequent NFI rotations of 5 year with no overlapping in observation years. This ensures the focus on robust estimates of change from the forest area. This applies to both forest remaining forest, and the afforested area.

6.3.7 Uncertainties and time series consistency

Danish national forest resource assessment has developed over the years from the earliest forest census more than a century ago to the current national inventory. More recently, the development has been quite rapid, thus influencing the estimation of forest carbon pools in relation to LULUCF.

In the 1990 forest census, the number of questionnaires sent to respondents was 22 300. In the subsequent inventory in 2000, the number of respondents increased to 32 300. This led to a substantial increase in estimated forest area, which is not possible to separate from the actual increase in forest area that occurred during that period of time.

In 2002, the sample-based forest inventory substituted the previous forest census, for the first time enabling forest statistics based on direct measurements and a consistent forest assessment according to the FAO forest definitions. Consequently, the change from questionnaire-based forest census to sample-based forest inventory has led to considerations on how to ensure the consistency over time. This have been obtained by combination of the satellite-based forest mapping (se 6.2.3) and re-estimation of the carbon pools back in time (Johannsen & Stupak, 2023). For the period from 2006 and onwards, only data from the Danish NFI is used. With the continued improvement of the aerial photographs forming the first sampling in the NFI, a gradual improvement of the forest area estimates were observed from the start of the NFI in 2002 and until 2008-2010. This coincide with the period where part of the afforestation in the 1976-1990 period had high increment rates, resulting in an overall large increase in the observed carbon pools in the total forest area.

In the estimation of the changes reported in each year, the different data (census based and NFI based) influence the frequency of updates. This causes the change estimates in the period from 1951 – 2000 to reflect the intervals of the census. I.e. average annual change for the interval between to subsequent census are estimated based on carbon pool estimates in the census year. E.g. 1951-1965, 1965-1976, 1976-1990 and 1990 -2000. Since the NFI are applied from 2006, the change from 2000-2006 are reporting the linear transition to the NFI based estimates. For the period from 2006 and onwards, the Danish NFI the change estimation needs to be based on two independent datasets, to avoid reporting of random sampling differences rather than actual changes. Hence, the reporting is based on two subsequent NFI rotations of five year with no overlapping in observation years. This ensures the focus on robust estimates of change from the forest area. This applies to both forest remaining forest, and the afforested area.

In a statistical sense, the Danish NFI has a cluster design with unequal cluster size. The estimation of carbon stocks is therefore associated with a statistical uncertainty. Design based estimators are available for such designs, but the Danish NFI design is further characterised by the partitioning of sample plots and unequal representation of different tree sizes within the circular sample plots. Considering the nature of the design, derivation of an analytical estimator may be a dubious undertaking.

A Tier 1 uncertainty estimates can be found in Table 6.14.

Table 6.14 Tier 1 estimates of the uncertainty for the forest.

		1990	2021					
		Emission/ sink, kt CO_2 eqv.	Emission/ sink, kt CO_2 eqv.	Activity data, %	Emission factor, %	Combined uncertainty	Total, uncertainty, %	Uncertainty, 95 %, kt CO_2 eqv.
4.A Forests		-1231.6	-2920.7				5.8	168.0
4.A.1 Forest land remaining forest land, Living biomass	CO_2	-244.4	-1284.3	5	2	5.4	5.4	69.2
4.A.1 Forest land remaining forest land, Dead organic matter	CO_2	-127.0	-635.8	5	3	6.0	6.0	38.0
4.A.1 Forest land remaining forest land, Organic soils	CO_2	147.4	126.9	10	50	51.0	51.0	64.7
4.A.2 Land converted to forest land	CO_2	-1036.8	-1173.6	10	9	13.3	13.3	155.9
4(II) A. Forest land, organic soils	CH_4	4.5	24.4	10	90	90.6	90.6	22.1
4(V) Biomass Burning	CH_4	0.7	0.0	10	30	31.6	0.0	0.0
4(V) Biomass burning	N_2O	0.4	0.0	10	30	31.6	0.0	0.0
4 (II) Drainage and rewetting	N_2O	23.6	21.7	10	50	51.0	51.0	11.1

6.3.8 QA/QC and verification

Continuous focus on the measurements of carbon pools in forest contribute to QA/QC and to the verification of the submissions. As we gain more data through resampling of permanent plots in the NFI, this will further support the verification of the data reported.

On-going development of the NFI in terms of sampling procedures and estimation methods is essential for the continued QA/QC process of the NFI.

New models for biomass calculations have previously been implemented based on a substantial dataset collected in long-term common garden experiments with tree species. Further, improvements to the existing biomass models were made by adding a novel set of biomass data, including six new broadleaved species (Nord-Larsen et al., 2017). Projects have looked at the consistency of forest carbon pool estimation across Europe (Diabolo), and the implemented models still provide the most consistent result for the Danish forests.

Integration with multi-phase and multi scale inventory, e.g. through other in-situ data like LiDAR scanning or satellite imagery, will contribute to the continued QA/QC process of the NFI and the carbon stock estimates for forests, when funding for this part of the verification becomes available.

6.3.9 Recalculation

In this reporting some recalculations have been implemented. In the following some key points are highlighted, mainly affecting afforestation (as also described in Section 6.2.11).

Organic soils

In the last reporting the area of rewetted forest area was based solely on comparing drained organic soils year by year. During the review process it became clear that this deviated from guidelines as rewetting not only apply for one year. Hence, a recalculation of the emissions from rewetted organic soils have been implemented. For the rewetted area, this is calculated each year, based on the area of drained forest area compared to the maximum drained area previously reported. There is assumed an equal share of rich and poor soils being rewetted. There is no calculation of emissions from rewetting of mineral soils. See also section on emissions from wet and drained forest soils.

6.3.10 Planned improvements

Below is a list of planned improvements.

- A constant focus on the QA/QC of the Land Use Matrix with focus on afforestation, deforestation vs temporary unstocked areas.
- A new national project in 2022 have worked to identify procedures for more frequent updates of forest mapping based on various EO data sources. Hopefully it will be implemented in the years to come and benefit the different aspects of the reporting as well.
- SINKS2, which is a continuation of SINKS project, is ongoing for further documentation of possible developments in carbon pools in soil and forest floor. It is expected that the data analysis and the results are ready for application in the reporting in 2023, as delays have occurred due to the COVID-19 pandemic. SINKS2 will deliver: 1) improved data for bulk densities of forest floor for modelling of forest floor C stocks based on forest floor depth measurements from the NFI, 2) estimates of SOC changes over time based on ca. 400 plots in DK compared to 125 plots at present, 3) new estimates of cropland to forest conversion effects on SOC based on repeated sampling and modelling, 4) bulk density measurements in mineral soil for development of improved pedo-transfer functions for estimation of bulk densities from measured soil C concentrations with an improve range of coverage that also includes soil with high C concentration.

6.3.11 Land converted to forest

See Section 6.2.1-6.2.8 for information on approaches used for representing land areas and on land-use databases used for the inventory preparation.

Forest definition

The definition of land converted to forest corresponds to the definition used for forest remaining forest (see Section 6.2) and the LULUCF categories used elsewhere.

Methodological issues for land converted to forest

When converting land to Forest Land, the living above- and below ground biomass is assumed to be removed from the land. E.g., for land converted from Cropland, a standard default loss value of 9 577 kg dry matter (DM) per hectare in above ground biomass and 2 298 kg DM per hectare in below ground biomass is used. This value is equivalent to the average harvest of living biomass for all cereals grown in Denmark from 2000 to 2010, including straw, stubble and glumes based on data from Statistics Denmark combined with expansion factors. The expansion factors are those used in modelling of turnover of organic matter in agricultural soil with the dynamic model, C-TOOL, see Section 6.3.7. For conversion from DM to carbon, a default concentration of 0.47 g C per g is used. The default values for the amount of living biomass removed is shown in Table 6.15.

Table 6.15 Default values for the amount of DM (dry matter, kg per hectare) used for estimating carbon stock changes where land use conversions take place. The default C stocks in mineral soil (<6%C in 0-25 cm) are used for estimation of C stock changes.

		Dry matter (DM), kg DM per hectare		Default C stock in mineral soil, tonnes C per ha
		Above ground biomass	Below ground biomass	
Forest land				142[a]
Christmas trees		21 277	4 255	120.8[b]
Cropland		9 577	2 298	120.8
Grassland	Improved Grassland (Grazing land)	2 400[c]	6 720	142[d]
	Unmanaged Grassland (Other grassland)	2 200	6 160	142
Wetlands	Flooded Wetland			
	Peat extraction	0	0	NE
	Other Wetland	3 600	10 080	NE
Settlements		2 200	2 200	96.6[e]
Other land		0	0	NA

[a] Average of all forest mineral soils (<6 % SOC, 262 plots in NFI and “Kvadratnet”).
[b] Same as for Cropland.
[c] Based on the default AGB of 2 400 kg DM and an R:S factor of 2.8 (IPCC 2006, Table 6.4, Table 6.1).
[d] Same as for Forest Land but restricted to soils with < 6 % OC..
[e] 80 % of the carbon stock in Cropland (IPCC, 2006 chapter 8.3.3.2).

Carbon pools of living and dead biomass and forest floors

As with forest remaining forest, Denmark applies the stock change method, hereby including both growth and harvesting in the overall estimation. The estimation of the different pools is based on the methodology for the Danish NFI, as described above for the area of forest remaining forest.

The amount of carbon in biomass in forests younger than 30 years established after 1990 has been assessed based on data from the latest NFI. This estimate reflect the composition of species and sites in the afforestation. Since there are no available data on the afforestation younger than 30 years back in time, the density in terms of carbon pools per hectare estimated for 2019 are applied for all reporting years, taking into account the varying area. There have been variations in the afforestation back in time to 1960 in terms of species and soil type composition. In the earlier afforestation, a higher proportion have been conifers, which could increase the pool due to higher growth. But at the same time a higher proportion have been on poorer soils, which could reduce the pool due to lower growth. Changes in management mainly affect the forest area after the age of 30. This results in applying the following estimates for the average carbon pools in afforestation areas of age 0-30: Above ground biomass 14.1 t C per ha, Below ground biomass 3.2 t C per ha, Dead wood 0.1 t C per ha and forest floor 6.4 t C per ha.

Similarly, the carbon pools in the age class of 30, which is transferred from the afforestation area to the forest remaining forest area is based on the estimation of this based on the composition of the afforestation 1990-2019, but focusing only on the age class 30. These considerations result in applying the following estimates for the age class 30: Above ground biomass 48.5 t C/ha, Below ground biomass 9.7 t C per ha, Dead wood 0.2 t C per ha and forest floor 6.9 t C per ha.

For further details, see Schou et al. (2014), Johannsen et al. (2019) and Johannsen & Stupak (2023).

To account for the grasses and herbs in the first 25 years of afforestation (corresponding to the situation in grasslands), an estimate of this is included. In practice it is assumed that afforestation initially will hold the same pools of AGB and BGB as unmanaged grassland (Table 6.15). These pools will linearly decrease over a period of 25 years, reflecting the reduced light to ground vegetation from the increasing crown cover of the trees established in the afforestation. This is supported by a number of observations of afforestation, with data for both trees and grass vegetation (se also Chapter 6.2.9).

Mineral soil

Several previous national field studies (Vesterdal et al., 2002b, Vesterdal et al., 2002a, Vesterdal et al., 2007) did not suggest statistically significant changes in mineral soil carbon in the decades following afforestation. In the forest soil inventory (SINKS project), the SOC content in depth 0-100 cm in forest land remaining forest land was compared with estimated SOC in the same depth for mineral soils (< 6%C in 0-25 cm) reported from a parallel project for cropland soils (Table 6.15). This comparison indicate that mineral soils are small sinks for CO_2 following afforestation of former cropland and hence a 100 year transition period has been applied for afforestated land before a new equilibrium state has been reached equivalent to 142 tonnes C per ha.

6.4 Cropland

Cropland emissions and removals are covered by CRF Table 4.B. Cropland in the reporting in 2021 consists of:

- Agricultural cropland, defined as land with cultivation of agricultural crops in annual rotation, mainly cereals, rape oilseed and root crops, approx. 2.3 million ha, incl. around 220.000 ha of grass in rotation

- Approximately 300 000 ha reported by the farmers as permanent grassland, categorised as the land use type Grassland. These ha are included in the modelling of the changes in soil carbon stock with Cropland. The emissions from these are thus reported in CL and reported as 'IE' in GL.
- Perennial woody crops, defined as horticultural woody crops, e.g. fruit and willow plantations, approx. 5 000 ha
- Hedges and other small biotopes in the landscape, which do not meet the definition of forest, approx. 100 000 ha
- Other agricultural land is defined as the difference between the three defined crop types and the total Cropland area in the land use matrix. Consequently, other cropland is without any major carbon stocks and is typically small undefined areas, minor roads (not included in settlements), roadsides, banks between fields without hedges etc., approx. 230 000 ha.

Table 6.16 shows the area and emissions from Cropland from 1990 and onwards from each main carbon pool and emission source.

Net emissions from Cropland overall are decreasing, but also vary a lot. Organic soils is by far the main source of emission, and has been since 1990, but has declined from 1108.9 kt C in 1990 to 706.5 kt C in 2021, a decline of about 34.3 %. Mineral soils changes back and forth from a net source to a net sink. In 2021 the mineral soils contributed with removals of CO_2. Emissions from the mineral soils are calculated with the dynamic 3-pooled model C-TOOL.

Table 6.16 Total area and annual emissions 1990 to 2021 from Cropland.

Cropland	Unit	1990	2000	2010	2015	2017	2018	2019	2020	2021
Area	1000 ha	2993.2	2943.3	2883.4	2827.1	2811.5	2810.7	2805.8	2801.9	2779.4
Living and dead biomass	kt C	20.5	-8.3	-3.5	80.4	10.7	2.6	7.5	62.1	161.7
Mineral soils	kt C	278.2	66.7	-217.2	-180.0	-180.01	158.8	63.7	-33.8	-144.4
Organic soils	kt C	1108.9	1007.1	889.3	773.4	753.3	729.8	732.7	714.4	706.5
Total	kt C	1407.6	1065.5	668.5	673.8	584.0	891.2	803.9	742.7	723.8
CH_4	kt CH_4	5.47	4.97	4.39	4.00	3.90	3.78	3.80	3.71	3.67
N_2O	kt N_2O	0.000	0.000	0.002	0.013	0.005	0.013	0.012	0.010	0.009
C	kt CO_2 eqv.	5161.1	3906.9	2451.3	2470.6	2141.2	3267.6	2947.8	2723.2	2654.0
CH_4	kt CO_2 eqv.	153.1	139.1	122.8	112.0	109.2	105.9	106.3	103.8	102.8
N_2O	kt CO_2 eqv.	0.0	0.1	0.4	3.5	1.4	3.4	3.1	2.7	2.3
Total	kt CO_2 eqv.	5314.3	4046.1	2574.5	2586.1	2251.7	3376.9	3057.2	2829.8	2759.1

All Cropland categories combined account for approximately 2.8 million ha in 2021, a decline from approximately 3.0 million ha in 1990, most of which has been converted to Forest Land (afforestation) and Settlements (urbanisation purposes).

6.4.1 Cropland area

The main activity data for the agricultural land use of cropland (4.B) from 1990 up to 2009 is based on data from Statistics Denmark and from 2010 and onwards the area is based on the annual update of the land use matrix, including 2021 information from the agricultural register and EU Land Parcel Information System (LPIS)[3]. The data is received from the Danish Agricultural

[3] In Danish: Landbrugsregistret (GLR) og Internet Markkort (IMK).

Agency as part of the Ministry of Food, Agriculture and Fisheries of Denmark. The LPIS today contains information of the exact geographical location of each field, because it is used as basis and documentation in the EU agricultural common policy subsidiary system.

Yield data from each region as reported by Statistics Denmark are used for the calculations.

The total cropped area with agricultural and perennial crops of approximately 2.62 million hectare consists of approximately 579 000 individual fields registered in the land parcel information system (LPIS). This gives an approximate field size of around five hectares. The agricultural register and LPIS today contain codes for more than 300 specific crops or land use activities, related to around 77 crop categories.

The main part of the agricultural area is grown with annual crops: cereals, grass in rotation, oilseed, sugar beets, potatoes and temporarily set-a-side. Permanent grass outside rotation with none or very little fertiliser application rates (often < 25 kg N per ha per year) is reported under Grassland.

The area with hedgerows and small biotopes is based on analysis of LiDAR measurements for year 2006 and 2014/2015 (see Section 6.3.6) combined with planting and removal statistics of hedges, also received from the Agricultural Agency of Denmark. Most establishment of hedges is subsidised in Denmark and therefore monitored, but only 30 to 40 hectares is planted annually in the most recent years.

Cropland area according to Statistics Denmark

The survey data from Statistics Denmark differs a little from the current LPIS system applied in the annual updates to the land use matrix (<±2 % for the major crops). Data from Statistics Denmark has been used in the historical mapping of the inventories Since 1990, the agricultural area recorded by Statistics Denmark (which excludes hedges and tree plantations) has decreased from 2.78 million hectares to 2.62 million hectares in 2021, see Table 6.17. The numbers of the land use matrix applied in the inventory and the numbers from Statistics Denmark thus are relatively coherent, considering differences in the categorical definitions of crops and in the references forming each dataset.

Table 6.17 shows the development in the agricultural area from 1990 to 2021 according to Statistics Denmark. The area reported to Statistics Denmark are in the land use matrix reported under either Cropland or Grassland. A general trend is a continuous decrease of the agricultural area by 6000 - 7000 ha per year. From 1993 to 2008, there was a mandatory European Union regulation for set-a-side (land area no longer cultivated, i.e. set-a-side and excluded from the regular crop rotation, in Danish: brak), due to overproduction of agricultural products. In these years, more than 200 000 ha were often left as set-a-side. In 2009, this regulation was lifted and the area ceased to a very low level. In the latter years, the reported area has increased again and for 2021 set-a-side area was reported to 77 065 ha. The increase is mainly caused by changes in statistical definitions and a change in farmers reporting. For the inventory, the set-a-side area is treated similar to Grassland.

Table 6.17 Cropland area in ha in Denmark 1990-2021 according to Statistics Denmark.

	1990	2000	2010	2015	2018	2019	2020	2021
Annual crops (CL[a])	2 236 535	1 938 633	2 049 304	2 064 949	2 047 746	2 028 233	2 004 373	2 003 467
Grass in rotation (CL)	306 325	330 834	327 319	258 202	265 518	284 099	283 256	275 604
Permanent grass (CL and GL[b])	217 235	166 261	199 859	254 770	212 657	206 687	222 405	234 288
Horticulture – vegetables (CL)	16 428	10 803	10 812	11 119	12 970	13 515	12 775	12 773
Perennial fruit trees and woody crops (CL)	10 267	9 892	8 181	5 761	7 607	6 754	7 117	6 741
Set-a-side (CL)	0	191 295	9 874	4 501	76 377	76 973	81 727	77 065
Other land and un-cropped areas (CL)	3 861	1 146	41 435	33 058	9 578	9 704	8 334	8 461
Total agricultural land area reported by Statistics Denmark	2 788 276	2 646 982	2 646 400	2 632 947	2 632 453	2 625 965	2 619 987	2 618 399
Willow and other crops for energy purposes (CL)[c]	588	695	4 049	5 478	5 039	4 928	4 837	4 766
Hedgerows (CL)[c]	98 643	100 602	99 524	103 105	103 399	103 430	103 474	103 495

[a]CL = in the inventory this area is reported as Cropland. [b]GL = in the inventory this area is reported as Grassland. [c]Data from the land use matrix, supplementary to the area from Statistics Denmark.

Yield

Despite the decreasing agricultural area, the total crop yield has increased since 1990, as measured in dry matter (million kg dry matter per year (Figure 6.5). The overall cereal yield has increased with 10 % during the same period (average 1990-1994 compared to average 2016-2020). Year 2018 was very dry and the consequences was a 25 % lower crop yield than the average.

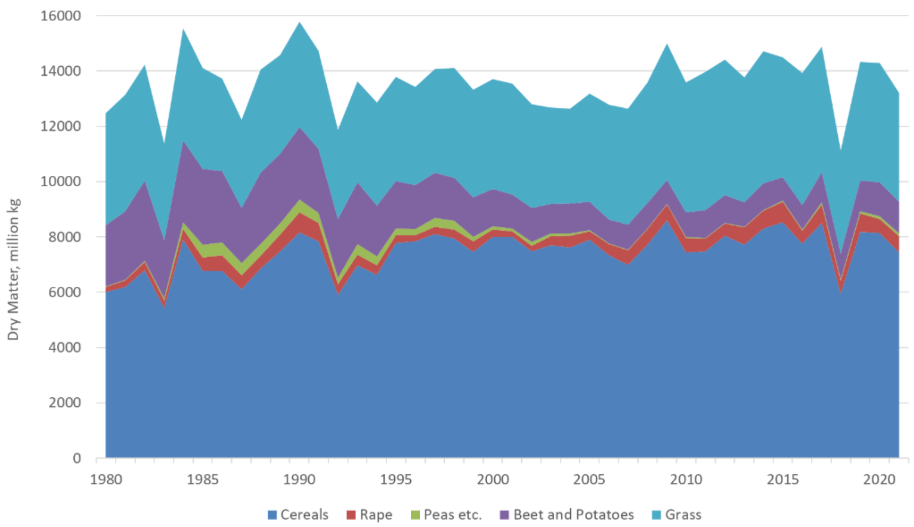

Figure 6.5 Total crop yield from the main crop categories given as kernel, roots, fruits and grass as measured in million kg dry matter per year, 1980-2021 (Data source: Statistics Denmark).

6.4.2 Cropland remaining Cropland

As explained previously in the chapter, all land use categories are divided into 'land remaining' and 'land converted to', reflecting the changes in the land use matrix. Emission and removals from Cropland remaining Cropland are covered by CRF Table 4.B.1.

6.4.3 Cropland - Methodological issues

The following data sources are used for determination of the Cropland area, for determination of land use changes, for allocation of natural, administrative and management parameters and development of emission factors for soils and biomass and for calculation of carbon stocks in soils and biomass:

- Agricultural area data from Statistics Denmark, 1980 to 2009
- Area data from Statistics Denmark[4], 1980 to 2010
- Harvest surveys from Statistics Denmark[5], 1980 to 2021
- Area with willow from the agricultural subsidiary system from 2011
- Crops grown on field block and individual field level and its geographical location from EUs Land Parcel Information System, 1998 to 2020, received from the Agricultural Agency as part of the Ministry of Food, Agriculture and Fisheries of Denmark
- Digital soil map, 1:25.000 (Greve et al., 2014)
- LiDAR analysis in 2006 and 2014/2015
- Hedgerow subsidized planting data 1977 to 2021, received from the Agricultural Agency as part of the Ministry of Food, Agriculture and Fisheries of Denmark.

6.4.4 Change in carbon stock in living biomass

Living biomass for all Cropland (incl. conversions from other land uses converted to Cropland) in 2021 accounted for a net emission of 148.9 kt C, equivalent to 546 kt CO_2 emissions.

Annual agricultural crops

For annual agricultural crops on cropland remaining cropland (CRF Table 4.B.1), it is assumed that no changes in above-ground, below-ground or dead biomass and litter are occurring, cf. IPPC 2006 (5.2.1.1). Information about the specific crops grown is thus not used in the estimates for living biomass from the annual crops. The variations in the actual agricultural area included in the LPIS system or collected by Statistics Denmark may be up to 50 000 hectares per year. When estimating the carbon stock in living biomass such changes may create large variations between years, which may be simple artefacts in the data. As the amount of living biomass is defined according to the time where the peak of living biomass is occurring, the variation in the area creates large fluctuations in the carbon stock in living biomass. To counteract this problem, the sub-division "Other agricultural land" has been created with a default carbon stock of living biomass as in the designated agricultural area. The default carbon stock in living biomass on other agricultural land is 5.9 t C per ha, equivalent to an average spring barley crop with aboveground biomass of 9 577 kg dry matter (DM) per hectare and a below ground biomass of 2 298 kg DM per hectare. Default dry matter values for the different biomass categories used in the inventory was given in Table 6.15. This default value is based on the average cereal yield in Denmark from 2001-2010 combined with the expansions factors for conversion into total living biomass as used in dynamic modelling for carbon stock changes in agricultural soils (6.4.3).

[4] Table AGF5 in Statistics Denmark.

[5] Table HST77, HALM1 in Statistics Denmark.

Fruit trees and other perennial woody plants

Fruit trees, other perennial commercial woody plants and durable horticultural plantations are included under Cropland (CFR Table 4.B). These are only of minor importance in Denmark and cover approximately 8 861 ha in 2021 of which around 4 766 ha, 54% is willow, out of a total Cropland of 2.8 million hectares. The total area for different main classes and the average C stock values for the living biomass (above ground and below ground) is given in Table 6.18. The calculation of the annual CO_2 removal and/or emission is based on the average stock figures multiplied with the area changes. This is used instead of a more complex growth model for the different tree categories, due to the limited area and small annual changes. Perennial horticultural crops account for approximately 0.07 % of the standing carbon stock.

The carbon fraction of dry matter (DM) is assumed 0.5 for all species.

Table 6.18 Tonnes living biomass per hectare and area in number of hectares, with perennial woody trees and bushes, 1990-2021.

	Living biomass, Mg DM per ha	Area, hectares						
		1990	2000	2010	2015	2019	2020	2021
Black currant	5.20	1269	1492	1848	1474	833	808	808
Other berries	5.20	663	611	620	0	0	0	0
Rosehip	13.99	0	0	197	154	195	191	184
Cherries	25.45	1787	2804	1743	1129	663	619	569
Plumes	25.45	0	0	68	67	81	78	90
Hazelnut and walnuts	25.45	0	0	14	27	40	56	85
Apples	33.76	2726	1678	1684	1519	1421	1408	1418
Pears	13.99	351	441	357	289	295	286	299
Elderberry	25.45	0	0	9	12	82	167	158
Grapes	5.20	0	0	45	79	105	138	149
Other fruit trees	13.99	0	0	60	138	92	100	259
Rowan-berries	33.76	0	0	16	26	31	1	1
Willow	17.43	588	695	4049	5478	4928	4837	4766
Miscanthus	17.43	1	6	156	69	77	80	76
Total, area in ha		7385	7727	10865	10459	8843	8770	8861

Hedgerows

Historical data on hedgerow plantings have mainly been provided by documentation of subsidiary schemes. Since the beginning of the early 1930s, governmental subsidiaries have been given to increase the area with hedgerows to reduce soil erosion. In the 1950-60's, 6-9 million single rowed conifers, mainly white spruce *(Picea glauca)* was planted annually. From around 1965, the annual rate decreased sharply to almost zero in lack of financial subsidies. As the older planting of white spruce were getting old, high replacement rates were seen in the 1980's and the 1990's, replacing white spruce with broad leaves. In 1990, 75 % of the replaced conifers hedgerows had been replaced with 3- to 6-rowed broadleaves hedges. The replacement rate has since gone down as well as the immediate need for hedges to lower sand drift from cultivated land, which is reflected by a decrease in the number of subsidized hedgerow plantings.

Since the 2020 submission (inventory of 2018), a new model was implemented. This model is an outcome from the Danish digital elevation model (DEM) where the terrain (DTM) and the surface height (DSM) is measured. In the inventory is used LiDAR measurements from 2006 and 2014/2015 (Levin et *al.*, 2020) and measurements of biomass combined with historical and current planting data to get a full time serie from 1990. The LiDAR methodology has a resolution of 0.4*0.4 m^2 in 2014/2015. The total volume of biomass is estimated as the difference between DSM and DTM for elements in Cropland and Grassland having a height > 2 meter and areas not reported in Forest land, Wetlands, Settlement, as horticulture/fruit plantations and willow and subtracted all building elements. The LiDAR measurements revealed an increase in the area with hedges and small biotopes in the period.

In combination with the LiDAR analysis, a measurement of approximately 10 000 m linear hedges (10.3 ha) was carried out by removing, chipping, burning and weighing the biomass. Analysis of the data showed that regardless of the height there was a stable biomass volume per m^3 of hedge/biotope of 2.54 (± 0.56) kg DM m^{-3} hedge. The analysis showed a tendency that more windy regions in Denmark have slightly lower hedges but as no significant differences in the volume per m^3 could be found these areas are reported with lower carbon stocks. To convert to carbon was used the IPCC default value of 0.47 and a Root/Shoot ratio of 0.192 (IPCC, 2006). The average height were estimated to 3.24 m (±1.72m) with an estimated average aboveground C stock of 38.7 tonnes C/ha. The volume density is higher than in the Danish NFI plots for trees with similar heights, most likely due to less light competition in hedges compared to forests. The measured DM m^{-3} hedge is similar to what have been found in other studies in Germany (Lingner et al., 2018) and UK (Axe et al., 2017).

For estimating changes in living biomass a growth model for planted hedges is included based on data for planted hedges. Data on planted hedges is from different sources (Landsforsøgene, 2023) and GIS data from the Danish EPA (EPA, 2023). The growth model assume a linear growth and a maximum carbon stock after 25 years. After this it is assumed that thinning is maintaining the carbon stock at this rate. As most new hedges are six-row broadleaves plants which may become higher than the average hedge it is assumed an average height at maturity at 4.96 meter (average measured height plus one Std dev) as a proxy. When a new analyse of the volume of hedges and trees in CL and GL based on updated DEM is available, the estimated biomass data will be updated accordingly. Currently is the Danish DEM updated for whole Denmark in a five-year rotation.

Table 6.19 shows the estimated planting and removal rates for hedgerows. For the years of LiDAR analysis, those area data are used and linearly interpolated. For years before 2006 and after 2015, area information on planting grants from the subsidiary system is used.

Table 6.19 Hedges planted and removed under the governmental subsidiary system 1990 to 2021.

	1990	2000	2010	2016	2017	2018	2019	2020	2021
Planted, ha	464.0	626.1	141.7	125.3	121.3	64.4	33.3	45.9	20.4
Removed, ha	522.0	219.1	13.0	8.6	6.9	1.2	2.0	2.1	- [a]
Net change, ha	-58.0	407.1	128.7	116.7	114.4	63.2	31.2	43.8	20.4
Net change, kt C per year	7.6	30.1	51.6	25.9	24.8	23.8	22.6	21.4	20.3

[a]Due to the insignificant removal rates, the analysis was not carried out for 2021.

6.4.5 Change in carbon stock in dead organic matter

No changes in dead organic matter are estimated, as this is assumed not occurring for this category.

6.4.6 Change in carbon stock in soils

Based on a GIS analysis of the data in the LPIS and a soil map of the organic soils (Greve et al., 2014), the agricultural area is distributed between mineral soils and organic soils and subdivided into Cropland (incl. grass in frequent rotation) and Grassland (rangeland, pastureland and permanent grassland).

Mineral soils

Emissions and removals for mineral soils in Cropland are reported in CRF Table 4.B. For carbon changes in mineral soils with annual agricultural crops, a 3-pooled dynamic soil model called C-TOOL is used (Taghizadeh-Toosi et al., 2014b). Mineral soils are defined as soils having < 6 % OC in the topsoil (0-30 cm). The output from C-TOOL include the carbon changes of both Cropland and Grassland, due to the technical settings of the model. As it is not possible to split the result, the entire output is reported under Cropland. Mineral soils in Grassland is therefore reported as 'Included Elsewhere' (IE). No change in the carbon stock in soils under perennial woody plants, hedgerows and "Other agricultural cropland" is expected as it is assumed to be at equilibrium. Carbon stock change for these categories is therefore reported as 'Not Occurring' (NO). These areas are also only a minor part of the Cropland area. For the area with agricultural crops, C-TOOL is run on a regional level with different soil types and with initialization in 1980.

C-TOOL

C-TOOL (Taghizadeh-Toosi et al., 2014b) is a 3-pooled dynamic model for estimation of medium- and long-term changes in soil carbon turnover. The technical details of C-TOOL is reported in Taghizadeh-Toosi (2015). The three different pools are; Fresh organic matter (FOM), Humified organic matter (HUM) and ROM (Resilient Organic Matter) and their approximate average half-live times (and dependent decomposition rates) are; 0.6-0.7 years (k_{FOM} = 1.44 per year), 30 years (k_{HUM} = 0.0336 ± 0.002 per year), and 600-800 years (k_{ROM} = 4.63 x 10-4 per year), respectively. When setting up the model, k_{FOM} and k_{ROM} is taken from short-term and long-term field experiments and based on these static parameters is k_{HUM} estimated with the long-term field experiments to 0.0336 ± 0.002 per year. (Taghizadeh-Toosi, A., 2015).

The main part of biomass returned to soil each year is in the first and easiest degradable FOM pool. This pool consists of mainly fresh straw, fresh manure, root residues, fungi and small animals and fluctuates very much between years depending on the harvest yield and climatic conditions. The FOM pool accounts for approximately 1-2 % of the total carbon stock in the upper 0–100 cm. The ROM pool is the most resilient part of the soil organic carbon. In most "old" soils, which has been cultured for hundreds of years it approximate around 50 % of the organic soil carbon (0-100 cm). The remaining amount of organic carbon is allocated to the HUM pool.

However, there is a difference to coarse sandy soils, which is old heathland in Jutland. In 1200-1800 of these, sandy soils were heavily overgrazed and turned into marginal heathland giving a low but very stable carbon content. Since the 1870's, this land has been cultivated, more farmed cattle were introduced and from the 1950's fertilized with mineral fertilizer. For these areas, our results show that the amount of HUM is much lower here, 29.0 t HUM per ha, compared to the other soil types, which have an average of 49.4 t HUM per ha (Table 6.20).

Table 6.20 Estimated amount of HUM and ROM in Jutland and on the Danish Islands.

	Total, t C per ha (0-100 cm)	
Location	HUM	ROM
Coarse Sand, Jutland	29.0	93.4
Loamy Sand, Jutland	42.2	80.4
Sandy Loam, Jutland	57.8	75.7
Loamy Sand, Islands	44.1	63.1
Sandy Loam, Islands	53.4	67.2
Average Loamy Sand and Sandy Loam	49.4	71.6

It is obvious that the ROM pool has a minor influence on the annual C stock changes because it reacts slowly. The FOM has a very large influence because in Denmark the process of turning organic matter (OM) from crop residues into soil organic matter (SOM) starts after harvest from August to October. If there is a large input of crop residues (CR) and low temperatures during autumn, the outcome from the modelling by 31 December of the reporting year, is that only a small amount of the applied CR has been degraded out of the approximate 3.5-5 tonnes C per ha, which is incorporated every year. The result is a rather high total content of SOM at the end of the year and the changes between two successive years are large, if the previous year showed the opposite pattern with a low crop yield and a high temperature in the autumn. Such changes can be seen as "artefacts" as it is a matter of definition of the organic matter, whether it is partly degraded as crop residues or SOM. Therefore, we have agreed with a previous ERT (UNFCCC review report) to exclude FOM from the reporting in soils and only include the HUM and ROM pools. As a result, the HUM pool is more or less solely responsible for the changes in the SOC stock between years.

In the case of the sandy heathland in Jutland, the low amount of HUM means that these soils will store higher amounts of C in the future than the other soil types, until it reach the equilibrium state between incorporation and degradation. The history of heathlands C stock can be explained as small annual inputs for hundreds of year has given a higher distribution ROM compared to soils that are more fertile and a low share of HUM. Furthermore, we find large amounts of inert C (partly degraded OM) comparable compared to the other soil types, which we assume is due to burning of the heathland for hundreds of years (biochar). In the case with the old heathland, the annual input of crop residues has increased tremendously due to cultivation and fertilization. In factual terms, the average Danish cereal yield has doubled from 1900 to 1965 but on sandy soils, it has quadrupled from a very low level (Statistics Denmark, annual year book). The consequence of this is that these sandy soils haven not reached their equilibrium state yet and are still increasing the SOC. This in contradiction to the old fertile clay soils, which are more in their equilibrium state, although still increasing their C stock due to increased annual CR input.

A simple diagram of C-TOOL is shown in Figure 6.6. C-TOOL is parameterised and validated against long-term field experiments (100-150 years) conducted in Denmark, the United Kingdom (Rothamsted) and Sweden and is "State-of-the-art". All dynamic models are allocating the total soil carbon stock into sub-compartments each having different degradation times. This distribution cannot be measured but have to be estimated from long-term experiments. As the models are parameterised on mineral soils the model cannot be used on soils having higher carbon contents such as organic soils as there is a limited number of data for validation and that the large amount of easily degradable OC in the organic soils affect the distribution in the different sub-pools. Therefore C-TOOL is only used on soils having < 6 % OC. For soils having >= 6 % OC is used fixed emission factors per ha. In the inventory soils having 6-12 % OC has been given an emission factor of 50 % of organic soils > 12 % OC.

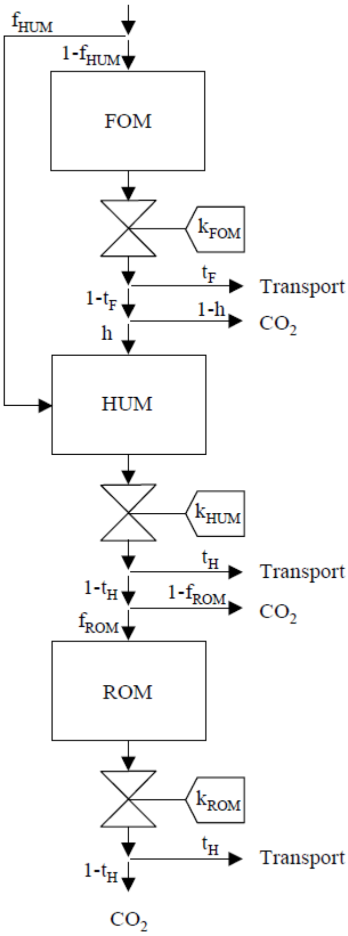

Figure 6.6 A simple diagram of C-TOOL.

Input data to C-TOOL and output

A major revision of the soil parameters was made in 2016. The new version (Version 2.3) was implemented in the 2017 submission for all years. Version 2.3 includes ALL agricultural mineral soils in cropland and grassland. In the modelling, Denmark is subdivided into eight counties. Each county are further subdivided into two or three soil types. On the islands, where the soils typical are loamy sand or loam, two different soil types are used. Jutland, which has a large area with sandy wash-out plains, are split into three different soil types. As C-TOOL treats all agricultural crops on mineral soils including within grassland the emission from grassland is reported as IE as these carbon stock changes are included under cropland. This is also to facilitate the trivial annual conversions from cropland to grassland and vice versa as mentioned in the Land use matrix (Table 6.4). Set-a-side is treated as a separate crop type in C-TOOL with a low input of organic matter similar to unfertilized permanent grass.

As carbon input to each region for each year is taken the actual crop area from the LPIS system and crop yields from Statistics Denmark (www.dst.dk Table AFG, AFG07, HST7 and HST77). The dry matter content depends on the actual crop. For cereals, it is 15 % (DST, 2021). The amount of agricultural residues returned to soil is the amount estimated by Statistics Denmark (www.dst.dk Table HALM and HALM1). The dry matter content depends on the actual crop. For cereal straw, it is 15 % (DST, 2021).

The amount of animal manure produced (Volatile Substance) and applied to soil is estimated with the same methodology as in the Agricultural sector for estimating CH_4 and N_2O emission where annually updated feeding and excreting data are provided for the regulation of the animal production in Denmark. Here detailed data on the number of animal, housing and manure type are available on farm level. As the animals are distributed unevenly over the country, data on the actual location of each farm and their herd/nitrogen excretion in the Danish mandatory nitrogen accounting system is used as proxy for the distribution of the animal manure on regions and soil types. From 2000, each farm has been geocoded on regions and soil type and multiplied with the animal units on the farm. For the years 1980 to 1999, the same distribution is used as in year 2000.

Since 1997, there has been a requirement for growing N catch crops in Denmark in order to reduce N-leaching. Besides reducing the N leaching, the catch crops increase the carbon stock in the soil. Since year 2000, the area has increased and in 2020 there were 505 000 ha where catch crops were included–- often after green maize for fodder or after spring cereals. The requirement for catch crops has altered the way of farming in two ways. Cattle farmers are typically sowing grass seed in their normal cereal fields. This new grass sword must not be ploughed into the soil before winter/next spring. For farmers growing grass seed, which is common in Denmark, the old grass seed fields are not ploughed in to the soil before next spring, in contradiction to the current situation where it would be ploughed early autumn and act as a carbon sink. Eriksen et al. (2014) have estimated that the mandatory catch crops expects to increase the amount of C returned to soil by 0.27 tonnes carbon per ha per year. The area with catch crops in each region is estimated from each farms' obligatory reporting to the Danish Agricultural Agency on which field each catch crops is grown, which is available for the inventory (LBST, 2023). As for the distribution of animal manure, the area with catch crops have been geocoded since 2000 and the organic matter input has been allocated to the different soil types.

More detailed figures on the distribution as an example of the crop yield and areas are given in Annex 3E, Table 3.E11-13.

C-TOOL is initiated with data from 1980. Actual regional monthly average temperatures are used as temperature driver. The main drivers in the degradation of soil biomass are temperature and humidity. The Danish climate is quite humid with winter temperatures around zero degrees Celsius and hence the importance of soil humidity on the model outcome is low in comparison to temperature, which has a high effect on the emission. As mentioned, when biomass is returned to the soil the major part of it is quite easily degradable. Warm winters with unfrozen soils in connection with high inputs of biomass will therefore, as a result, give high emissions from the soil compared to more cold years, which will give low emissions. The variation in the input to C-TOOL results inter-annual variation in the carbon input to the soil for all years. Combined with inter-annual differences in the temperature, this creates inter-annual differences in the net carbon stock change in mineral soils, where low yields combined with high temperatures, reduce the total amount of carbon in agricultural soils. The opposite situation, whit the combination of high yield and low temperatures, leads to an increase of the carbon stock in soils.

Figure 6.7 shows the total SOC included in the model as well as the annual changes. The blue line represent all three pools (FOM, HUM and ROM) and the red line represent only HUM and ROM. It is obvious, that the total carbon stock fluctuates more than the two more steady pools, HUM and ROM. 2017 was a good year for growing cereals giving high yields compared to 2016. For 2018, the yields were very low due to a severe draught in the growing season. Consequently, an increase in the overall SOC stock compared to 2016 is seen and a large decrease from 2017 to 2018 (Figure 6.6). In 2019 and 2020 the crop yields were back to normal.

Two examples

Both year 2006 and 2007 were bad cropping years with cereal crop yields of 7-9 % below the average of 2001-2010. The average Danish temperature in 2007 was, however, 1.9 °C higher than the average of the 30-year period 1961-1990 of 7.7 °C . Therefore, both due to the low C input and a high degradation rate, the agricultural soils were estimated to have a high loss of carbon in these years, cf. Figure 6.6 and 6.7.

In recent years (1999 - 2021), Denmark has experienced very warm winters, except from 2010, which was very cold at 7.0 °C average against 7.7 °C. This means that the degradation goes down. The average cereal yield was 3.5 % lower than the average of 2001-2010. The result was an increased carbon stock in the soil, and lower emissions.

In 19 out of the last 20 years, the annual average temperature has been above the average temperature of 7.7 °C from 1961-1990. The average temperature in the latest standard 30-year period, 1991-2020 was 8.7°C, a full degree Celsius above 1961-1990. The minimum of the latest average was in February of -0.9°C and average maximum in July and August of 21.2°C (Rubek et al., 2021). Year 2020 had an average temperature of 9.8°C or 2.1°C above the average from 1961 to 1990. The average temperature of 2021 was exactly average at 8.7°C (DMI, 2022).

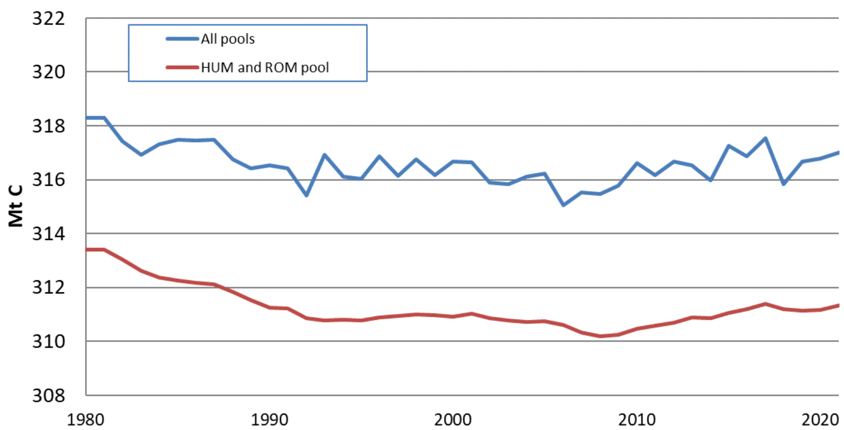

Figure 6.7 The development in the C stock in agricultural soils (Cropland and Grassland), 1980-2021, Mt C (million tonnes C).

As a whole, the modelled emissions are found to be the most reliable emission estimates reflecting the Danish conditions. As described Danish farmers have faced increased demands for lower environmental impact since the mid-1980s. The general effect a decrease in the carbon stock in soil is during the 1980s shows, while during the 1990s, the carbon stock seemed to stabilise due to the higher input of organic matter. Taking into account the decreasing agricultural area and the increased global temperatures, a relatively steady total carbon stock was modelled between 2000 and 2010, while the total SOC increase after 2010. Since 1990, C-TOOL has estimated a decline of 0.03 % of the total SOC in the mineral agricultural soils (average 1988-1992 to average 2017-2021). No precise uncertainty calculation has been made. However, it is assumed that the uncertainty of the annual loss/gain is around 25 %. Denmark has very good data on harvest yields and cultivated area data, which indicate a low uncertainty.

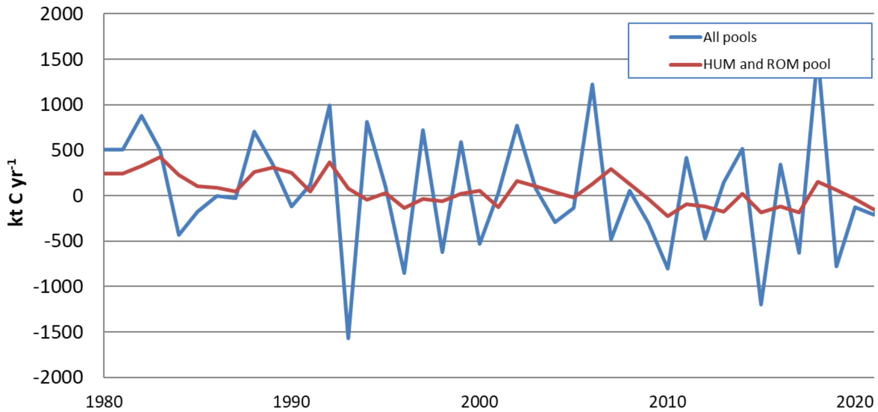

Figure 6.8 Estimated annual changes of gains and losses in the C stock in mineral soils 1981 to 2021, expressed in kilo tonnes C per year.

Verification of C-TOOL

C-TOOL is partly parameterised with data from the Danish Agricultural soil sampling grid. The grid was established in 1987 in a 7 x 7 km^2 grid. In 1987, > 600 agricultural plots were sampled and analysed for carbon. Half of the grid were resampled in 1998 and a full resampling of 464 plots was made in 2008/2009. Figure 6.9 shows the development of the carbon stock in 0-100 cm depth in the paired plots, which indicate an increase for the soil C stock at the sandy soils (Coarse Sand, Fine Sand and Loamy Sand). This is mainly due to increase of the crop yields, which increase the amount of organic matter returned to soil. Furthermore, the Danish cattle herd is located on the sandy soils and typically have large areas with grass in rotation. This favours the soil C stock. Contrary to this, a loss in the C stock on the loamy soils (Sandy Loam and Loam) is observed. On the loamy soils, annual crops are the most common cultivars and usually have a limited number of cattle and pigs. The measurements uncertainty is high, so overall it is concluded that the modelled results are in line what is found in plot sampling.

As C-TOOL is partly parameterised with the development in the soil sampling grid, the model output will mimic the measured development in the soil carbon stock in mineral soils. The variation in measured carbon stock in paired soil samples in the soil sampling grid is high. The conclusion is that the modelled outcome from C-TOOL represents a proper value for the development of the carbon stock in the Danish agricultural soils. A new sampling in the grid was made in 2018/2019. The data has not been analysed yet. This will further verify the development.

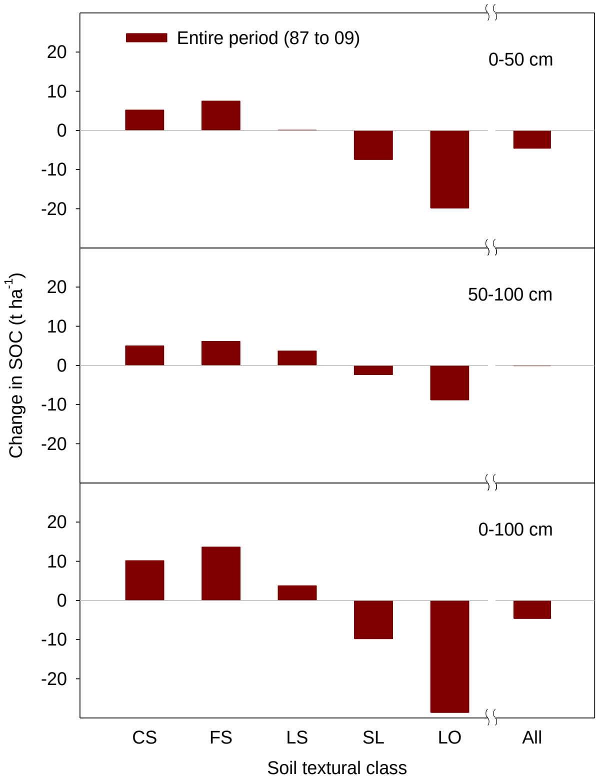

Figure 6.9 The change in carbon stock in soil (0–- 100 cm) in >460 paired agricultural plots from 1987 to 2009 (Taghizadeh-Toosi et al., 2014a).

Organic soils

Emissions and removals from Cropland on organic soils is reflected in CRF Table 4.B.1. As C-TOOL only models the emissions from the mineral soils, the estimates for the emissions from Cropland (as well as other land use categories) on organic soils constitutes its own separate calculation.

The basic Danish soil classification system from 1975 (dca.au.dk – den danske jordklassificering, 2023) has a definition for organic soils as having >=10 % organic matter (OM) in the topsoil, equivalent to 6 % OC. In 2010, a new soil map of the organic soils was made for the inventory based on the definition in the IPCC guidelines (Greve et al., 2014), see Figure 6.10. The soil map is a statistical map based on >10 000 soil samples down to the mineral soil in 30 cm intervals combined with the detailed digital elevation map (DEM) for each 1.6 x 1.6 m^2 covering the entire Denmark, water table maps and other old maps with organic soils. The definition of an organic soil in the map is 20 % organic matter with a depth of minimum 30 cm (Greve et al., 2014). The total area with organic soils covered by the soil map has been estimated to 298 000 ha. In 2010, 177 135 ha of the organic area was included in the farmers Land Parcel Information System.

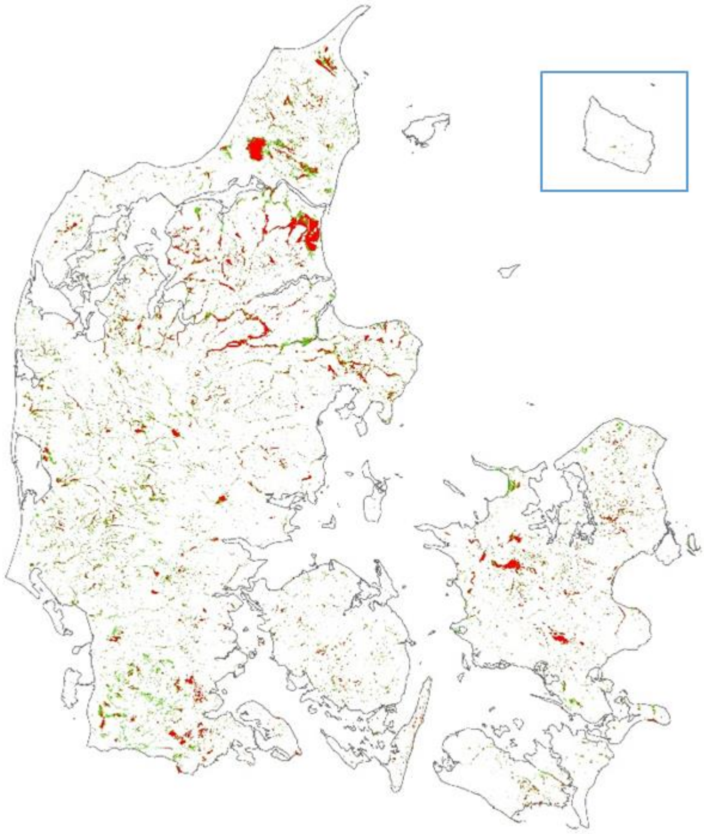

Figure 6.10 The organic soil map for Denmark year 2010, > 6 % OC (Greve et al., 2014). Green colour indicates 6-12 % OC and red colour indicates >12 % OC soils.

To estimate the actual land use of organic soils, the digital field map from LPIS has been placed on top of the organic soil map. The digital field map include all agricultural fields in Denmark (>570 000 fields). This map from the EU subsidiary system is precisely mapped with an uncertainty down to < ± 0.5 meter. The actual grown crop is known for each field. In total, more than 300 different crop types or combination of crop and crop management are recorded. In 2021, 88 073 hectares with annual crops and 80 709 with perennial grass were located on the organic soil area in the defined CL with >= 6 % OC. Every year some areas are falling out of the field map. This means that the farmers are no longer applying for subsidies on these areas. Some of them are found in the map for Wetlands (4.D), but not all of them. In 2021, 3 341 hectares could not be recognized. Further drainage of the organic soils in Denmark has not been allowed for many years. The most likely situation therefore is that these areas have become wet and not suitable for cropping purposes. These areas in the inventory are referred to as 'Abandoned land' and have been assigned an emission of 3.6 tonnes C per ha, which is the default standard for shallow-drained nutrient-rich grassland from the 2013 Wetland Supplement (IPCC 2014), see Table 6.21.

The previous Danish soil classification carried out in 1975, estimated that there were 243 000 hectares of organic soils in agricultural land (>= 6 % OC). Of these were 176 124 ha in the Cropland and the remaining 66 875 ha were with grass. In 2010, it was only possible to find 180 000 ha. The major reason for the drastic reduction is that Denmark is quite flat with shallow organic layers, which in combination with the intensive agricultural utilisation and high drainage rates has oxidized a major part of the organic matter.

Emission factors for organic soils

Soil C stock change

An intensive research programme has been carried out to monitor the CO_2 emission from three organic soils in Denmark with annual crops in rotation and permanent fertilized grassland (Elsgaard et al., 2012). The overall results, which are applied in the inventory is shown in Table 6.18 and compared with the IPCC default values. For areas not reported in the field map from LPIS, default Tier 1 emission factors from the 2013 Wetland Supplement (IPCC 2014) are used.

Maljanen et al. (2010) reviewed the GHG balance of managed organic peatlands in the Nordic countries. For areas with agricultural grasslands, the available studies suggested a net CO_2 emission of 4.9 ± 3.2 t C per m^2 per year (mean +/- standard deviation, n = 4). The available studies represented three Finnish and one Norwegian site (Lohila et al., 2004; Maljanen et al., 2001, 2004; Grønlund et al., 2008). The up-scaled annual emission from the Danish declining carbon stock is in line with these figures when taking into account the differences in temperatures. Considering that the IPCC estimate also covers the boreal zone, the measured Danish values seem to be in line with the IPCC guidelines. Emissions from organic soils on permanent grassland are reported under Grassland (CRF Table 4.C.1). The emission factors are given in Table 6.21.

The dominating use of the organic soils in cultivation is fertilised annual crops and grass in rotation. As C-TOOL has shown not to be able to simulate the emissions from soils having >6 % OC, fixed emission factors have been used for this area. As this level does not qualify as organic in the scientific world and hence little attention has been paid to these soils and no data can be found in scientific literature. Normally, mineral soils in equilibrium will have an organic matter of 1-1.5 % OC. Soils with higher contents are most likely developed under humid conditions with low degradation rates. Drained and managed soils having >= 6-12 % OC can therefore not be seen as being in their equilibrium state and will evidently lose carbon.

It has therefore been decided to allocate an emission of 50 % of what was measured for soils > 12 % OC to the soils of 6-12 % OC, in an attempt to account for these losses. These emissions are included in CRF Tables 4.B and 4.C.

Table 6.21 Emission factors of C and CH_4 from organic soils, tonnes C per ha per year.

	Cropland Annual crops and grass in rotation	Grassland Permanent grass		Abandoned land	
	C, tonnes per year	C, tonnes per year	CH_4, kg per year	C, tonnes per year	CH_4, kg per year
Soils > 12 % OC	11.5 (SE = ±2.0)	8.4 (SE = ±1.0)	16	3.6	39
Soils 6-12 % OC[a]	5.75	4.2	8	1.8	19.5
IPCC 2014, Boreal and Temperate	7.9 (CI = 6.5-9.4)	3.8-6.1 (CI = 5.0-7.3)	16	3.6 (CI = 1.8-5.4)[b]	39

[a] 50 % of the emissions measured and estimated for soils > 12 % OC
[b] IPCC 2014 standard value for 'Grassland shallow drained'

N_2O, CH_4 and CO_2 emissions from drainage and rewetting of organic soils

These emissions are covered by CRF Table 4(II) and briefly described in Section 6.10 in NIR.

As emission factor for N_2O from the 2013 Wetland Supplement, the default value of 13 kg N_2O-N per ha per year is used for the area of organic soils with > 12 % OC. This emission is reported in the agricultural sector, 3Da6 (cultivation of organic soils).

For CH_4 from ditches is used the default methodology in the Wetlands Supplement (IPCC, 2014) with a default fraction of ditches of 5 percent of the organic area and an emission factor of $EF_{CH4\_Ditch,p}$ of 1165 kg (95 % CI: 335-1995 kg) CH_4 per ha per year. As the area with organic soils is based on the accurate size and position of each field in Denmark, the estimated ditch area is supplementary to the reported area. For the shallow-drained abandoned organic soils a CH_4 emission factor of 39 kg CH_4 per ha per year for soils with >12 % OC and 19.5 CH_4 per ha per year for soils with 6-12 % OC are reported. The category of abandoned land is the area of organic soils that are wet enough to cause CH_4 emissions and defined as the area that has been included in the LPIS field maps but where farmers have since ceased to apply for subsidies. It is assumed that these areas are no longer included in the subsidy schemes because they have become too wet to be farmed.

All CO_2 emissions from organic soils converted from other land use categories to Cropland are reported under 4.B.1. The related N_2O emission is reported in the agricultural sector in CRF Table 3.Da5. CO_2-emissions from leached dissolved organic carbon (DOC) is estimated based on the methodology in the Wetlands Supplement (IPCC, 2014). The emission factor $_{EFDOC\_DRAINED}$ of 0.31 t C per ha per year (95 % CI: 0.19–0.46) is applied.

To estimate the emission from the organic soils, a linear decrease in the area with organic soils between the first and second mappings in 1975 and 2010 has been assumed. The total CO_2 emissions from the organic soils in Cropland are given in Table 6.22.

Table 6.22 Emissions from Cropland on organic soils 1990 to 2021.

	1990	2000	2010	2015	2017	2018	2019	2020	2021
Cropland, 6-12 % OC, ha	79618	74845	69159	64169	63110	61731	61690	60582	59970
Cropland, >= 12 % OC, ha	54082	47851	40718	34980	33802	32498	32754	31790	31444
Cropland, total, ha	133700	122697	109877	99149	96911	94228	94444	92372	91414
Emission, from drained land, kt C	1079.7	980.7	865.9	752.6	733.0	710.1	713.0	695.2	687.5
Emission from leached C, kt C	29.1	26.4	23.3	20.8	20.3	19.6	19.7	19.2	19.0
CH_4, kt CH_4	5.5	5.0	4.4	4.0	3.9	3.8	3.8	3.7	3.7
Emission, total, kt CO_2	4218.9	3831.7	3383.4	2947.7	2871.1	2781.8	2793.0	2723.4	2693.5

6.4.7 Uncertainties and time series consistency

A Tier 1 uncertainty analysis has been made for the Cropland part of the LULUCF sector, see Table 6.23. The uncertainty in the activity data for the agricultural sector is very low. The highest uncertainty is associated with the emission factors and the modelling. Especially the emission/sink from mineral soils and organic soils have a high influence on the overall uncertainty.

Table 6.23 Tier 1 uncertainty analysis for Cropland for 2021.

		1990	2021					
		Emission/ sink, kt CO_2 eqv.	Emission/ sink, kt CO_2 eqv.	Activity data, %	Emission factor, %	Combined uncertainty	Total, uncertainty, %	Uncertainty, 95 %, kt CO_2 eqv.
4.B Cropland		5314.3	2759.1				35.7	984.3
4.B.1 Cropland remaining cropland, Living biomass	CO_2	74.6	539.4	3	15	15.2	15.2	82.0
4.B.1 Cropland remaining cropland, Mineral soils	CO_2	932.2	-546.2	3	75	75.0	75.0	409.8
4.B.1 Cropland remaining cropland, Organic soils	CO_2	3959.1	2520.8	3	50	50.1	50.1	1263.2
4.B.2 Forest land converted to cropland	CO_2	2.2	96.8	10	50	51.0	51.0	49.4
4.B.2 Other land uses converted to cropland	CO_2	86.3	-26.8	10	50	51.0	51.0	13.6
4(II) Cropland on organic soils	CO_2	106.7	69.8	3	40	40.1	40.1	28.0
4(III) Mineralization/immobilization, Cropland	N_2O	0.0	2.3	10	50	51.0	51.0	1.2
4(II) Cropland on organic soils	CH_4	153	102.8	10	90	90.6	1025.9	0.2

The time series are complete.

6.4.8 QA/QC and verification

A general QA/QC plan is developed for Cropland. The following Points of Measures (PM) are carried out:

- Collection and error check on in-data
- Control of sums
- Comparison with other data.

The area estimates for Cropland and Grassland since 2010 are very precise due to unrestricted access to detailed data from EUs Integrated Administration and Control System (IACS) on agricultural crops on field level and the use of the vector based Land Parcel Information System (LPIS). This access is granted to both Statistics Denmark and DCE. The total uncertainty in the major crop harvest data is estimated by Statistics Denmark to be <2 %. The QA of crop data is made by Statistics Denmark. Together with detailed soil maps, this gives a unique possibility to monitor and assess the agricultural crops on different soil types and hence track changes in land use. However, IACS and LPIS are only available from 1998 and onwards and estimates for 1990 are therefore more uncertain. The uncertainty in the LPIS data dating back before 2010 similarly is slightly more uncertain than the more recent data, due to the higher geographical detail level since then.

Data on newly planted and removed hedgerows are based on subsidised hedgerows and QA is carried out by the Danish Agricultural Agency, who is responsible for the administration of the subsidy scheme. The uncertainty in the number of plants used for the hedgerows is not estimated but is assumed very low because of the subsidy system. There is an unknown uncertainty in the number of un-registered removals of hedgerows. A linear approach has therefore been made for "missing" hedges over the years.

Establishment of wetlands is based on vector maps received from every county in Denmark. The uncertainty is not estimated but assumed very low due to the subsidised system.

As shown in Figure 6.7 and 6.8, the increase in carbon stock as estimated by C-TOOL seems close to the results from 464 paired soil samples.

A range of experts from the Faculty of Agricultural Sciences, Aarhus University, are repeatedly involved in discussions and report writings on topics related to the inventory.

6.4.9 Recalculations

Recalculations of living biomass in CL remaining CL has been made due a reallocation of the areas in CL. This will further be improved in the next submission, see Planned Improvements, 6.4.10.

The annual amount of volatile solids in animal manure has been updated with new figures for all years from 2010 to 2020. This has affected the emission estimates for the carbon stock in mineral soils in that period, because it is used as an input to the C-TOOL modelling.

6.4.10 Planned improvements

A 1.2 million € project has been started in 2021 to investigate the emissions from the organic soils. This project includes a detailed modelling/mapping of the groundwater level in drained organic agricultural soils. Resampling is conducted on > 1000 organic soils within the organic soil map from 2010 (Greve et al., 2014) and based on changes in the peat layer, to develop a new C degradation model. It is expected that the results will be ready for implementation in the 2024 submission.

A revision of the Land Use Matrix is taking place, looking specifically at the allocation of land between Cropland/Grassland and a subdivision of Settlement into more detailed categories with different carbon stocks. Because of the detailed agricultural data we have, we need to reconsider the allocation permanent grassland either by moving them to CL having their own living biomass classes or in the land use matrix reallocate some areas with CL into GL. The first possibility is the most likely so GL in the future only will cover very marginal grazing areas such as heath land and natural habitats and not permanent grazing land reported by the farmers. This solution will also solve the issue that the estimated carbon stock for mineral soils in the permanent grassland is included in the C-TOOL modelling and thus reported as IE in CRF Table 4C.1. Furthermore this approach will also move the majority of organic soils reported in GL into the CL sector. The current approach may lead to an overestimation of the losses of living biomass. This task will be implemented in the 2024 submission.

When funding become available a new analysis of biomass in hedges and other biotopes based on the most recent DEM will be performed.

In 2024 an updated version of C-TOOL will be developed, which is expected to be used in the 2025 submission.

6.4.11 Land converted to Cropland

Emissions and removals from land converted to Cropland are covered by CRF Table 4.B.2. Agriculture covers more than 65 % of the total area in Denmark, heavily impacting the environment. As a consequence, there are many initiatives to convert agricultural land into natural habitats and forest, meanwhile the continuous development of infrastructure also demands more land. Land converted to Cropland is therefore limited in practice.

The area converted from other land uses to Cropland is based on remote sensing of the Danish area in 1990, 2005, 2011, 2012-2021 combined with data in LPIS of which crops are grown in each field. See detailed descriptions in chapter Section 6.2.

Methodological issues

The largest challenge methodologically in the reporting is that the farmers in one year may report that a certain field is Cropland and the next year is permanent Grassland. The field may register as Grassland for several years before it is once again ploughed and turned into annual Cropland, for one year. Because of the detailed information available in the annual LPIS data, it has previously been difficult to preserve a conservative estimate of conversions between these two land use categories. To minimize the conversion ratios it is decided that Cropland and Grassland has to be registered in the same category for five years before the conversion is accounted for in the inventory, which has reduced the number of hectares in conversion. However, as the carbon stock changes in mineral soils are estimated using C-TOOL, which combines the calculation for Cropland and Grassland, the effect of this has no impact on the overall emission estimate from agricultural soils.

Change in carbon stock in living biomass

For land converted to Cropland, a standard default gain value of 9 577 kg DM (dry matter) per hectare in above ground biomass and 2 298 kg DM per hectare in below ground biomass, equivalent to 5.9 t C in living biomass per hectare is used. This value is equivalent to the average harvest of living biomass for all cereals grown in Denmark from 2001 to 2010, including straw, stubble and glumes. For conversion from DM to carbon, a default fraction of 0.5 kg C per kg DM is used.

For conversion from Cropland to other land use categories, the same value is used and recorded as a loss of carbon in the respective category (4A2, 4C2, 4D2 and 4E2).

The loss in living biomass for conversion from another land use category into CL is estimated as the default value for DM in that particular land use category. I.e. for deforested areas, the average carbon stock per hectare for all deforested areas, reported with the NFI, is used.

Change in carbon stock in dead organic matter

When Forest land is converted to Cropland, it is assumed that all dead organic matter (DOM) from the forest will be instantly oxidated. Due to current harvest practises (chipping), no significant amount of DOM is left on site. The actual amount of C lost depends on which type of forest is converted and estimated via the annual NFI. N_2O emissions from DOM decomposition is covered by Section 6.11.

Conversion of DOM from other categories is assumed as not occurring, as no dead organic matter is reported for these categories.

Change in carbon stock in soils

When land is converted into Cropland, the change in C stock in the soil is estimated as the difference between the new estimated equilibrium state of Cropland (120.8 t C per ha) and the equilibrium C state of the soil for the old land use category. The actual amount thus depends on which type of land it is converted from, see Table 6.15. To reach the new equilibrium state, the transition period of 30 years is used.

E.g. when an area of mineral Forest land is converted into Cropland, there is a net change in the C stock in the soil of -20.2 t C per ha (120.8 t C – 142 t C per ha), equal to an annual loss of 0.7 t C per ha in a period of 30 years. It is reported as an annual loss of soil C (CO_2) in the Cropland category, while the entire C pool in Cropland has increased due to the simple fact of an increased area.

N_2O emissions for land converted to Cropland are reported with Agriculture, see also Section 6.11.

Uncertainties and time series consistency

The time series are complete.

See uncertainties and time series consistency in Section 6.4.6.

QA/QC and verification

See QA/QC and verification in Section 6.4.8.

Recalculation

See recalculation in Section 6.4.9.

Planned improvements

See planned improvements in Section 6.4.10.

6.5 Grassland

Grassland emissions and removals are covered by CRF Table 4.C.

6.5.1 Grassland definition

Grassland is defined in the land use matrix as the remaining land category after subtracting the areas of Settlements, Forest land, Cropland, Wetlands and Other land from the total land area. As Cropland includes all perennial woody areas such as hedges, shelterbelts, fruit plantations and other wooded areas that do not qualify as forest, no perennial woody crops is reported in Grassland. Thus, Grassland consist of heath- scrubland, meadows and marginal agricultural grazed land.

For inventory purposes Grassland is further split into grazing grassland and other grassland. Grazing grassland is the area with permanent grassland as recorded by Statistics Denmark. Other grassland is the difference between the grassland area in the land use matrix and the area reported by Statistics Denmark.

6.5.2 Grassland area

The total area with grassland has been estimated in the Land Use Matrix. In 1990, the total area was 146 388 hectares and in 2021 the area had increased to 181 329 hectares. This is quite a small area of around 4.2 % of the total land area of 4.3 million ha, however this is also impacted by the uncertainty to accurately report conversions between Grassland and Cropland. According to Statistics Denmark, there are 234 288 ha of permanent grassland in 2021, cf. Table 6.17. This means that part of what is reported by Statistics Denmark, in the inventory is reported under CL.

As C-stock changes in the mineral soils are modelled as a whole with C-TOOL the allocation between cropland and grassland has no effect on the emission estimates from that main emission source. CO_2 emission from mineral soils estimated with C-TOOL are reported under Cropland, except where land use conversion into Cropland has taken place. The emission from organic soils has decreased due to a decrease in the area with Grassland on organic soils.

Table 6.24 Total area and annual emissions 1990 to 2021 from Grassland.

Grassland	1990	2000	2010	2015	2017	2018	2019	2020	2021
Area, 1000 ha	146.4	140.3	141.5	168.2	173.3	170.0	170.8	168.9	181.3
Living and dead biomass, kt C	2.7	-0.6	9.8	46.6	19.2	52.5	33.8	32.2	60.1
Mineral soils, kt C	14.4	9.3	4.0	1.2	0.1	-0.5	-1.0	-1.0	-1.0
Organic soils, kt C	558.6	502.6	471.6	500.1	511.7	527.0	523.9	532.2	537.3
Total, kt C	575.6	511.3	485.4	547.9	531.0	579.1	556.7	563.4	596.4
CH_4, kt CH_4	4.76	4.28	4.02	4.26	4.36	4.49	4.47	4.54	4.58
N_2O, kt N_2O	0.000	0.000	0.001	0.008	0.000	0.003	0.000	0.001	0.001
C, kt CO_2 eqv.	2110.7	1874.9	1779.8	2008.9	1946.8	2123.4	2041.2	2065.7	2186.8
CH_4, kt CO_2 eqv.	133.3	120.0	112.6	119.4	122.1	125.8	125.1	127.0	128.3
N_2O, kt CO_2 eqv.	0.0	0.0	0.3	2.0	0.0	0.7	0.1	0.1	0.2
Total, kt CO_2 eqv.	2244.0	1994.9	1892.7	2130.3	2069.0	2249.9	2166.4	2192.9	2315.2

6.5.3 Grassland remaining grassland

The emissions and removals from Grassland remaining Grassland are covered by CRF Table 4.C.1. Denmark is an intensive agricultural country with small holders and small fields where cropland and grassland is mixed making it difficult to distinguish between dedicated Cropland and dedicated Grassland. According to the Danish Land Parcel Information System (LPIS), there are approx. 175 000 fields of total 310 000 ha with permanent grassland in 2021 giving an average size of two ha. Some of them cannot be regarded as permanent grassland, as they are registered as permanent Grassland only for a short period of time before they are registered as Cropland again and these areas are therefore included in the Cropland category.

6.5.4 Grassland – methodological issues

The area for grazing grassland is the area reported by statistics Denmark and the rest of the grassland is the residual part of the grassland area. The area with organic soils in grassland is estimated from the organic soil map of 2010 with an overlay of the fields where the farmers are reporting agricultural crops. Permanent grass fields are those reported by the farmers as permanent grassland according to the guidance for the LPIS database (Danish Agricultural Agency, 2022).

6.5.5 Change in carbon stock in living biomass

No changes in living biomass are assumed for grassland remaining grassland, except for minor conversions between “Grazing land” and “Other grassland”. There is a difference of 380 kg C per hectare between the two subdivisions. For “Grazing land”, a gain value of 4560 kg C per hectare is used, and for “Other grassland” not purely free of woody trees/bushes, it is assumed that there is a living biomass of 4180 kg C per hectare.

However, due to a high inter-annual land use conversion between especially Grassland and Cropland, resulting in an overall decrease in the area of Grassland remaining, Grassland remaining Grassland is showing a loss in carbon stock over time. This has some effect on the allocation of the emissions in the inventory, but limited net effect, as the estimated loss is often countered by an increase in C in living biomass for the land use category, to which Grassland is converted.

6.5.6 Change in carbon stock in dead organic matter

No changes in dead organic matter are estimated, as this is assumed not occurring for this category.

6.5.7 Change in carbon stock in soils

No changes in the carbon stock in GL mineral soils is reported for Grassland, which can be seen as purely uncultivated grassland. For grassland, which is part of the agricultural area, as defined by the LPIS, the emission is included under Cropland and therefore reported as 'Included Elsewhere' (IE) under Grassland. See Section 6.4.6.

For drained organic soils, a nationally developed emission factor of 8.4 tonnes C per ha per year is used for soils with at least 12 % OC (Elsgaard et al., 2012). For organic soils having 6-12 % OC an emission factor of 4.2 tonnes C per ha per year is used. See Table 6.18 and the section on emission factors from organic soils in Cropland – 6.4.6. As the reported area with organic soils has decreased around 1% since 1990, the overall emission from Grassland has gone down with around almost 4 %, including CH_4 emissions. The reduction is mainly driven by a change from soils of >= 12 % OC to soils with 6-12 % OC. The rich soils of >= 12 % OC decreased down to a minimum of 35 983 in 2012 and the soils of 6-12 % down to 30 945 in 2009, but since then both areas have increased again almost to the level of 1990, even with the Wetlands restoration and conversion of Grassland into Wetlands.

Since 2010, there has been a marginalisation of organic croplands turning into grassland, increasing the reported area with grass, and hence increasing the emission of CO_2 and CH_4 from Grassland over the last decade, Table 6.25.

Table 6.25 CO_2 emissions from drained Grassland on organic soils 1990 to 2021.

	1990	2000	2010	2015	2016	2017	2018	2019	2021
Grassland, 6-12 % OC, ha	34922	32829	32839	35240	35923	37106	36980	37649	38050
Grassland, >= 12 % OC, ha	46668	41292	37720	39796	40787	41956	41658	42273	42659
Grassland, total, ha	81590	74120	70559	75036	76709	79063	78638	79922	80709
Emission, drained land, kt C	538.7	484.7	454.8	482.3	493.5	508.3	505.2	513.2	518.1
Emission from leached C, kt C	19.9	17.9	16.8	17.8	18.2	18.8	18.6	18.9	19.1
CH_4, kt CH_4	4.8	4.3	4.0	4.3	4.4	4.5	4.5	4.5	4.6
Emission, total, kt CO_2	2181.4	1962.9	1841.6	1953.0	1998.4	2058.3	2046.0	2078.3	2098.2

In agriculture, CRF Table 3D, N_2O emissions from both Cropland and Grassland are reported. See Chapter 5, Section 5.6.

6.5.8 Uncertainties and time series consistency

The time series are complete.

Uncertainty estimates are given in Table 6.26.

Table 6.26 Tier 1 uncertainty analysis for Grassland for 2021.Total emission are included biomass burning

		1990	2021					
		Emission/ sink, kt CO_2 eqv.	Emission/ sink, kt CO_2 eqv.	Activity data, %	Emission factor, %	Combined uncertainty	Total, uncertainty, %	Uncertainty, 95 %, kt CO_2 eqv.
4.C Grassland		2244.0	2315.2				42.7	987.5
4.C.1 Grassland remaining grassland, Living biomass	CO_2	7.5	86.9	3	7	7.4	7.4	6.5
4.C.1 Grassland remaining grassland, Organic soils	CO_2	1974.2	1892.6	3	50	50.1	50.1	948.4
4.C.2 Forest land converted to grassland		2.4	13.4	10	50	51.0	51.0	6.8
4.C.2 Other land uses converted to grassland	CO_2	53.7	123.8	10	50	51.0	51.0	63.1
4(II) Grassland on organic soils	CO_2	72.9	70.1	3	40	40.1	40.1	28.1
4(II) Grassland on organic soils	CH_4	133.3	128.2	10	90	90.6	90.6	116.1
4(V) Biomass burning	CH_4	0.002	0.014	10	30	31.6	31.6	0.004
4(V) Biomass burning	N_2O	0.002	0.012	10	30	31.6	31.6	0.004
4(III) Mineralization/immobilization, Grassland	N_2O	0.004	0.144	10	90	90.6	90.6	0.130

6.5.9 QA/QC and verification

See QA/QC and verification in Section 6.4.

6.5.10 Recalculations

Recalculations of living biomass in GL remaining GL has been made due to a reallocation of the areas in GL. This will further be improved in the next submission, see Planned Improvements, 6.5.9.

6.5.11 Planned improvements

A new land use matrix for GL is planned for the next inventory. See 6.4.10 (Cropland).

A new project initiated in 2021, will look further on the emission factors from organic soils, see also Section 6.4.10. It is expected that the results will be ready for implementation in the 2024 submission.

A revised Land Use Matrix is taking place with a possible reallocation of some Cropland to Grassland. This will probably be available for the 2024 submission combined with new estimates for carbon stock in living biomass.

Collection of new data on soil organic carbon in Grassland will be performed in the coming years for implementation in the inventory.

6.5.12 Land converted to Grassland

Emissions and removals from land converted to Grassland is covered by CRF Table 4.C.2. All land areas converted to Grassland is converted from either Cropland or Forest land. As agricultural land (reported as Cropland) covers more than 64 % of the total land area, and to reduce the environmental impact, it has been a political priority to incentivize turning cropland into grassland or forest. Where deforestation takes place, it is often turned into Grassland, Settlements or Wetlands.

The area converted from other land uses to Grassland now is based on use the digital field maps from LPIS, see Section 6.2.

Areas used for gravel pits are normally converted to Grassland. The normal procedure is to remove the topsoil before the digging starts, return it again after and then the area is turned into marginal grassland/recreational area. To reduce the extent of land conversions, areas with gravel pits are converted directly from Cropland to Grassland instead of Cropland to Settlement to Grassland. As an example of an open gravel pit and a restored area adjacent, please see: Hedeland resort.

Methodological issues

Change in carbon stock in living biomass

For land converted to "grazing land", a default gain value of 4560 kg C per hectare is used. For "Other grassland" not purely free of woody trees/bushes, it is assumed that there is a living biomass of 4180 kg C per hectare. See also DM figures in Table 6.15. For conversion from DM to C, a default fraction of 0.5 kg C per kg DM is used. The gain value is always countered by the living biomass C stock value of the former land use category, determining whether or not the change results in a net gain or a net loss.

For conversion from Grassland to other land use categories, the same values are used, but recorded as a loss of carbon in the respective category (4A2, 4B2, 4D2 and 4E2).

Change in carbon stock in dead organic matter

When Forest land is converted to Grassland, it is assumed that all dead organic matter will be cleared and instant oxidation will take place and reported in Grassland. The exact amount is estimated annually based on the NFI.

N_2O emissions from DOM decomposition is covered by Section 6.11.

Emissions associated with dead organic matter from conversion from other categories is assumed as NO, as no dead organic matter is reported for these categories.

Change in carbon stock in soils

When land is converted into Grassland, the change in C stock in the soil is estimated as the difference between the estimated equilibrium state of Grassland (142 t C per ha) and the equilibrium C state of the soil for the old land use category. The actual C change therefore depends on which type of land it is converted from, see Table 6.15. To reach the new equilibrium state, the transition period of 30 years is used.

For changes on mineral soils from another land use to Grassland, as defined by the LPIS, the emission is included under Cropland and therefore reported as IE under Grassland. See Section 6.4.6.

The default value of the equilibrium state for Grasslands is higher than the other land use categories and based on that of mineral soils for forests, at 142 tonnes C per ha. All conversions to Grassland therefore results in a net positive C stock change (sink effect), except for conversions from Forest land, which will have no impact on the soil C stock.

N_2O emissions from land converted to Grassland are reported with Agriculture, see also Section 6.11.

Uncertainties and time series consistency

See uncertainties and time series consistency in Section 6.5.6.

QA/QC and verification

See QA/QC and verification in Section 6.5.7.

Recalculation

See recalculation in Section 6.5.8

Planned improvements

See planned improvements in Section 6.5.9.

6.6 Wetlands

Wetlands emissions and removals are covered by CRF Table 4.D and CRF Table 4(II).

In Denmark, wetlands include the two main categories of flooded wetlands (permanently water covered) and periodically water covered wetlands[6]. Flooded wetlands are lakes and rivers with a permanent water cover throughout the year. Areas and CH_4 emission from flooded Wetlands are reported CRF Table 4(II) under 4.D.2.2. Periodically covered wetlands are areas with raised water tables that flood the area in certain periods over the year, such as bogs. Emission from these periodically covered wetlands are reported in CRF Table 4(II) under 4.D.2.3 under "Land converted to Other Wetlands." For inventory purposes, the categories are further subdivided into managed and unmanaged land. All wetlands in Denmark are categorised as managed except for lakes, fens and bogs present before 1990. Potential emissions from unmanaged areas are not included in the inventory (IPCC, 2006).

Wetland emission make up only a minor share, ranging between 2 – 4 % of the net LULUCF emissions on average from 2018 - 2021. There is a lot of relative annual variation in the emissions from Wetlands, which were 105 kt CO_2 eqv. in 1990 and in 2021 summed up to 89.7 kt CO_2 eqv. Table 6.27 presents the overall area and related emissions from Wetlands in 1990 – 2021. The emission sources have also changed. The area of peat extraction has been halved, resulting in lower losses of C, meanwhile the total area of wetlands and especially re-established wetlands on organic soils from Cropland and Grassland has increased, causing higher emissions of CH_4. All Wetlands make up 130 920 hectares, equal to around 3 % of the Danish terrestrial area. Total area and emissions from 1990 – 2021 can be seen in Table 6.27.

[6] IPCC CRF category term for periodically covered wetlands: Other wetlands.

Table 6.27 Total area and annual emissions 1990 to 2021 from Wetlands.

Wetlands	1990	2000	2010	2015	2017	2018	2019	2020	2021
Flooded area, lakes, 1000 ha	53.1	54.4	56.0	57.2	57.2	57.2	58.3	59.1	59.6
Periodically water covered, 1000 ha	48.6	51.8	57.1	61.3	64.0	65.8	66.8	68.0	70.5
Peat extraction area, 1000 ha	1.6	1.6	1.6	0.8	0.8	0.8	0.8	0.8	0.8
Wetlands, total, 1000 ha	103.3	107.8	114.7	119.3	122.1	123.8	125.9	127.9	130.9
Managed Wetlands, Living and dead biomass, kt C	0.9	0.9	3.6	1.7	-2.4	-0.8	3.9	9.7	3.2
Peat extraction, soil organic matter, kt C	27.1	18.5	14.2	11.1	8.3	14.3	8.1	11.6	11.6
Total, kt C	28.0	19.4	17.8	12.8	6.0	13.5	12.0	21.3	14.8
CH_4, kt CH_4	0.071	0.256	0.598	0.822	1.005	1.036	1.076	1.160	1.256
N_2O, kt N_2O	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
C, kt CO_2 eqv.	102.8	71.1	65.2	46.9	21.8	49.6	44.0	78.0	54.4
CH4, kt CO_2 eqv	2.0	7.2	16.8	23.0	28.1	29.0	30.1	32.5	35.2
N2O, kt CO_2 eqv.	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Total, kt CO_2 eqv.	105.0	78.5	82.1	70.0	50.1	78.7	74.3	110.6	89.7

6.6.1 Wetland area

In the beginning of 1990, the total area with wetland was estimated to be 103 267 hectares. By the end of 2021, this area had increased to 130 920 hectares. The area for wetlands remaining wetlands is primarily based on data from the Danish Geodata Agency and Natura 2000 maps (moors and other natural habitats). The area with peat excavation is a vector map layer made by DCE based on aerial photos of the three excavation sites. All locations are nutrient poor raised bogs. The area of the open surface peat extraction is about 300 hectares (Larsen, 2014). Based on the aerial photos, it is estimated that 800 hectares are continuously affected by drainage from the extraction activities. The actual three locations are Fuglsø mose on Djursland, Lille Vildmose and Store Vildmose – both in Northern Jutland.

Figure 6.11 provides a recent visual on the geographic distribution of established wetlands and areas with increased water tables since 1990 as of 2019 Wetlands remaining wetlands are not included in the map.

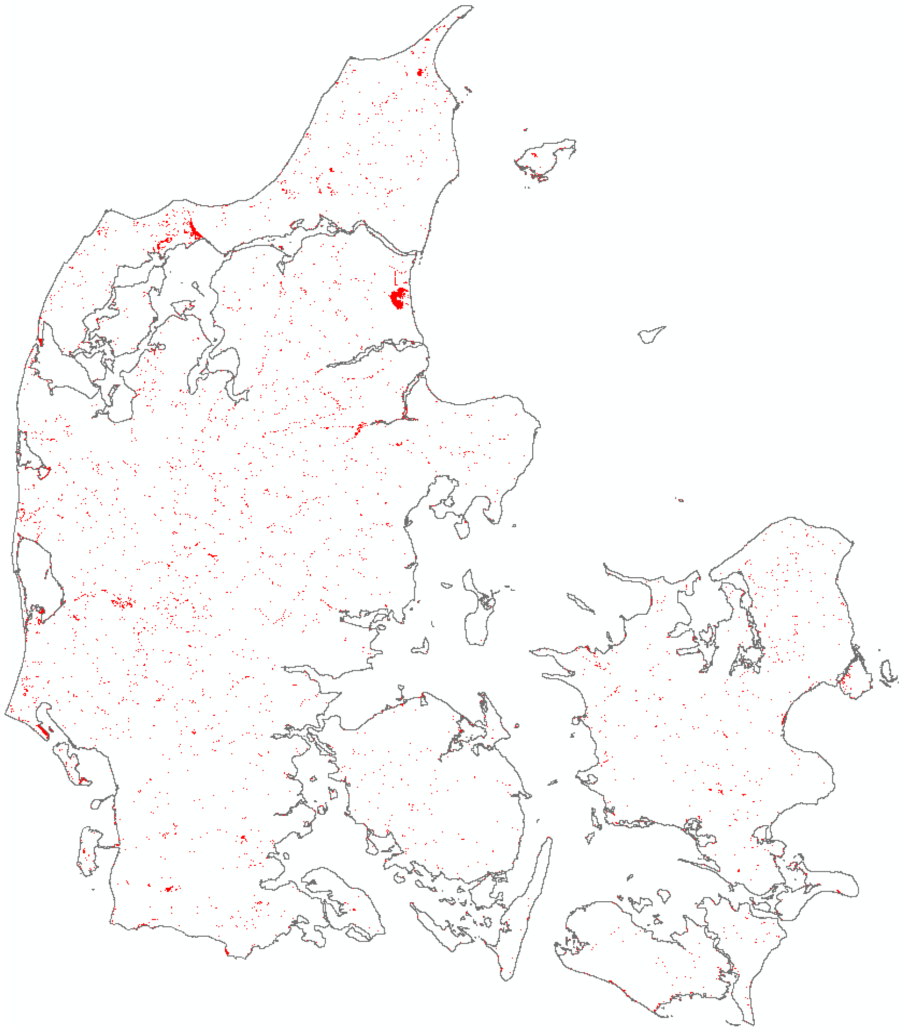

Figure 6.11 Areas with established wetlands and increased water tables in 2019.

6.6.2 Wetlands remaining wetlands

The reporting for Wetlands remaining Wetlands include only land which was considered as Wetlands before 1990, subdivided in area for peat extraction, flooded land and periodically flooded land. No emissions are reported for land which were considered as flooded or periodically flooded land before 1990 as no guidance is given in the 2006 IPCC Guidelines.

Of this, 53 091 ha were lakes and rivers in 1990 - increasing to 59 630 ha by the end of 2021, all inside the > 7000 km long coastline. In the beginning of 1990, the total area with periodically covered wetlands remaining wetlands was estimated to be 49 856 hectares. By the end of 2020, the area with periodically water covered wetlands remaining wetlands had increased to 68 727 hectares.

6.6.3 Peat extraction - Methodological issues

As elaborated, approximately 300 hectares are utilized for peat extraction, but 800 hectares are drained and affected by the excavation activity. A default area of 5 % ditches is also included. Aside for that area, the amount of excavated peat from each individual extraction site is used as activity data. The amount is reported to and published by Statistics Denmark on an annual basis (www.dst.dk, Table RST01).

6.6.4 Change in carbon stock in living biomass

No changes in living biomass are occurring.

6.6.5 Change in carbon stock in dead organic matter

Dead organic matter is not occurring.

6.6.6 Change in carbon stock in soils

The surface emission from the open peat extraction area is calculated according to Tier 1 from the 2013 Wetlands Supplement (IPCC 2014).

The total amount of peat excavated is decreasing and has been reduced almost 60 % from 399 000 m^3 in 1990 to 165 000 m^3 in 2021. In 2017, 107 000 m^3 were excavated; due to the very warm summer in 2018 a significantly increased harvest was reported at 213 000 m^3, in 2019 it was back down at 103 000 m^3 and in 2021 the reported amount was 165 000 m^3.

For conversion to carbon, a density factor of 200 kg per m^3 is used, applying information directly from (Larsen, 2014) who is responsible for the majority of the extraction sites. Furthermore, a DM content of 0.5, an ash content of 0.02 and a carbon content of 0.58 kg C per kg OM are applied.

In 2021 the change in C stock in soil from peat extraction areas resulted in emissions of 42.6 kt CO_2 eqv.

For other wetland areas in wetlands remaining wetlands, no changes are reported.

6.6.7 CH_4 and N_2O emissions

The CH_4 and N_2O emissions from peat land extraction areas are based on the 2013 Wetland Supplement and apply the emission factors of 33.20 kg CH_4 per hectare and 0.3 kg N_2O-N per hectare (IPCC 2014). The CH_4 emission factor is a weighted average of the emission factor for drained peatland (6.1 kg CH_4 per ha per year) and the emission factor for drained peatland ditches (542 kg CH_4 per ha per year).

6.6.8 Recalculation

A recalculation has been made for 2020 due to updated data on peat extraction.

6.6.9 Planned improvements

No specific improvements are planned.

6.6.10 Flooded Wetlands - Methodological issues

No emissions are estimated from flooded land as the IPCC 2006 guidelines do not provide any methodology. Consequently the whole timeseries is reported as 'Not Estimated' (NE).

6.6.11 Periodically covered Wetlands - Methodological issues

No changes in the carbon stocks and emissions are reported from unmanaged periodically water covered remaining wetlands. Only emissions from wetlands established from 1990 and onwards are reported, in land converted to Wetlands.

6.6.12 Uncertainties and time series consistency

Table 6.28 shows the emission estimates and estimated uncertainties for Wetlands.

Table 6.28 Tier 1 uncertainty analysis for Wetlands remaining Wetlands and re-established Wetlands for 2021.

		1990	2021					
		Emission/ sink, kt CO_2 eqv.	Emission/ sink, kt CO_2 eqv.	Activity data, %	Emission factor, %	Combined uncertainty	Total, uncertainty, %	Uncertainty, 95 %, kt CO_2 eqv.
4.D Wetlands		105.0	89.7				51.0	45.7
4.D.1.1 Peat extraction remaining peat extraction	CO_2	99.5	42.6	10	75	75.7	75.7	32.2
4.D.1.2 Flooded land remaining flooded land	CO_2	NE	0.0	10	75	75.7	0.0	0.0
4.D.2. Land converted to wetlands	CO_2	3.2	11.8	10	75	75.7	75.7	8.9
4(II) Land converted to wetlands	CH_4	0.5	34.4	10	90	90.6	90.6	31.2
4(II) Peat extraction	CH_4	1.5	0.7	10	90	90.6	90.6	0.7
4(II) Peat extraction remaining peat extraction	N_2O	0.2	0.1	10	90	90.6	90.6	0.1

The time series are complete.

6.6.13 QA/QC and verification

The peat excavation area has been verified with aerial photos and the amount of excavated peat is reported by Statistics Denmark.

6.6.14 Land converted to Wetlands

Emissions and removals from land converted to Wetland is reported in CRF Table 4.D.2 and Table 4(II). In order to restore nature and reduce the environmental impact, Denmark has actively re-established wetlands (Figure 6.10). The size of each restoration project range from less than 1 ha and up to 2 500 ha. The public benefit of the restoration programme is more nature and a reduction in leaching of nitrogen into lakes, rivers and coastal water and a reduction of C losses/emissions in relation to former Cropland on organic soils. The establishment of wetlands takes place either as large areas turned into lakes (flooded) or low laying fens (periodically water covered).

Since 1990, 30 476 ha of new Wetlands have been established. These are primarily established on Cropland and Grassland and a small area of primarily state owned forests. Of this, 6 674 hectares are converted into new lakes. A major part is restored as government managed and funded projects part of the Danish Action Plan for the Aquatic Environment part two (VMP II, 1997-2006). The establishment often takes place in connection to existing wetlands.

Water reservoirs for human purposes have not been established for the past 100 years, and hence are not occurring.

Methodological issues

Geographical vector layers are available for almost all established wetlands and information on wetland restauration areas for various years are available from the Danish Agricultural Agency (Danish Agricultural Agency, 2021a).

Change in carbon stock in living biomass

For land converted to periodically covered wetland, a standard default gain value of 3 600 kg DM (dry matter) per hectare in above ground biomass and 10 080 kg DM per hectare in below ground biomass is used. For conversion from DM to carbon, a default fraction of 0.5 kg C per kg DM is used (IPCC 2014), see values for the different land use categories in Table 6.15. If the living biomass C stock was higher in the former land use category the difference is accounted as instantly oxidized through a C stock loss, reported in Wetlands.

For conversion from wetland to other land use categories, the same values are applied and recorded as a loss of carbon in the respective land use category of 'conversion to' (4A2, 4B2, 4C2 and 4E2).

Change in carbon stock in dead organic matter

When forest is converted to wetland, it is assumed that dead organic matter will be submerged and not degrade. The latest UNFCCC review indicated that this is in accordance with the 2006 IPCC Guidelines. For the next submission this will be investigated further if instant oxidation should be implemented. The area is very marginal, around 5 ha per year. Emissions associated with dead organic matter from conversion from other categories is assumed as NO, as no dead organic matter is reported for these categories.

Change in carbon stock in soils

It is assumed that no carbon sequestration or carbon loss is assumed for land converted to periodically covered wetlands or flooded wetlands (lakes) (IPCC, 2006; 2014) as the figures in the Wetland Supplement are within the uncertainty range for temperate and cold climates which is the case for Denmark.

CH_4 and N_2O emissions

According to the 2013 Wetlands Supplement, the N_2O emission is negligible from restored wetlands (Chapter 3). Therefore, no N_2O emission has been estimated for land converted to wetlands.

According to the 2013 Wetlands Supplement, the CH_4 emission is 216 kg CH_4-C per ha for temperate areas, equivalent to 288 kg CH_4 per ha or 8064 kg CO_2 eqv. per ha, from restored rich wetlands with more than 12 % OC (Chapter 3, Table 3.3). Following the assumption of half the emission from soils with 6-12 % OC, an emission factor of 144 kg CH_4 per ha, or 4032 kg CO_2 eqv. per ha is applied to these soils.

As we currently do not have national data on area with ditches or national emission factors on CH4 emission from these the default value from the 2013 Wetlands Supplement (IPCC, 2014) is applied and multiplied with a standard factor for the ditch area of 5 %. Emissions from the area with ditches are added to the emissions from the reported hectares of agricultural land, as ditches are not a part of the digital field map.

The CH_4 from established wetlands is estimated as the sum of organic land (>= 12 % OC) converted from other land uses to wetlands since 1990 multiplied with the default emission factor of 288 kg CH_4 per ha. The slightly deviation in the reported IEF in CRF Table 4(II) is due to roundings.

Uncertainties and time series consistency

The time series are complete. For uncertainty analysis, see Section 6.5.1.

QA/QC and verification

No verification has been made yet.

Recalculation

A recalculation has been made for 2020 due to updated data on peat extraction.

Planned improvements

An evaluation of actual water level on wetlands before and after conversion from cropland and grassland to wetland is being conducted in 2021 to 2024. The results of the project are expected to be implemented with the 2024 submission (inventory of 2022).

6.7 Settlements

Emissions and removals from Settlements are covered by CRF Table 4.E. Settlements are defined by developed land including transportation infrastructure and human settlements.

Emissions from Settlements are limited and contribute only around 8 % of LULUCF net emissions with a total of 232.63 kt CO_2 eqv. in 2021. Settlements emissions have been relatively stable since early 2000's and represent a 51 % reduction from Settlement emissions level in 1990. It is assumed that there are no changes in the C stock for remaining Settlements, and hence all reported emissions relates to changes from other land uses to Settlements, causing e.g. instant oxidation of living biomass and a C stock loss from the soil.

The total Settlements area has been estimated to 486 614 hectares by the end of 1989 increasing to 541 472 hectares by the end of 2021 or to 12.5 % of the total Danish area (Table 6.29). All Settlements are located on mineral soils.

Table 6.29 Total area and annual emissions 1990 to 2021 from Settlements[a].

Settlements	1990	2000	2010	2015	2017	2018	2019	2020	2021
Settlement remaining Settlement, 1000 ha	368.8	410.1	456.1	473.1	479.9	483.2	486.6	487.6	488.5
Land converted to Settlements, 1000 ha	118.8	86.8	55.7	53.9	53.9	52.2	49.9	51.6	53.0
Settlement, total, 1000 ha	487.6	496.9	511.8	527.0	533.7	535.4	536.5	539.1	541.5
Living and dead biomass, kt C	4.5	4.6	10.1	7.8	8.1	12.0	9.0	15.1	11.6
Soil, kt C	112.3	81.4	50.5	48.3	48.1	46.6	44.6	46.1	47.5
Total, kt C	116.8	86.0	60.6	56.1	56.1	58.7	53.6	61.2	59.1
N_2O, kt N_2O	0.147	0.106	0.066	0.062	0.062	0.060	0.057	0.059	0.060
C, kt CO_2 eqv.	428.1	315.1	222.2	205.6	205.7	215.0	196.5	224.4	216.5
N_2O, kt CO_2 eqv.	39.0	28.2	17.4	16.5	16.4	15.8	15.1	15.5	16.0
Total, kt CO_2 eqv.	467.4	343.5	239.8	222.3	222.2	231.0	211.7	240.1	232.6

[a] Rounding may result in minor deviations between the table and the CRF tables

6.7.1 Settlements remaining settlements

The annual changes in carbon stock in settlements remaining settlements is assumed to be negligible, all changes are reported as NA in the CRF Table 4.E.

No changes are reported to the area with Settlements remaining settlements. The area is estimated based on publicly available cadastral maps, the topographical database of 2005 and 2011, the Danish building register and the Danish areal information system, see Section 6.2.1.The area increases as Settlement areas established >30 years ago are transferred from 'land converted to Settlement' to 'Settlements remaining settlements'. These are based on the original date of the registration of the land parcel in the cadastral maps, e.g. a change from agricultural land to a permanent residence or a road.

6.7.2 Methodological issues

6.7.3 Change in carbon stock in living biomass

No changes in carbon stocks are reported for settlements remaining settlements.

6.7.4 Change in carbon stock in dead organic matter

No changes in carbon stocks are reported for settlements remaining settlements.

6.7.5 Change in carbon stock in soils

No changes in carbon stock in soils are reported for Settlements remaining settlements.

6.7.6 Uncertainties and time series consistency

Uncertainty estimates and emissions for land converted to settlements are shown in Table 6.30.

Table 6.30 Tier 1 uncertainty analysis for Settlements for 2021.

		1990	2021					
		Emission/ sink, kt CO_2 eqv.	Emission/ sink, kt CO_2 eqv.	Activity data, %	Emission factor, %	Combined uncertainty	Total, uncertainty, %	Uncertainty, 95 %, Gg CO_2 eqv.
4.E Settlements		467.4	232.6				63.2	146.9
4.E.2 Forest land converted to Settlements	CO_2	4.4	25.0	10	75	75.7	75.7	18.9
4.E.2 Other land uses converted to Settlements	CO_2	424.0	191.6	10	75	75.7	75.7	145.0
4(III) Mineralization/immobilization, Land converted to Settlements	N_2O	39.0	16.0	10.0	90.0	90.6	90.6	14.5

The time series are complete.

6.7.7 QA/QC and verification

Changes in Settlements area are based on statutory registers and thus very reliable.

6.7.8 Recalculations

No recalculation has been made.

6.7.9 Planned improvements

No improvements are planned.

6.7.10 Land converted to settlement

Emissions from land converted to Settlements are covered by CRF Table 4.E.2. Land use conversion to Settlements is mostly taking place around the big cities and primarily on Cropland. 47 485 ha of Cropland has been converted since 1990, and 5 109 ha of Grassland has been converted to Settlements.

The area converted to Settlements is based on area statistics, cadastral maps and other digital maps to establish the land use matrix from 1960. For simplicity, and for the years 1990 to 2011, only three occasions are used (1990, 2005 and 2011) with a linear increase in the area in the years between. Annual recorded changes in cadastral maps are used to estimate the annual changes from 2011 and onwards. The increase in Settlements is relatively stable, and the minor area fluctuations are most likely the result of major road and railway constructions being completed and included or as the definitions applied to the registrations change slightly over the years.

Methodological issues

Change in carbon stock in living biomass

For land converted to Settlements, a default gain value of 2200 kg DM (dry matter) per hectare in above ground biomass and 2200 kg DM per hectare in below ground biomass is used. For conversion from DM to carbon, a default fraction of 0.5 kg carbon per kg DM is used (IPCC 2014). See Table 6.15. Living biomass values for the former land use category are assumed instantly oxidized and reported with Settlements.

Conversion from Settlements to other land use categories does not occur.

Change in carbon stock in dead organic matter

When Forest land is converted to Settlements, it is assumed that all dead organic matter and litter will be cleared and an instant oxidation effect is applied. Conversion from other categories is reported as not applicable, as no dead organic matter is reported for other land use categories.

The decomposition of the organic carbon in the dead organic matter also release nitrogen, causing N_2O emissions, reported on in Section 6.11 and covered by CRF Table 4 (III).

Change in carbon stock in soils

A default value of 96.7 tonnes carbon per ha is applied for Settlements (Table 6.15), calculated as 80 % of the carbon stock in mineral agricultural soils, as the 2006 IPCC Guidelines assume that 20 % of the SOC can be lost (IPCC 2006, Chapter 8.3.3.2). For all areas converted from other land use to Settlements, it is assumed that the equilibrium state will be reached after 30 years, and the annual loss is reported as 1/30 of the total decrease in C.

N_2O emissions from decomposition of the organic carbon in the soils is also covered by Section 6.11 and CRF Table 4 (III).

Uncertainties and time series consistency

See uncertainties and time series consistency in Section 6.7.6.

The time series are complete.

QA/QC and verification

Changes in Settlements area are based on public statutory registers and thus very reliable.

Recalculations

No recalculations have been made.

Planned improvements

A subdivision of SE into different area categories is planned according to the proportion of greenspace. It will probably be available for the 2024 submission.

6.8 Other Land

Emissions and removals from Other land is covered by CRF Table 4.F. The land area is defined as land with little or no vegetation and consequently no or very limited carbon stocks, both as living or dead biomass or as carbon in the soil. No permanent snow cover exists in Denmark. Other land is thus restricted to beaches and sand dunes and a very small insignificant area with rocks and cliffs, in total estimated to 26 433 hectares. Data input for the estimation of land area, see Section 6.2.1.

As the area is kept constant in the land use matrix over the entire period of the inventory, no land use change from Forest land (4.A), Cropland (4.B), Grassland (4.C), Wetlands (4.D) or Settlements (4.E) is reported and therefore no emissions are reported either.

6.9 Direct N_2O emissions from N fertilization of Forest Land and Other Land use

No emissions are reported in the CRF Table 4(I), that cover direct nitrous oxide (N_2O) emissions from nitrogen inputs to managed soils. Since there is only one common national statistics for N fertilization in agriculture and forestry, the minor share of fertilization taking place in the Danish forests is reported under Agriculture in chapter 5 of the inventory and covered by CRF Table 3.Ds1. Data from the Danish nitrogen fertiliser accounts are controlled by the Danish Agricultural Agency and made available annually for inventory purposes by the DAA as part of the Ministry of Food, Agriculture and Fisheries (Danish Agricultural Agency, 2022).

6.10 Emissions and removals from drainage and rewetting and other management of organic and mineral soils

Emissions from drainage and other management of the soils are elaborated in this section and covered by CRF Table 4(II). They are described further in the sections of their respective land use categories.

6.10.1 Methodological issues

The CO_2 emissions reported here relate to drainage, causing leaching of C in the form of dissolved organic carbon (DOC) and are reported on for Cropland and Grassland. DOC is a fraction of C with a very small particle size related to the process of decomposition of organic matter vulnerable to loss through leaching. The methodology from the 2013 Wetland Supplement is used for this purpose. Leached carbon from Cropland and Grassland is not elaborated here, as it is covered in their own respective sections, see 6.4.4 and 6.5.5.

Emissions of N_2O in this section relates to the N being mineralized in the soils. These N_2O emissions reported here only concern Forest land and Wetlands, since all N related emissions from Cropland and Grassland are covered by Agriculture CRF Table 3.D. Very few data exist for N_2O emissions in Danish forests. A Tier 1 emission factor of 2.8 kg N_2O-N per ha drained forest soil from the 2013 Wetland Supplement is applied (IPCC, 2014 - Table 2.5).

CH_4 emissions also take place if soils are rewetted or only shallow drained, resulting in occurrences of anaerobic conditions. CH_4 emissions apply to all organic soils affected by these activities and thus are reported for all land use categories.

The rewetted areas are defined as wet areas that are still to some degree affected by former drainage and not wet enough to be considered converted to Wetlands and the emissions therefore still relate to the original land use category of Forest land, Cropland or Grassland. Rewetted Grassland is accounted for as drained grassland, and therefore reported as 'IE'. Emissions from drained soils concern both Forest land, Cropland, Grassland and Wetlands.

6.10.2 Emissions of N_2O from drained soils – Forest land and Wetlands

The emissions from Forest land are described in detail in Section 6.3.5 and the data on the area of drained and rewetted mineral and organic forest soils is given in Table 6.7. Rewetted forest soils are assumed to have an N_2O emission corresponding to the natural level and emissions from rewetted FL soils are therefore by default set to zero and the report only concerns the drained soils. Remaining soil categories do not apply, since they are either too dry or too wet to produce nitrous oxide.

The emission factor of 2.8 (range 0.57 – 6.1) kg N_2O-N per ha per year (Table 2.5 in IPCC 2014, p. 2.33) is applied to drained organic forest soils. The total N_2O emission from forest soils is estimated to 0.090 kt N_2O (23.6 kt CO_2 eqv.) in 1990 and 0.08 kt N_2O (21.7 kt CO_2 eqv.) in 2021.

N_2O emissions from drained Wetlands only apply to drained peat excavation areas and are negligible, at about 0.0004 kt N_2O (0.1 kt CO_2 eqv.) in 2021.

6.10.3 Emissions of CH_4 from drained and rewetted organic soils

All CH_4 emissions from the LULUCF sector are covered here, and in 2021 amounted to 10.38 kt CH_4. This equals 290.6 kt CO_2 equivalents, roughly 12 % of net LULUCF emissions.

For forest soils, the CH_4 emission is based on the emission factors in Table 6.12, and include a default area of ditches of 2.5 % for (IPCC, 2014). They are described in Section 6.3.5 Emission from soils: Reporting on methane emissions.

For Cropland the emissions are reported in Section 6.4.6 Change in carbon stock in soils - Emission factors for organic soils, Table 6.19. Emission factors are presented in Table 6.18.

For Grassland the emissions are reported in Section 6.5.5 and emission factors in Table 6.18.

For Wetlands the emissions are reported on in Section in 6.6.7 and 6.6.14.

6.11 Direct nitrous oxide (N_2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matter

This section covers N_2O emissions from mineralization of N through decomposition of organic matter, which are reported in CRF 4(III). Emissions are also briefly described and covered in Section 6.3.5 for Forest land, Section 6.4.6 for Cropland, Section 6.5.5 and Section 6.5.10 for Grassland and Section 6.6.13 for Wetlands.

In the context of the inventory and according to 2006 IPCC Guidelines, N_2O emissions are only estimated when there is a decrease of carbon in mineral soils or dead organic matter (DOM). The soils loose carbon in cases where the land subject to conversion has a higher soil C equilibrium state than the land use category, which it is converted to. The land use conversions involving C loss are Forest land and Grassland to Cropland and all land use conversions into Settlements. DOM decomposition only relates to Forest land conversions to other land uses, as no DOM is reported for the other categories.

6.11.1 Methodological issues

According to 2006 IPCC Guidelines a default fraction of 1 % of the total N content is assumed emitted as N_2O-N during mineralization following conversion of land use. This factor is applied both to the N content in soils that loose C and to the N content of dead organic matter, that is instantly oxidized following land use conversions from Forest land to other land uses.

Concerning Forest land, it is assumed, that the forest floor containing the dead organic matter (DOM) disappears regardless of whether the land use conversion is into CL, GL, WE or SE. Based on the NFI an annually updated amount of DOM biomass, 16 t C per ha in 2021, together with a C:N value of 22 (Vejre et al., 2003), the average nitrogen content of forest floor DOM is calculated and used to estimate the N mineralized. For forest soil C loss concerning conversions to other land uses, the average C content of 142 t C per ha and the C:N ratio of 22 is applied.

For all conversions to agricultural soils (representing conversions to both Cropland and Grassland), N_2O emissions due to long-term changes in the carbon stock in the mineral soils are estimated by C-TOOL based on 20 subdivisions (counties and soil types) and reported under Agriculture, CRF Table 3D.1.5 and therefore as 'IE' in Table 4(III). The C:N ratio of the individual mineral soil type is used for the calculations, ranging from 10.53 to 15.89 t C per ha.

For estimation of the N_2O emission from conversions of CL and GL to SE, the C loss is estimated from the average soil C stock of the respective land use classes (CL: 120.8 t C per ha, GL: 142 t C per ha) and the difference to Settlements (96.6 t C per ha), see Table 6.12, is combined with a C:N value of 12 for CL and 15 for GL

6.11.2 Emissions of N_2O from deforestation and other land-use conversion

In 2021, the total emission of N_2O from mineralization of organic matter has been estimated to 0.069 kt N_2O, equivalent to 18.5 kt CO_2 eqv., which is about 0.8 % of net LULUCF emissions. The far major part of this is conversion of Forest land to Cropland and Settlements. It reflects the expected release of N in the soil organic matter when soil organic matter is degraded in the process where land is converted to a land use class having a lower default soil carbon stock like conversion to Settlements.

6.12 Biomass burning

Biomass burning is reported in CRF Table 4(V). Burning of forest and field burning of biomass is prohibited in Denmark and burning of woody debris from hedgerows happens very rarely (often collected and used in power plants). Wildfires are seldom in Denmark and the area affected thus is small. This is normally around 0-10 hectares per year, but due to the drought in 2018, the number of ha affected by wildfires increased to more than 2000 hectares; mainly in Cropland and Grassland, the emissions of which are reported with Agriculture in chapter 5. Hence, In LULUCF only burned biomass from Forest land and heath (Grassland) is reported. Only methane and nitrous oxide emissions are included, as the impact to the standing C stock of the living biomass is assumed negligible, considering the historical trend. Some controlled burning of heathland is taking place to maintain the heathland vegetation. In 2021, 290 hectares were reported, while the average over the last twenty years is 426 ha annually, from 2002 - 2021.

Data on wild and controlled fires is collected by the Danish Nature Agency (DNA) for the period 1990 to 2021. The emission factors are taken from the 2006 IPCC Guidelines. The forest fires typically happen on poor sandy soils with more open forest stands, and the default standing wood volume is estimated by DNA at 150 cubic meter of solid biomass per hectare, which is slightly lower than the average of the Danish forests. The fraction of above ground biomass burned for forests is taken from the guidelines (0.34). For heath land expert DNA estimates are used; 50 cubic meters slid biomass per ha of which a fraction of 0.33 is considered burned.

Table 6.31 Burned areas in Forest and Heathland (Grassland) 1990 –2021, ha per year.

	1990	2000	2010	2015	2017	2018	2019	2020	2021
Forest area burned, ha	150	0	0	0	0	0	0	0	0
Heathland area burned, ha	47	121.6	359	714	187.61	574.48	233.95	29.7	290.2
Total burned area, ha	197	121.6	359	714	187.61	574.48	233.95	29.7	290.2
Emission, CH_4, kt	0.026	0.000	0.001	0.001	0.000	0.001	0.001	0.000	0.000
Emission, N_2O, kt[a]	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total, kt CO_2 eqv.	1.116	0.011	0.031	0.062	0.016	0.057	0.057	0.003	0.026

[a] Minor deviations to CRF tables due to rounding.

Uncertainty estimates are given in Table 6.32.

Table 6.32 Tier 1 uncertainty analysis for Biomass burning for 2021.

	1990	2021					
	Emission/ sink, kt CO_2 eqv.	Emission/ sink, kt CO_2 eqv.	Activity data, %	Emission factor, %	Combined uncertainty	Total, uncertainty, %	Uncertainty, 95 %, kt CO_2 eqv.
4(V) Biomass Burning	1.12	0.03				22.4	0.0
4(V) Biomass Burning CH_4	0.73	0.01	10	30	31.6	31.6	0.004
4(V) Biomass burning N_2O	0.38	0.01	10	30	31.6	31.6	0.004

6.13 Harvested Wood Products (HWP)

Carbon emissions from harvested wood products (HWP), which are covered by CRF Table 4.Gs1 and 4.Gs2, have been reported since 2013. Denmark has chosen to report under Approach B, the production approach, which refers to equations 12.1, 12.3 and 12.A.6 of volume 4 of the 2006 IPCC Guidelines.

Carbon in the HWP pool is accounted for based on the semi-finished wood product categories: sawn wood, wood-based panels and paper, and paper products with default half-lives of 35, 25 and two years. HWP originating from imported wood is excluded. HWP originating from deforestation activities is excluded from the calculations, as they are accounted as instantaneous oxidation. The amount is estimated directly as biomass in deforested areas able to produce HWP products and biomass from deforested areas with a canopy height above 10 m.

For calculating carbon stocks in HWP, Denmark has applied the default first order decay (FOD) model stipulated by the IPCC, with the default half-lives (IPCC Tier 2 methodology). Activity data has been collected from international databases as well as from surveying the Danish wood industry. Carbon conversion factors have been derived from national forest inventory data (IPCC Tier 3 methodology).

The primary source for data on the HWP pool in Denmark is an annual questionnaire that now provides the basis for all Danish reporting to e.g. EUROSTAT and FAO, and serves as input to Statistics Denmark. Previously, there was no collection of data on the actual amounts and hence the previous reports were mainly based on data with less accuracy.

A comparison was performed for the year included in the questionnaire 2011-2013 and subsequently an extensive validation of activity data was carried out leading to corrections of historic data, especially regarding the production and export of sawnwood. The details and graphs can be found in Schou et al. (2015), where also an extensive validation of activity data, including comparison with the FAO data, was performed. The corrected data are available in the report.

According to a questionnaire on the production of the Danish wood industry, the production of sawnwood in 2021 was about 387 000 m^3, while the production of wood-based panels was about 349 000 m^3. The questionnaire covered an estimated >90 % of the revenue generated in the sawnwood sector and 100 % of the sector revenue for wood-based panels (there were only two relevant companies). A cross validation of the roundwood consumption showed an average deviation of 8 % for 2011-2013 between the questionnaire and the figures reported by Statistics Denmark based on harvest and trade statistics. As of 2021, the HWP pool originating from domestic harvest and domestic consumption consisted of about 6.5 million tonnes carbon (60 % from sawnwood and 40 % from wood-based panels – the paper pool was insignificant). This is equivalent to 15 % of the carbon stock in live forest biomass.

The total inflow in terms of gains of carbon to the HWP pool in 2021 is reported to about 164 kt carbon – 71 kt C from sawnwood and 93 kt C from wood-based panels. The outflow recorded as the losses from the pool is reported to about 170 kt carbon in 2021 – 77 kt from sawnwood, 71 kt from wood-based panels and 22 kt from paper and paperboard. Applying the respective half-lives, there has been a net carbon sequestration in HWP of about 15.2 kt carbon in 2021, equal to 55.87 kt CO_2 eqv., see Table 6.33.

The estimate of the size of the total HWP stock is quite uncertain, as the empirical basis for the First Order Model (FOD) and the attached half-lives is weak. Conducting direct inventories of the carbon stock may be a method to reduce uncertainty. In the Danish case, estimates based on the FOD model for the total HWP pool, including imported wood and converted to finished wood products actually came quite close, when measured per capita, to estimates from Finland originating from a direct inventory. Regarding estimates for pool changes, uncertainty on half-life may be of less importance, as longer retention time in the pool may be traded off against higher emissions levels from the historic pool. This depends on the characteristics of the pool, i.e. the size of the pool vs. the recent inflow. Uncertainty on activity data relates to both uncertainty on measurements, e.g. caused by reporting errors, and statistical uncertainty, caused by variation in the sampled population.

Judging from the coverage and the validation results, surveying the production of semi-finished wood products in Denmark by questionnaire has been successful. It will be repeated in the following years as part of the future reporting of HWP.

Recalculation

In the review of the reporting for 2020, the calculation of annual inflow and outflow was recalculated, as there were identified a shift in formulas in the database behind the reporting. The data for harvest, production and export remain unchanged, but the flow calculations now clearly refer to the year of reporting. This has affected all wood pools for the period 1990-2020.

Table 6.33 HWP in use from domestic harvest and exported HWP in 2021 (CRF Table 4.Gs1).

	Gains, t C	Losses, t C	Half-life, yr	Annual Change in stock, kt C	Net emissions/ removals from HWP in use, kt CO_2
	HWP produced and consumed domestically				
Sawnwood	57	-65	35	-8	30
Wood panels	77	-53	25	24	-88
Paper and paperboard	IE	-0.01	2	-0.01	0.03
Total	134.2	-118.4		15.9	-58.2
	HWP produced and exported				
Sawnwood	13.9	-11.9	35.0	2.0	-7.5
Wood panels	15.8	-18.4	25.0	-2.7	9.7
Paper and paperboard	NA	0.0	2.0	0.0	0.1
Total	29.7	-30.3		-0.6	2.3

Uncertainty estimates are given in Table 6.31.

Table 6.34 Uncertainty in HWP in use from domestic harvest.

		1990	2021					
		Emission/ sink, kt CO_2 eqv.	Emission/ sink, kt CO_2 eqv.	Activity data, %	Emission factor, %	Combined uncertainty	Total, uncertainty, %	Uncertainty, 95 %, kt CO_2 eqv.
4.G Harvested wood products	CO_2	-2.4	-55.9	25	75	79.1	79.1	44.2

Planned improvements

The last UNFCCC review recommended an updating of the calculation of HWP originating from deforestation. This will be investigated for the next submission.

6.14 QA/QC plan

A first step of development and implementation of a general QA/QC plan for all sectors started in 2004 which is described in a publicised manual (Sørensen et al., 2005). The manual describes the concepts of quality work and how to handle quality management by using Critical Control Points and a list of Point of Measurements. These are further unfolded and updated in the quality manuals for the Danish greenhouse gas inventory version two and three in Nielsen et al. 2013 and 2018. For more detailed information of the structure in the general QA/QC plan, please refer to Chapter 1.6 for QA/QC.

A complete list Points of Measures (PM) are given in Table 1.2. PM related to the agricultural inventory is listed below in Chapter 5.13.3 and are primarily connected to data storage and data processing level 1. For PM not mentioned below please refer to Chapter 1.6.

The QA/QC work specific for the LULUCF sector is still improved. The overall framework regarding a QA/QC plan for LULUCF are constructed in form of six stages and each stage focus on quality assurance and quality check in different part of the inventory process.

6.14.1 QA/QC plan expressed in Critical Control Points and Point of Measurements

Data storage level 1

Data Storage level 1	3. Completeness	DS.1.3.1	Documentation showing that all possible national data sources are included by setting down the reasoning behind the selection of datasets.

The following external data are in used in the LULUCF sector.

- Data from multiple public GIS-layers to develop the annual Land Use Matrix (Building register, cadastral maps, lakes, railroads, afforestation, subsidized hedges and small biotopes, wetland restoration maps etc.
- Data from the Danish national forest inventory carried out by Department of Geosciences and Natural Resource Management, Copenhagen University
- Data from the annual agricultural census made by Statistics Denmark
- Land parcel information from the Danish Agricultural Agency including location of all agricultural fields
- Soil type maps – mineral and organic
- Input of organic matter to agricultural soils from manure is estimated in the agricultural sector.

Carbon stock changes are generally measured or modelled. The used emission factors comes primarily from IPCC Wetland supplement (IPCC 2014) and country specific measurements.

Statistics Denmark

The agricultural census made by Statistics Denmark is the main supply of basic agricultural data for crops. This include crop area and harvest yields and amount of excavated peat.

Danish Agricultural Agency

The Danish Agricultural Agency is responsible for handing all EU subsidiaries to the Danish farmers. All data needed for the inventory purpose is given freely to be used in the inventory. This include detailed field maps, all subsidized activities in the landscape including afforestation, areas with catch crops on farm level, location of all animals in Denmark, etc. These data are very precise.

The Danish Agricultural Agency, as the controlling authority, performs analysis of crop areas and their location. On average, 1600 to 2000 samples are analysed every year. Uncertainty in the data is seen as negligible.

National Forest Inventory

The Department of Geosciences and Natural Management (IGN), University of Copenhagen, who is responsible for the forest part of the inventory, carries out the NFI. IGN has been given unrestricted legal access to all NFI plots to monitor their current state of the forests.

Data Storage level 1	1. Accuracy	DS.1.1.1	General level of uncertainty for every dataset including the reasoning for the specific values

The most important emission source is related to the carbon stock in the forest, carbon stock changes in mineral agricultural soils and loss of carbon from the cultivated organic agricultural soils.

The uncertainty on the absolute C stock in the forest has been estimated to approximately 2 %. This in a very large C stock. However, because of the large stock the difference in the C stock between two consecutive measuring years can be very large, yielding a change in the emission around 80-100%. It is very difficult to reduce this uncertainty.

The same is also valid for the dynamic modelling of C stock in the mineral agricultural soils. The very large C stock of 100-120 tonnes C/ha may cause that small annual changes in input between years gives large changes in the estimated emissions between years. The input of agricultural debris to the model is estimate by Statistics Denmark. These data are well documented.

As the reported area with organic soils are almost constant combined with a fixed EF for the organic soils only little variation is seen between years. The largest uncertainty in relation to organic soils are the related to the country specific EF.

Regarding uncertainties for the remaining emission sources, see Chapter 6.

Data Storage level 1	1. Accuracy	DS.1.1.2	Quantification of the uncertainty level of every single data value including the reasoning for the specific values.

Please, refer to Chapter 6.

Data Storage level 1	1. Comparability	DS.1.2.1	Comparability of the data values with similar data from other countries, which are comparable with Denmark, and evaluation of discrepancy.

The estimated emission from the forest depends on growth rate (species, weather conditions) and harvest rate. It is assumed that the NFI with > 10 000 sampling plots can cover this variability. The outcome cannot directly be compared to other countries. The general view is that the Danish forests is a sink like many other European forests.

Only a few countries are modelling the carbon stock changes in mineral agricultural soils. The Danish model estimates the agricultural soils to be in steady state or a slightly increase in the carbon stock. This because of an increasing biomass input to the soils due increased yield levels and more catch crops.

The area with organic soils differs between countries and is difficult to compare. Denmark has a large share of cultivated organic soils > 12 % OC. The Danish reporting include organic soils having 6-12% OC. These soils will also have large emissions, as the organic matter in these drained soils at a certain point in the future will approach the equilibrium state for cultivated organic soils of 1-1.5 % OC. As no other countries report emissions from 6-12 % OC soils a direct comparability is difficult. The Danish CS EF for soils >12 % OC is slightly higher than the IPCC default (IPCC 2014) but similar to the German CS EF used in the German 2020 submission to UNFCCC.

Data Storage level 1	4. Consistency	DS.1.4.1	The origin of external data has to be preserved whenever possible without explicit arguments (referring to other PMs).

External data received are stored in the original format in the quality management database system.

Data Storage level 1	6. Robustness	DS.1.6.1	Explicit agreements between the external institution holding the data and DCE about the conditions of delivery.

DCE has established formal data agreements with all institutes and organisations, which deliver data, to assure that the necessary data is available to prepare the inventory on time.

Data Storage level 1	6. Robustness	DS.1.6.2	At least two employees must have a detailed insight into the gathering of every external data set.

Please refer to Chapter 1.7.

Data Storage level 1	7. Transparency	DS.1.7.1	Summary of each dataset including the reasoning for selecting the specific dataset.

Please refer to DS 1.1.1.

Data Storage level 1	7. Transparency	DS.1.7.2	The archiving of data sets needs to be easy accessible for any person in the emission inventory.

Please refer to Chapter 1.7.

Data Storage level 1	7. Transparency	DS.1.7.3	References for citation for any external data set have to be available for any single value in any dataset.

A great deal of documentation already exists in the literature list, and is also achieved in the quality management database system.

Data Storage level 1	7. Transparency	DS.1.7.4	Listing of external contacts for every dataset.

Statistics Denmark:
Mrs. Mona Larsen (mla@dst.dk)

Mr. Karsten K. Larsen (kkl@dst.dk)

DCA (Aarhus University):
Mr. Mogens H. Greve (greve@agro.au.dk)

Danish Agricultural Agency:
Mr. Sebastian Iuel Berg (SEBBER@lbst.dk)

Mr. Lars West Andersen (laes@lbst.dk)

The Danish Nature Agency
Mrs Marianne Damholdt Bergin (mardb@nst.dk)

Data processing level 1

Data Processing level 1	1. Accuracy	DP.1.1.1	Uncertainty assessment for every data source as input to Data Storage level 2 in relation to type of variability. (Distribution as: normal, log normal or other type of variability).

The Approach 1 methodology is used to calculate the uncertainties for the agricultural sector. The uncertainties are based on a combination of IPCC guidelines and expert judgement and measured uncertainty in the National Forest Inventory) and a normal distribution is assumed.

Data Processing level 1	1. Accuracy	DP.1.1.2	Uncertainty assessment for every data source as input to Data Storage level 2 in relation to scale of variability (size of variation intervals).

Please refer to DP 1.1.1.

Data Processing level 1	1. Accuracy	DP.1.1.3	Evaluation of the methodological approach using international guidelines.

Data sources and calculation methodology developments are continuously discussed in cooperation with specialists and researchers in different institutes and research sections. Consequently, both the data and methods are evaluated continually according to the latest knowledge and information.

Data Processing level 1	1. Accuracy	DP.1.1.4	Verification of calculation results using guideline values

The methodological approach is consistent with the IPCC 2006 Guidelines and the 2013 Wetland Supplement (IPCC 2014). See Chapter 6.

Data Processing level 1	2. Comparability	DP.1.2.1	The inventory calculation has to follow the international guidelines suggested by UN-FCCC and IPCC.

The methodological approach is consistent with the IPCC 2006 Guidelines and the 2013 Wetland Supplement (IPCC 2014).

Data Processing level 1	3. Completeness	DP.1.3.1	Assessment of the most important quantitative knowledge, which is lacking.

The most important lacking information is the emission from the organic soils. Over time the organic soils becomes more wet due to lack of drainage. Hence the used EF should be reduced over time. There is no information on emissions from soils having 6-12 % OC. As times go, the organic matter disappears and the drained soils will reach a low equilibrium state. This should lead to reclassification of the area with organic soils from e.g. 6-12 % OC in the previous years and 0-6 % in the future. No information is available on this issue. There is on-going work to increase the accuracy of this emission source.

Data Processing level 1	3. Completeness	DP.1.3.2	Assessment of the most important missing accessibility to critical data sources

All known major sources are included in the inventory. In Denmark, only very few data are restricted. Accessibility is not a key issue; it is more lack of data.

Data Processing level 1	4. Consistency	DP.1.4.1	In order to keep consistency at a high level, an explicit description of the activities needs to accompany any change in the calculation procedure

The calculation procedure is consistent for all years.

Data Processing level 1	4. Consistency	DP.1.4.2	Identification of parameters (e.g. activity data, constants) that are common to multiple source categories and confirmation that there is consistency in the values used for these parameters in the emission calculations

Please refer to Chapter 1.7.

Data Processing level 1	5. Correctness	DP.1.5.1	Show at least once, by independent calculation, the correctness of every data manipulation.

During the development of the model, all persons involved in preparation of the agricultural section have made thorough checks.

Data Processing level 1	5. Correctness	DP.1.5.2	Verification of calculation results using time series.

Time series for activity data, emission factors and national emission are performed to check consistency in the methodology, to avoid errors, to identify and explain considerable year to year variations.

Data Processing level 1	5. Correctness	DP.1.5.3	Verification of calculation results using other measures.

None

Data Processing level 1	5. Correctness	DP.1.5.4	Show one-to-one correctness between external data sources and the databases at Data Storage level 2

In the database key ids is used to identify the unique data. The data on DS level 1 is linked to the key id used in the database so a clear reference from DS level 1 to higher levels of both DP and DS is secured.

Data Processing level 1	6. Robustness	DP.1.6.1	Any calculation must be anchored to two responsible persons that can replace each other in the technical issue of performing the calculations.

Please refer to Chapter 1.7.

Data Processing level 1	7. Transparency	DP.1.7.1	The calculation principle and equations used must be described.

All calculation principles are described in the NIR.

Data Processing level 1	7. Transparency	DP.1.7.2	The theoretical reasoning for all methods must be described.

All theoretical reasoning is described in the NIR.

Data Processing level 1	7. Transparency	DP.1.7.3	Explicit listing of assumptions behind methods.

All theoretical reasoning is described in the NIR.

Data Processing level 1	7. Transparency	DP.1.7.4	Clear reference to dataset at Data Storage level 1.

Links between the different dataset are constructed.

Data Processing level 1	7. Transparency	DP.1.7.5	A manual log to collect information about recalculations.

Changes compared with the last emissions report are described in the NIR and the national emission changes is given in a table under the section, "Recalculation". The text describes whether the change is caused by changes in the dataset or changes in the methodology used. Furthermore, a log table is filled in when data are updated or adjusted continuously.

Data storage and processing level 2

For point of measurements not mentioned below, please refer to Chapter 1.7.

Data Storage level 2	5. Correctness	DS.2.5.1	Documentation of a correct connection between all data types at level 2 to data at level 1.

A manual checklist is under development for correct connection between all data types at level 1 and 2.

Data Processing level 2	5. Correctness	DS.2.5.2	Check if a correct data import to level 2 has been made.

A manual checklist is under development for correctness of data import to level 2.

6.15 Category-specific improvements

6.15.1 Response to the review process

The table below contains the recommendations of the most recent UNFCCC review of the Danish greenhouse gas inventory, where the report is published. The Danish inventory was reviewed in 2021. The table details the status of implementation of the recommendations as well as references to where improvements have been implemented in this report.

Table 6.32 Main recommendations from the latest UNFCCC review.

CRF category/ issue	Review recommendation	Review report/ paragraph	MS response/ status of implementation	Chapter/ section in the NIR
4. General (LULUCF)	Ensure consistent reporting of the area of organic soils between the NIR and CRF Tables 4.A–4.F and improve QC procedures for consistent reporting of the areas of organic soils. For category 4.B, there were small differences of reported organic soils areas for cropland within the range 3-14 ha between Table 6.19 of the NIR2022 (p. 503) and the CRF Table 4.B for the years 1990, 2000 and 2010. During the review, the Party clarified that the reported organic soils areas in the NIR were correct ones and there was error in CRF Table 4.B which occurred during the process of allocating the organic soils areas for cropland into cropland remaining cropland and forest land converted to cropland. The party also clarified that the reported emissions (all emissions were reported under cropland remaining cropland and “IE” was used for forest land converted to cropland) were properly estimated by using correct AD.	L.1	Implemented	Section 6.3, 6.4, 6.5 and 6.6.
4.A Forest land – CO_2	Include in the NIR synthesized information on the main parameters defining the characteristics used in the calculation of biomass and growing stocks. The Party provided the information on assumptions, parameters and some references relating to estimating emissions and removals from forest carbon pools in its NIR (Section 6.2.4, p.478-479), which includes the calculation methods with some parameter values (i.e. wood density, reduction factor) and data for growing stocks by species or by a group of species. The information does not include all the parameter values used in the calculation of carbon stock in biomass and some important values are missing e.g. bio-mass expansion factors. During the review, the Party clarified that the explanations will be included in the next NIR report and will also be published as a separate report.	L.2	Additional tables and supplementary text has been included in NIR.	See text and direct links in Section 6.3.4 and Table 6.3 + 6.4

	The ERT considers that the recommendation has not yet been fully addressed because the Party has not yet included synthesized information on the main parameters. This issue can be fully addressed if the Party includes data in tabular format in future NIRs of the values for the biomass expansion factor, root–shoot ratio, wood density by tree species, and areas and volumes by species. References to the sources of the parameters should be provided.			
4.A Forest land – CO_2	Ensure time-series consistency by revising the living biomass estimates to address the inconsistency caused by the use of different data sources for the periods before and after 2006. The Party had recalculated living biomass estimates in its 2021 submission - resolving the sharp changes of the IEF for the volume of living biomass per ha in forests that existed in its 2020 submission. In the NIR 2022, the Party provided an additional explanation of forest area mapping (p.477). The ERT considers the time-series inconsistency originally reported in the NIR 2020 is resolved. The ERT also considers the recommendation of including additional information referred in ID#L.4 below is expected to contribute to a better understanding of the trend in the time series of forest land carbon stock change estimates when using the NFI surveys from the year 2002 for the recent part of the time series and the forest census in 1990 and 2000 for the earlier part of the time series.	L.3	Consistency in the reporting has been implemented	See Section 6.3
4.A Forest land – CO_2	Include in the NIR information on the approaches for using the NFI surveys or the forest census to estimate the carbon stock changes in pools of living biomass, litter and deadwood under forest land for 1990–2006 and for 2007 onward to enable consistency to be assessed for all reporting years. The Party did not include the relevant information in the NIR. During the review, the Party explained it will be included in the next submission and also indicated that additionally a separate report will be published covering the issues of forest land estimations, including the information referred in ID#L.5 below and ARR2021 (ID#L.17).	L.4	A number of sections have been elaborated with additional text and references	See Section 6.3.1 - 6.3.5
4.A.1 Forest land remaining forest land – CO_2	The Party did not provide a description in its NIR related to this issue including the information referred in ARR2021 (ID#L.6). During the review, the Party explained it will be included in the next submission as a part of a separate report referred in ID#L.4 above.	L.5	The information will be included in the separate report	
4.A.1 Forest land remaining forest land – CO_2	Explain the reasons for any significant inter-annual changes in deadwood/ha in the NIR and provide a justification as to why the changes do not result in underestimation of emissions or overestimation of removals. The Party had recalculated its deadwood estimation in its 2021 submission resolving the significant inter-annual changes of the IEF for deadwood amount per ha existed in its 2020 submission. The Party had not included the suggested information in ARR2021 yet in its NIR. During the review, the Party explained it will be included in the next submission in a separate report referred in ID#L.4 above.	L.6	The information will be included in the separate report	

4.A.2 Land converted to forest land – CO_2	Improve the transparency of the NIR by explaining how land converted to forest land changed over the entire time series. The Party reported areas of all land use changes including land converted to forest land from 1960 to 2020 in the Annex 3E of the NIR (Table 3E.18, p. 892-893).	L.7	Reference to the Annex is included in the text	NIR 6.2.3
4.A.2 Land converted to forest land – CO_2	Provide transparent information in the NIR on the transition period applied to construct the land-use change matrix, ensuring that the information reported in the NIR reflects the actual methodological approaches applied for estimating emissions and removals as reported in the CRF tables. The Party provided information in its NIR (Annex 3.E, p.889-890 and 892-893) on the approach it uses to construct its land use change matrix based on a 30 year transition period by using annual land use changes starting from 1960.	L.8	More information is given in the NIR and link to Levin and Gyldenkærne (2022)	NIR 6.2
4.D.1.2 Flooded land remaining flooded land	Change its reporting from “NO” to “NE” for all carbon pools under subcategory 4.D.1.2 Flooded land remaining flooded land and justify its use of the notation key by explaining that a methodology is not provided by the 2006 IPCC Guidelines in NIR Sections 6.5.9 and 16.6.6. The Party reported by using “NA” or “0” instead of “NE” in the NIR (Table 6.25, p.512) and “NA” in the CRF Table 4.D. During the review, the Party explained it will be corrected in next submission. The ERT considers the recommendation has not fully addressed yet.	L.9	Included	NIR 6.6.1 and CRF Table 4.D.
4.E.2 Land converted to settlements – CO_2	Include in the NIR information on the EF used in the calculation for mineral soils under the category land converted to settlements. The Party reported in its NIR (p.516) information about the EF (referenced soil organic carbon amount as well as the transition period) used in the calculation for mineral soils under the category land converted to settlements. During the review, the Party also provided additional information on the improvements that have been made in this calculation in recent years: using 100 years transition period with start in 1990 for the land area matrix for the 2019 submission; using 30 years transition period with start in 1990 for the land area matrix for the 2020 submission and using 30 years transition period with start in 1960 for the land area matrix in 1960 for the 2021 and 2022 submissions. The ERT considers that the information in the NIR correctly explained the methodology about calculation of carbon stock changes in mineral soils under the category land converted to settlements and that the recommendation was properly addressed.	L.10	Included	NIR 6.7.10
4(II) Emissions/removals from drainage and rewetting and other management of organic/mineral soils – N_2O	Include in the NIR information on the methodological approach and the EFs used for calculating off-site emissions from leaching of dissolved organic carbon in cropland, grassland and wetlands. The Party did not update the information in the NIR. During the review, the Party explained it will be included in the next submission.	L.11ST	Included	NIR Section 6.4.4, 6.5.5 and 6.10.1

4(II) Emissions/removals from drainage and rewetting and other management of organic/mineral soils – N_2O	Report "NO" for N_2O emissions from rewetted organic soils for Greenland and update the text in NIR Section 16.6.11. The Party did not update the information in the NIR. During the review, the Party explained it will be corrected in next submission.	L.12	Implemented	See GL CRF
4.D.2 Land converted to wetlands – CO_2	The Party reported small area of land conversion from forest land to wetlands (mostly reported less than 5 ha annually except for years 2005-2011 – 108 ha annually). The Party explained in its NIR (p.513) that carbon stock changes in dead organic matter for forest land converted to wetlands were assumed as clearing all dead organic matter with instant oxidation. However, "NA" was used for the dead organic matter cell in CRF Table 4.D for forest land converted to flooded land and forest land converted to other wetlands, although losses in living biomass were estimated. During the review, the Party clarified that the explanation in the NIR was wrong, and the carbon losses were not estimated for forest land converted to wetlands, as it was assumed dead organic matters remained on land. The ERT notes that the 2006 IPCC guidelines does not provide methodological guidance about treatment of dead organic matter for land converted to flooded land (Section 7.3.2.1, chapter 7, vol. 4), and that the Wetlands Supplement does not provide methodological guidance suggesting to calculate carbon losses of dead organic matter resulting from rewetting activity taken for inland wetlands mineral soils under Tier 1 (section 5.2.1.1 and 5.3.1.1), which is considered applicable to land converted to partly water covered wetlands in Denmark. Therefore, the current approach of using "NA" under Tier 1 for carbon stock changes in dead organic matter in forest land converted to wetlands was not out of guidance provided in the IPCC Guidelines and Guidance. The ERT recommends the Party to add correct explanation of the methodology applied for carbon stock changes in dead organic matter for forest land converted to wetlands in its NIR.	L.13	No changes made but we will look on if for the next submission. The area is normally less than 5 ha per year	See Section 6.6.13
4.G HWP – CO_2	The Party reported HWP originating from deforestation based on as instantaneous oxidation (IO) in the estimation of HWP carbon stock change for reporting under the convention (NIR p.520) in order to be consistent with KP-LULUCF accounting calculated based on the HWP rules and modality in line with Decision 2/CMP.7 and the 2013 KP supplement. In the 19th Lead Reviewer Meeting held in March 2022, the lead reviewers discussed how to treat this type of reporting and concluded to check whether the reporting of HWP under the convention is in line with the methodologies in the 2006 guidelines and the UNFCCC reporting guidelines from the view of accuracy and comparability. This means that the emissions calculated as IO for HWP originating from deforestation is considered in the context of "insignificant" in line with para 37(b) of decision 24/CP.19. During the review, the Party clarified that annual impact of the emissions from HWP origination from deforestation is in the range from 1.6 to 61.4 kt CO_2 for the whole time series and the numbers exceeded	L.14	Will be analysed further for the next submission. Text added in the NIR	Included in planned improment in 6.13

	the insignificant threshold of the Party (0.05% of the national total emissions) for years 2005-2012, 2014-2016 and 2020. The ERT recommends that the Party considers updating calculation of HWP originating from deforestation taking into a fact that impact exceeded insignificant threshold for some years and also priority of maintaining consistency between the KP-LULUCF reporting and the LULUCF reporting will not be necessary in its future submissions.			

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7 Waste

7.1 Overview of the sector

The waste sector consists of the *CRF source categories: 5.A. Solid Waste Disposal*, *5.B. Biological treatment of solid waste*, *5.C. Incineration and open burning of waste*, *5.D. Wastewater treatment and discharge* and *5.E. Other*. The data presented in Chapter 7 relate to Denmark only, whereas information for Greenland is included in Chapter 16 and for the Faroe Islands in Annex 8.

Emissions from sludge spreading on fields, are included in agriculture, see Chapter 5.

In Table 7.1.1, an overview of all emissions from the waste sector is presented. The emissions are taken from the CRF tables and are presented as rounded figures. The full time series is presented in Annex 3F, Table 3F-1.1.

Table 7.1.1 Emissions for the waste sector, kt CO_2 equivalents.

		1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021
5.A. Solid waste disposal	CH_4	1526	1241	978	737	611	546	495	483	465	458	434
5.B. Biological treatment of solid waste	CH_4	36	58	103	130	158	207	303	330	369	415	497
5.B. Biological treatment of solid waste	N_2O	20	27	50	50	56	58	64	64	67	66	65
5.C. Incineration and open burning of waste	CH_4	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
5.C. Incineration and open burning of waste	N_2O	0.17	0.18	0.19	0.20	0.25	0.24	0.24	0.25	0.25	0.24	0.25
5.D. Waste water treatment and discharge	CH_4	67	72	82	82	77	77	82	83	84	89	87
5.D. Waste water treatment and discharge	N_2O	301	218	154	147	124	137	133	134	128	131	127
5.E. Other	CO_2	22	24	22	22	23	22	24	24	23	23	22
5.E. Other	CH_4	3	3	3	3	3	3	3	3	3	3	3
5. Waste	total	1975	1643	1394	1171	1053	1050	1105	1122	1139	1184	1234

5.A. Solid Waste Disposal is the dominant source in the waste sector with contributions in the time series varying from 79.7 % (1993) to 35.1 % (2021) of the total emission given in CO_2 equivalents. The emissions are decreasing throughout the time series, due to a reduction in the amounts of organic waste deposited at landfills. Comparing 2021 with 1990, the emissions from Solid Waste Disposal Sites have decreased with 71.6 %.

5.B. Biological treatment of solid waste consists of CH_4 emissions from 5.B.1 composting and 5.B.2 industrial and manure-based biogas production and N_2O emissions from 5.B.1 composting. The contribution from 5.B to the total emission from the waste sector provided in units CO_2 equivalent ranges from 2.8 % in 1990 to 45.5 % in 2021; CH_4 contributes the most to the sub-sector 5.B, varying between contributions of 64.7 % (1990) and 88.4 % (2021). Comparing 2021 with 1990, the sum of CH_4 and N_2O emissions (in units CO_2 equivalent) from composting and manure-based biogas plants in total have increased 905 %.

The increase in the GHG emission trend from category *5.B* is most significant for sub-sector 5.B.2, Anaerobic digestion at biogas facilities, the level of methane emissions in 2021 being a factor 64 higher than in the methane emission level in 1990. The methane emission from biogas production increases from 6.3 kt in 1990 to 402.5 kt CO_2 equivalents in 2021, while the GHG emission from composting increased from 49.7 kt in 1990 to 159.4 kt CO_2 equivalents in 2021.

5.C. Incineration and open burning of waste contributes with CH_4 and N_2O emissions from human and animal cremations. The contribution to the sectorial total ranges between 0.01 % and 0.03 %throughout the time series. The trend for the total CO_2 equivalent emissions 1990 - 2021 from this source have increased with 46.6 %.

5.D. Waste water treatment and discharge contributes with CH_4 and N_2O emissions. The contribution to CO_2 equivalent emissions from the sum of CH_4 and N_2O is between 14.6 % (1993) and 21.4 % (2008).

The contribution from CH_4 to the 5.D sub-sector total of CO_2 equivalents increases from 18.2 % in 1990 to 40.8 % in 2021. The CH_4 emissions increases steadily over the time series from 67 kt CO_2 equivalents in 1990 to 87 kt CO_2 equivalents in 2021, while N_2O emissions decreases from 301 kt CO_2 equivalents in 1990 to 127 kt CO_2 equivalents in 2021. The N_2O emission in 2021 compared to 1990 shows a decrease of 57.9 %, while for CH_4 a steady increase from 1990 to 2021 of 30.5 % is observed.

The trend for the total CO_2 equivalent emissions from sector 5.D Wastewater treatment and discharge has decreased from 367 kt CO_2 equivalents in 1990 to 214 kt CO_2 equivalents in 2021. Compared to 1990, the GHG emissions in 2021 have decreased with 41.8 %.

5.E. Other. This source contributes with CO_2 and CH_4 emissions from accidental fires. No emission factors for N_2O are available. The contribution to the total emissions from the waste sector varies between 1.3 % and 2.6 %. Compared to 1990, the GHG emissions in 2021 have decreased with 1.2 %.

As a result for the entire waste sector, the emission in units of CO_2 equivalents (provided in Table 7.1.1) is decreasing throughout the time series; the emission in 2021 has decreased with 37.5 % compared to 1990.

The Waste sector's contribution to the national total including LULUCF is between 1.5 % (2004) and 2.7 % in 2021.

Table 7.1.2 Reported emissions, calculation methods and type of emissions factors for the subcategory waste handling in the Danish inventory, (CS=country specific, D=default).

CRF Source	Emissions reported	Method	Emission factor
5.A Solid Waste Disposal	CH_4	Tier 2, CS	CS, D
5.B Biological treatment of solid waste			
5.B.1 Composting	CH_4	Tier 1, Tier 2	D, CS
5.B.1 Composting	N_2O	Tier 1, Tier 2	D, CS
5.B.2 Anaerobic digestion at biogas facilities	CH_4	Tier 2	CS
5.C Incineration and open burning of waste			
5.C.1 Incineration of corpses	CH_4	Tier 1	D, CS
5.C.1 Incineration of corpses	N_2O	Tier 1	D, CS
5.C.2 Incineration of carcasses	CH_4	Tier 1	D, CS
5.C.2 Incineration of carcasses	N_2O	Tier 1	D, CS
5.D Wastewater treatment and discharge			
5.D.1 Domestic wastewater	N_2O	CS	CS
5.D.1 Domestic wastewater	CH_4	CS	CS
5.D.2 Industrial wastewater	N_2O	CS	CS
5.E Other			
5.E.1 Accidental fires	CO_2	Tier 1, CS	CS, OTH
5.E.1 Accidental fires	CH_4	Tier 1, CS	CS, OTH

7.1.1 Key category identification

In the key category analysis (KCA) the waste emissions are divided into thirteen categories. In the Approach 1 KCA, four of the thirteen categories are identified as a key category. At Approach 2 KCA, six of the thirteen source categories are identified as key categories for this year's submission (Table 7.1.3). The Approach 1 key category analysis is based on ranking of absolute quantitative emissions/removals, while the Approach 2 KCA takes into account the uncertainties in the calculated emissions (cf. Chapter 1.5).

Of the thirteen source categories shown in Table 7.1.3, five categories, i.e. *5.A Solid Waste Disposal*, *5.B.1 Composting, 5.B.2 Anaerobic digestion at biogas facilities*, *5.D.1 Domestic wastewater* and *5.D.2 Industrial wastewater* are identified as key sources for level. And *5.A Solid Waste Disposal*, *5.B.1 Composting, 5.B.2 Anaerobic digestion at biogas facilities*, *5.B.1 Composting* and *5.D.2 Industrial wastewater* are identified as key sources for trend.

Key source categories for level

According to the level analysis, for both Approach 1 and 2 KCA, *5.A. Solid Waste Disposal* is a key category for level in 1990 and 2021.

Category *5.B.1 Composting* is a key category for CH_4 emissions in 2021 according to the level assessment for Approach 2 KCA only. Category *5.B.2 Anaerobic digestion at biogas facilities* is identified as key category for level in 2021 according to both the Approach 1 and 2 KCA.

Category *5.D.1 Domestic wastewater* is a key category for N_2O emissions in 2021 according to the level analysis, for both Approach 1 and 2 KCA. And 5.D.2 Industrial wastewater is a key category for N_2O emission in 1990 according to Approach 1 KCA only.

Key source categories for trend

Both category *5.A. Solid Waste Disposal* and *5.B.2 Anaerobic digestion at biogas facilities* are CH_4 key categories for trend from 1990 to 2021 according to both Approach 1 and 2 KCA. Category *5.B.1 Composting* is identified as a key category for CH_4 and N_2O emission trend according to the Approach 2 KCA only.

Category *5.D.2 Industrial wastewater* is a key category for the N_2O emission trend according to both the Approach 1 and 2 KCA.

Identified key source categories within the waste sector are presented in Table 7.1.3. For further information on the KCA level and trend assessments please refer to Chapter 1.5 and Annex 1.

Table 7.1.3 Key category identification Approach 1 and Approach 2 from the waste sector 1990 and 2021.

		Approach 1			Approach 2		
		1990	2021	1990-2021	1990	2021	1990-2021
5.A Solid waste disposal	CH_4	Level	Level	Trend	Level	Level	Trend
5.B.1. Composting	CH_4	-	-	-	-	Level	Trend
5.B.1. Composting	N_2O	-	-	-	-	-	Trend
5.B.2. Anaerobic digestion at biogas facilities	CH_4	-	Level	Trend	-	Level	Trend
5.C.1 Incineration of corpses	CH_4	-	-	-	-	-	-
5.C.1 Incineration of corpses	N_2O	-	-	-	-	-	-
5.C.2 Incineration of carcasses	CH_4	-	-	-	-	-	-
5.C.2 Incineration of carcasses	N_2O	-	-	-	-	-	-
5.D.1 Domestic wastewater	CH_4	-	-	-	-	-	-
5.D.1 Domestic wastewater	N_2O	-	Level	-	-	Level	-
5.D.2 Industrial wastewater	N_2O	Level	-	Trend	-	-	Trend
5.E Accidental fires*	CO_2	-	-	-	-	-	-
5.E Accidental fires*	CH_4	-	-	-	-	-	-

* Vehicles and Buildings.

7.2 Solid waste disposal

A quantitative overview of the source category is provided in Table 7.2.1 presenting the amounts of landfilled waste, the annual gross emissions of CH_4, the recovered CH_4 in terms of collected biogas at the landfill sites used for energy production, the amount of CH_4 oxidised in the top layers and the resulting net CH_4 emissions. The CH_4 emission from the Danish landfills has decreased 71.6 % from 1990 to 2021.

A full time series of these data are presented in Annex Table 3F-2.2.

Table 7.2.1 Annual amounts of total deposited waste, annual degraded amount, gross methane emissions, recovered methane collected for biogas production, oxidised methane in the top layer and resulting net emissions.

	Landfilled waste	Annual degraded amount	Generated methane	Recovered methane	Methane oxidised in the top layers	Net methane emission	
	kt	kt	kt CH_4	kt CH_4	kt CH_4	kt CH_4	kt CO_2 eqv.
1990	3569	103	61.1	0.5	6.1	54.5	1526
1995	2200	63	56.8	7.6	4.9	44.3	1241
2000	1781	50	50.1	11.3	3.9	34.9	978
2005	1095	7	39.2	9.9	2.9	26.3	737
2010	1865	9	30.0	5.7	2.4	21.8	611
2015	2425	9	25.1	3.4	2.2	19.5	546
2018	2401	9	22.3	3.1	1.9	17.3	483
2019	2712	7	21.5	3.0	1.8	16.6	465
2020	2748	6	20.6	2.5	1.8	16.4	458
2021	2572	11	19.8	2.5	1.7	15.5	434

The yearly methane emission is a function of the type and amount of degradable organic waste deposited (Table 7.2.2 and 7.2.3). The net methane emission results from the gross emission minus the amount of recovered methane collected for bioenergy production minus the amount of methane oxidised in the top layers of the landfills (Eq. 7.2.7). The decreasing trend in the net CH_4 emission is explained by an exponential decrease over time according to first order decay kinetics (Eq. 7.2.4) and a significant decrease in the amount of degradable organic waste deposited at landfills in Denmark (cf. Table 7.2.1, Table 7.2.4, Table 7.2.5, Annex Table 3F-2.2 and Annex Table 3F-2.3).

7.2.1 Source category description

Waste management in Denmark has changed much over the last decades. In the first half of the 20th century, the landfills were relatively primitive, but up through the 20th century the landfills became more and more regulated and streamlined. The Danish waste strategies have shifted over the decades from a focus on waste as a necessary burden (deposition) to a resource for energy production (combustion) to now a resource (recycling).

According to the Danish EPA, there are approx. 2500 old uncontrolled landfills (DEPA, 2013a), typically constructed before 1973 (DEPA, 2001a, page 21). With the adoption of the Environmental Protection Act in 1973 (MIM, 1985), and implementation of the first regulation on environmental approval of landfills requirements to location, design and operation in a controlled manner was put forward by Danish Environmental Protection Agency (DEPA, 1974). Since 1974, only managed waste disposal sites with bottom membranes and/or leachate collection systems have been constructed in Denmark (DEPA, 1974).

A recent survey of the opportunities and challenges in landfill mining in Denmark performed by the knowledge centre for mineral resources reports a total of 4,000 waste disposal sites in Denmark corresponding to an area of 143 km^2 or 0.3 % of Denmark´s land area (GEUS, 2020, page 15).

In 1999, the European Landfill Directive was adopted (EU, 1999) providing Member States a timeframe of 10 years to implement the rules. These were implemented in Denmark in 2001 in the form of the Executive Order on landfills (MIM, 2001). Besides setting up requirements for how the waste may be disposed of, the Deposit Order also contain requirements for providing security, which must ensure that sufficient funds are saved to cover the costs of decommissioning and post-treatment of the landfill (DEPA, 2002). As a consequence of the stricter rules for interior design, many landfills were closed by the end of the year 2000 and in the period until 2009. The closing of landfill sites in Denmark peaked around 1980, measured in number of landfills. In 2000, a large peak in closed down deposit site capacity occurs; measured in m^2. (GEUS, 2020, page18).

All waste deposited in Denmark is reported under the CRF source category *5.A.1 Managed waste disposal sites,* as all landfills in Denmark are managed assuming that all closed landfills have been through post-treatment and are covered by a 1 m top soil layer before 1990.

The amount of deposited organic waste has decreased markedly throughout the time series. The general development in the amount of solid waste disposed of at landfills is influenced by government instruments such as the "Action plan for Waste and Recycling 1993-1997" and "Waste 21 1998-2004" (Danish Government, 1999). The latter plan had, inter alia, the goal to recycle 64 %, incinerate 24 % and deposit 12 % of all waste. The goal for deposited waste was met in 2000. In 2003, the Danish Government set up targets for the year 2008 for waste handling in a "Waste Strategy 2005-2008" report (Danish Government, 2003). According to this strategy, the target for 2008 is a maximum of 9 % of the total waste to be deposited at landfills. In the ISAG data for the year 2003, data shows that this target was met, since 8.3 % of total waste was deposited in 2003 (ISAG). Waste Strategy 2009-12, part I (Danish Government, 2009) was the sixth waste management plan or strategy adopted by the successive governments dating back to 1986. Waste Strategy 2009-2012 set up targets for 2012 according to which a maximum of 6 % of the total waste produced is to be deposited (Danish Government, 2009). This target has met in 2012 as 5.7 % of all produced waste was deposited at landfills. Since 2013, the percentage of waste deposited at landfills has reached a more steady level at 3-4 % of the total waste produced in the country.

Data on final disposal of waste in Denmark is presented in Annex Table 3F-2.1.

Waste Strategy 2009-2012, Part II included goals of continued decrease in the amount of waste being deposited in Denmark and an increase in reuse, recycling and recovery (Danish Government, 2010). This report includes an evaluation of the capacity of Danish solid waste disposal sites divided into waste classes: inert, mineral, mixed and hazardous waste. The same waste classes are defined in the Statutory Order for Landfill (MIM, 2011), which leads to the Statutory Order for Waste (MIM, 2012) regarding characterisation of the waste according to the EWC[1]-system. A list of EWCs is included in Annex 2 of MIM (2012).

Biological decomposition of organic waste at solid waste disposal sites (SWDS) is a source of CH_4 emissions.

7.2.2 Emission model

The estimation of CH_4 emissions from Danish landfills is based on a First Order Decay (FOD) model as recommended by the IPCC (2006).

[1] The EWC (European Waste Code) system is called EAK (Det Europæiske Affaldskatalog) in Danish.

Denmark is applying the model using country-specific activity data for both the current and historical waste disposed in landfills. This makes the Danish methodology equivalent to the IPCC Tier 2 methodology (IPCC, 2006). For a description of the national activity data used in the model see Chapter 7.2.3.

The degradation of a deposited waste type of quantity N is modelled according to first order kinetics. The mathematical formulation of this type of exponential decay is

$$\frac{dN}{dt} = -k \cdot N \qquad \text{Eq. 7.2.1}$$

where *k* is the decay constant. Equation 7.2.1 can be solved for the simple case of a momentarily single deposition at time t (W_t) yielding:

$$N(t) = W_t \cdot e^{-k\,t} \qquad \text{Eq. 7.2.2}$$

where *k* relates to the half-life for the content of degradable organic carbon (DOC) in the bulk waste, as:

$$t_{1/2} = \frac{ln2}{k} \Rightarrow k = \frac{ln2}{t_{1/2}} \qquad \text{Eq. 7.2.3}$$

The content of degradable organic carbon (DOC_i), half-life times ($t_{½}$) and the corresponding methane generation constants (*k*) are provided in Table 7.2.2.

The amount of generated methane decreases exponentially over time according to first order decay kinetics of the content of degradable organic carbon in the deposited waste.

At a given year (t) the amount of degradable organic carbon (D*DOCm*(t)) which decomposes is a result of accumulated contributions from all former years deposit of waste (*W*(*x*)), where *x* is years since depositing. The residue of organic matter, i.e. decomposable DOC, left from waste deposited at landfill sites *x* years ago, is calculated using the exponential decomposition rule (Eq. 7.2.4).

$$DDOCm(t) = W_i \cdot DOC_i \cdot DOC_f \cdot MCF + DDOCm(t-1) \cdot e^{-k} \qquad \text{Eq. 7.2.4}$$

where MCF is the methane correction factor, DOC_i is the mass fraction of degradable organic carbon in the deposited waste types (Table 7.2.2), DOC_f represents the fraction of the degradable organic carbon that will decompose at the SDWS.

Eq. 7.2.4 assumes that the deposition of degradable organic carbon takes place momentarily once a year and just after the time *t*, where *t* is defined as whole years (integer: *t*=1,2...), so Eq. 7.2.4 consists of two overall contributions that may be expressed as

DDOCm(t) = *New deposit* + *Remaining part of former years deposit*

The total amount of degraded organic matter during year *t* ($DDOCm\ decomp_T$) is assumed to be equal to the degradation during year t of the organic matter that was deposited at the beginning of the year (*DDOCm*(*t*-1)):

$$DDOCm\ decomp_T = DDOCm(t-1) \cdot (1 - e^{-k}) \qquad \text{Eq. 7.2.5}$$

Based on Equation 7.2.4 and 7.2.5 it is possible to calculate the degraded amount of organic matter in a step wise manner based on last year result. The degraded amount of organic matter is assumed to generate the CH_4 as described by

$$CH_4\ generated_T = DDOCm\ decomp_T \cdot F \cdot 16/12 \qquad \text{Eq. 7.2.6}$$

where F is the fraction of methane in the gas from landfills and 16/12 is the molecular conversion factor from units of C to CH_4.

For deriving the net emissions, the amount of recovered or collected methane as well as the amount of oxidised methane in the top layer of the landfill needs to be subtracted from the generated methane:

$$CH_4\ Emission = \left(\sum_x CH_4\ generated_{x,T} - R_T\right) \cdot (1 - OX_T) \qquad \text{Eq. 7.2.7}$$

where *CH_4 Emissions* is the methane emitted in year *T*, in units of kt, *T* is the inventory year, *x* is the waste category or type. R_T is the amount of recovered CH_4 at the Danish disposal sites, which are used for energy production. OX_T is the assumed oxidation of CH_4 in the top layer.

The amount of CH_4 recovered, *R(t)*, is calculated as:

$$R_T = \frac{B \cdot 0.41 \cdot 0.678\text{kg/m}^3}{15.19\text{MJ/m}^3} \qquad \text{Eq. 7.2.8}$$

where B is the collected amount of biogas as reported by the DEA in units of MJ. The constants applied in Eq. 7.2.8 are described in Chapter 7.2.3 in the section on *Methane recovery*.

The content of degradable organic matter, DOC_i values, in each waste type is kept constant for the whole time series. The methane generation potential per unit waste type *i* is obtained from equation 7.2.9:

$$\frac{L_{o,i}}{W_i} = DOC_f \cdot MCF \cdot F \cdot \frac{16}{12} \cdot DOC_i = \frac{1}{3} \cdot DOC_i \qquad \text{Eq. 7.2.9}$$

The methane generation potentials for each deposited degradable waste fraction is presented in Figure 7.2.2.

7.2.3 Model input

According to the IPCC (2006), the FOD method requires data to be collected or estimated for historical disposals of waste over a time period of 3 to 5 half-lives in order to achieve an acceptably accurate result. The IPCC therefore consider it good practice to use disposal data for at least 50 years. As the reporting of emissions begin in 1990, this implies that the model should start in 1940, which has been chosen as the starting point for the Danish FOD model.

Key parameters

The Danish model used to estimate emissions from landfills are mostly using default values from the IPCC (2006). Applied key parameters are presented in Table 7.2.2 and Table 7.2.3.

Half-life times are dependent on the climate. Denmark has a mean annual temperature below 20 degrees Celsius and therefore the relevant default values for Denmark is the values for boreal and temperate climate. IPCC (2006) also distinguishes between wet and dry climate using the ratio between annual precipitation and evapotranspiration as a proxy. Denmark has a ratio greater than 1 and is therefore categorised as wet.

Table 7.2.2 Content of degradable organic matter (DOC_i), half-life times ($t_{½}$) and calculated degradation rates constants (k) for each waste type in wet weight.

Waste type	DOC_i %	$t_{½}$ yr	k yr^{-1}
Food waste	15[a]	4[c]	0.16
Paper & cardboard	40[a]	12[c]	0.06
Wood	43[a]	23[c]	0.03
Plastics	-	-	-
Textiles	24[a]	12[c]	0.06
Rubber & leather	39[a]	23[c]	0.03
Garden & park waste	20[a]	7[c]	0.09
Chemicals, degradable*	10[b]	7	0.1[b]
Chemicals, inert	-	-	-
Electrical waste	-	-	-
Glass	-	-	-
Metal	-	-	-
Demolition	4[a]	23[c]	0.03
Soil, sand & stone	-	-	-
Particulate matter & dust	-	-	-
Sludge, inert	-	-	-
Domestic sludge, degradable	5[a]	4[c]	0.16
Industrial sludge, degradable	9[a]	4[c]	0.16
Ash & slag	-	-	-
Other not combustible waste	-	-	-

*Mainly oil and organic solutions
[a]IPCC (2006) default, Vol. 5, Chapter 2, Table 2.4, Table 2.4 and Section 2.3.2.
[b]Pipatti (2001)
[c]IPCC (2006) default, Vol. 5, Chapter 3, Table 3.4. Rubber & leather is assumed to have a half-life time similar to that of wood. For demolition waste, the degradable fraction is assumed to be wood and the half-life for wood is therefore used.

Table 7.2.3 Key parameters applied to the Danish FOD emission model.

Parameter	Name	Value	Reference
MCF	Methane correction factor	1	IPCC (2006), Vol. 5, Chap. 2, page 3.14. Managed SWDS
DOC_f	Fraction of degradable organic carbon which decomposes	0.5	IPCC (2006), Vol. 5, Chap. 2, page 3.13
F	Fraction of CH_4 in generated landfill gas	0.5	IPCC (2006), Vol. 5, Chap. 2, page 3.15
OX_T	Oxidation factor	0.1*	IPCC (2006), Vol. 5, Chap. 2, page 3.15

*The default value for industrialised countries with covered, well-managed disposal sites. In Denmark, all landfills have been required to cover the deposited material with soil at least since 1974 (DEPA, 1974) and by all indications even before then.

Methane recovery

The Danish Energy Agency registers the biogas amounts recovered at disposal sites in energy units (TJ) (DEA, 2022). The amount of gas expressed in terms of energy is converted to volume of gas using the net calorific value of 15.19 MJ per Nm^3, which has been calculated as the average of measurements from three different landfill sites (DGC, 2009; Vattenfall, 2010; Verdo, 2011). As for the FOD model, the content of CH_4 in the gas recovered is estimated to 41 % (DGC, 2009) and the density of CH_4 is calculated to 0.678 kg per m^3 at 15 degrees Celsius.

Activity data
Information on deposited waste is available from the following sources:

- DEPA (1974) for 1970
- DEPA (1993a) for 1985
- The ISAG database for 1994-2009
- The ADS data system from 2010 onward

Data on total deposited waste from the four different sources are not directly comparable, e.g. because some sources contain large amounts of soil/stone while other sources omit this fraction. All though uncertainties a higher in the two early references, there is no reason to suspect that any of the four sources omit any degradable waste.

Activity data for 1940-1969 are projected using population and GDP data as surrogate data.

Figure 7.2.1 presents total deposited waste amounts for the entire time series.

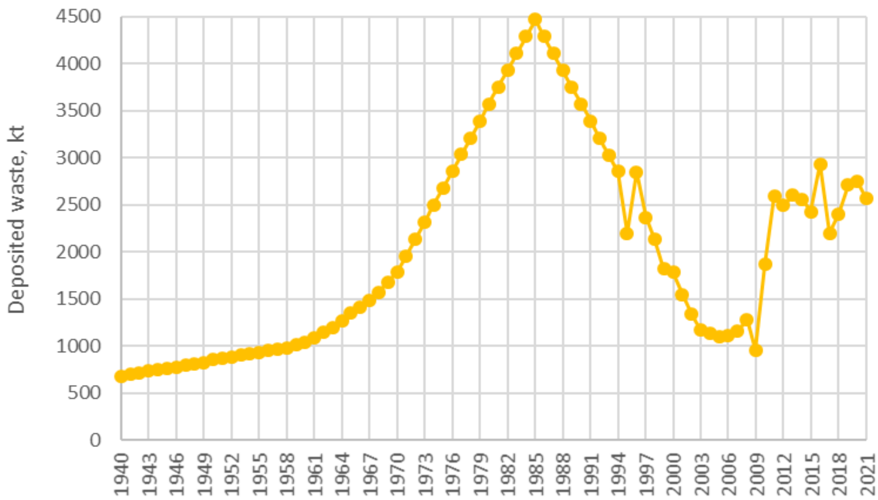

Figure 7.2.1 Deposited waste amount, kt.

A fluctuation is seen in the first years after the introduction of ISAG (1994-1996). It is likely that the shift from one data reporting system to a new (ISAG) has caused temporary problems for the users.

A sharp decline (-25%) in total deposited waste is seen from 2008-2009. The global financial crisis is expected to be the mail explanation for the temporary lower amounts of waste.

The general level of deposited waste increases from 1100-1200 kt in the years 2003-2008 to 2500-2600 kt in the years 2011-2014. However, the increase is caused by in increased registration of inert waste and is not decisive for the emission trend.

The amounts of waste deposited have been allocated into 20 waste types for the entire time series since 1940, as presented in Table 7.2.4 and in Annex Table 3F-2.3.

Table 7.2.4 Waste amounts according to the 20 DCE waste types of which 10 represent inert waste fractions, kt.

Waste types	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Food waste	125.2	84.2	65.1	3.6	20.4	18.1	22.4	21.9	11.1	19.5
Paper & cardboard	176.4	90.5	74.8	4.9	9.1	9.3	10.4	9.3	5.2	12.8
Wood	139.0	96.1	78.3	7.1	9.0	9.4	7.4	4.6	5.2	11.0
Textiles	8.8	7.4	6.0	0.2	4.9	5.4	4.8	2.9	2.2	10.0
Rubber & leather	3.6	2.5	2.0	0.1	6.4	6.5	6.2	4.3	2.9	10.8
Garden & park waste	120.5	49.9	36.6	1.9	6.5	5.9	1.7	2.1	1.2	1.2
Domestic sludge, degradable	169.3	99.5	92.3	27.4	7.2	3.7	3.8	3.2	2.4	1.1
Industrial sludge, degradable	61.0	63.5	24.8	12.8	5.5	2.2	4.3	2.0	1.9	1.5
Chemicals, degradable	46.0	38.6	26.8	7.1	6.4	6.0	6.1	4.2	4.6	4.8
Demolition	278.2	220.8	201.3	143.3	30.2	51.2	74.3	61.2	60.6	52.1
Plastics	92.9	134.8	99.1	4.7	12.0	9.9	10.2	7.8	5.6	13.3
Glass	73.2	79.0	62.4	54.8	6.9	6.4	5.4	2.9	3.4	11.1
Metal	155.6	106.0	86.1	152.0	80.2	50.2	8.5	22.3	46.3	52.3
Sludge, inert	95.7	52.2	39.4	16.9	0.0	3.5	7.9	7.8	8.1	7.4
Chemicals, inert	47.8	38.6	26.8	7.4	2.5	3.3	2.2	1.4	1.0	2.8
Electric waste	34.7	38.6	27.7	91.8	3.1	2.2	2.4	1.3	0.8	1.5
Ash & slag	828.4	289.4	150.4	56.2	5.9	33.3	25.2	20.4	18.7	19.4
Particulate matter & dust	43.1	38.6	26.7	7.1	60.0	42.6	80.5	31.4	1.6	3.6
Soil, sand & stone	567.2	339.8	313.5	201.6	1491	2045	2001	2403	2461	2233
Other waste, inert	502.3	330.0	340.9	294.4	97.9	110.5	116.4	98.7	104.0	103.6
Total degradable	1128	752.8	607.9	208.5	105.7	117.7	141.6	115.5	97.4	124.7
Total inert	2441	1447	1173	887	1760	2307	2259	2597	2650	2448
Total	3569	2200	1781	1095	1865	2425	2401	2712	2748	2572

Data on the amounts of solid waste deposited at managed solid waste disposal sites, are registered and published in the national ISAG (1994-2009) and ADS (2010-present) databases administered by the Danish Environmental Protection Agency (DEPA). Information on the waste amounts and types deposited at SWDSs in 1970 and 1985, is available from the reports DEPA (1974) and DEPA (1993a). Data for 1971-1984 have been determined by assuming a linear development between 1970 and 1985, while data for the period 1940-1969 have been extrapolated from 1970 according to population and GDP.

The available data on deposited waste is often registered as e.g. "combustible waste", all waste data from the four sources has therefore been allocated to the 20 DCE waste fractions presented in Table 7.2.4. The DCE waste fractions are comparable to the IPCC recommended waste fractions and given key parameters like content of degradable carbon and half-life times, see Table 7.2.2.

Waste amounts for the whole time series, i.e. 1940- 2021, for each of the 20 waste fractions, are provided in Annex Table 3F-2.3.

7.2.1 Model output

The annual amounts of the waste types (Table 7.2.4) and their emission generation potentials per mass unit (Eq. 7.2.9) are used to calculate the deposited CH_4 generation potential and the actual generated CH_4 emission from the annually amount of deposited waste (Eq. 7.2.6).

Figure 7.2.2 shows the time trend in annual amounts of deposited methane generation potential for each of the deposited waste type per year.

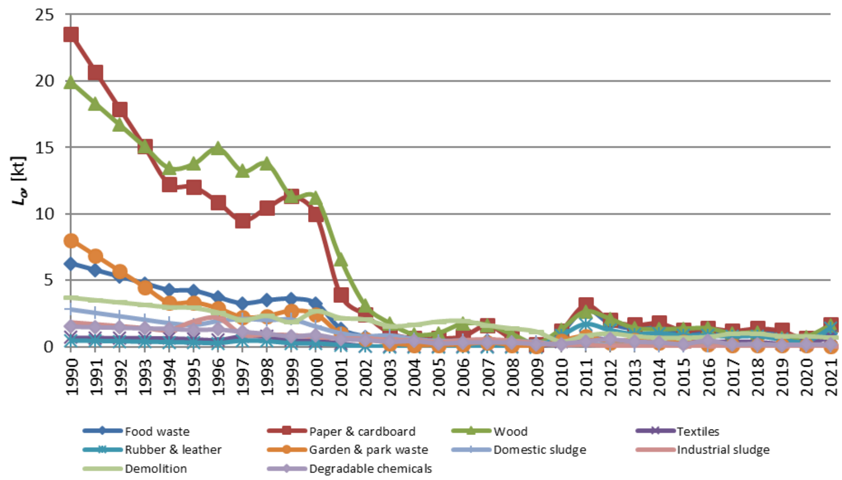

Figure 7.2.2 Annual amounts of deposited methane generation potential per waste type.

Figure 7.2.2 shows that the amounts of yearly deposited methane generation potential has decreased significantly in the period from 1990 to 2004. Only a fraction of the deposited methane generation potential is released per year; i.e. a function of the degradation rate constants of the individual waste types, the content of degradable organic carbon and according to first order degradation kinetics for each waste type (Eq. 7.2.1 to 7.2.6 and Table 7.2.2). The seemingly significant fluctuations in the yearly amounts of deposited methane generation potentials become insignificant when looking at the annual implied emission factors, calculated from the net methane emission per waste type divided by the accumulated amount of decomposable organic matter (DDOCma) per waste type (Table 7.2.5), as illustrated in Figure 7.2.3.

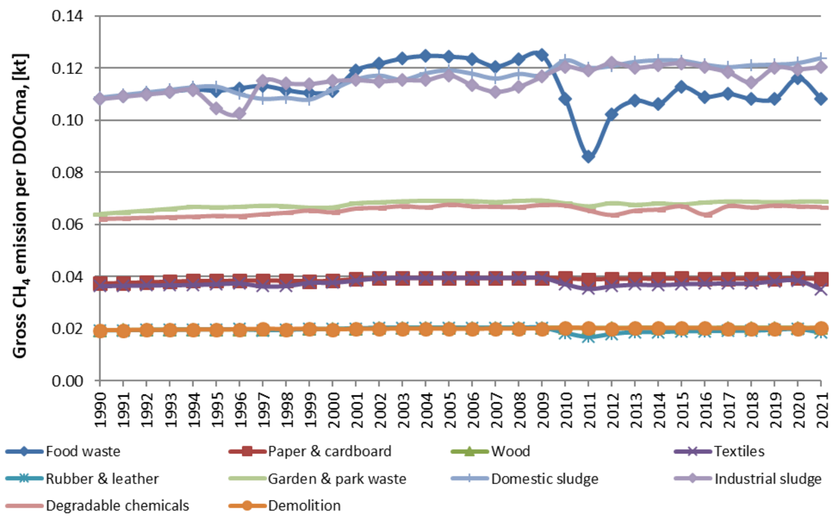

Figure 7.2.3 Annual gross implied emission factors for each waste type.

Figure 7.2.3 shows the time trend in the gross implied methane emission factor calculated as the gross methane emission divided by the accumulated (or remaining) amount of degradable organic carbon (DDOCma) within each waste type (the sum across waste types are provided in Table 7.2.5).

The year 2011 was the first year of the waste reporting system ADS. Waste amounts registered as being deposited this year increased significantly for all degradable fractions except sludge compared to ISAG data that ended in 2009. The effect of this increase on the implied emission factor is most significant for food waste, cf. Figure 7.2.3. Due to the mechanics of the FOD model, an increase in deposited degradable waste leads to an instant increase in

DDOCm and DDOCma, but the methane generation only increases slightly the first year. As the level of deposited degradable waste types stabilises, so does the implied emission factor.

As may be observed from comparing Figure 7.2.3 with Figure 7.2.2, food waste and sludge has the highest gross methane emission factors but wood and paper & cardboard have the highest yearly methane generation potentials. The higher methane emission factor (Figure 7.2.3) for food waste and sludge throughout the time series may be explained by the lower half-life (high CH_4 release rate) compared to other waste types. While the higher annual amounts of deposited methane generation potential for wood and paper & cardboard is a result of the higher DOC values compared to other waste types.

The net CH_4 emission (Eq. 7.2.7) is obtained upon subtraction of the recovered CH_4, utilized for energy production at some of the sites, and the amount of oxidized methane in the SWDS top layers from the gross methane emission. The annual total amounts of deposited waste, accumulated degradable organic waste, degraded organic matter and the calculated CH_4 emissions are presented in Table 7.2.5.

Table 7.2.5 Waste deposited, total degradable matter, annual degraded organic matter and resulting CH_4 emissions. Full time series in Annex Table 3F-2.2

	Total landfilled waste	Annual amount of degraded D*DOCm*. Eq. 7.2.5	Accumulated amount of decomposable D*DOCm* Eq. 7.2.4	Annual deposited CH_4 potential Eq. 7.2.9	Annual Gross CH_4 emission Eq. 7.2.6	Recovered methane	Annual net emission before oxidation Eq. 7.2.7	Annual net emission after oxidation	Implied Emission Factor	
	kt	kt	kt	kt CH_4	kt CH_4	kt CH_4	kt CH_4	kt CH_4	kt CH_4/ kt waste	kt CH_4/kt DDOCm
1990	3569	103.2	1644	68.8	61.1	0.5	60.6	54.5	0.02	0.03
1995	2200	63.1	1574	42.1	56.8	7.6	49.2	44.3	0.02	0.03
2000	1781	50.2	1454	33.5	50.1	11.3	38.8	34.9	0.02	0.02
2005	1095	7.5	1192	5.0	39.2	10.0	29.2	26.3	0.02	0.02
2010	1865	9.1	982	6.1	30.0	5.7	24.3	21.8	0.01	0.02
2015	2425	9.3	846	6.2	25.1	3.4	21.7	19.5	0.01	0.02
2018	2401	9.4	770	6.3	22.3	3.1	19.2	17.3	0.01	0.02
2019	2712	7.5	746	5.0	21.5	3.0	18.5	16.6	0.01	0.02
2020	2748	5.5	720	3.7	20.6	2.4	18.2	16.4	0.01	0.02
2021	2572	11.2	702	7.5	19.8	2.6	17.2	15.5	0.01	0.02

The total waste amount in the second column of Table 7.2.5 is the sum of the amounts of the 20 different waste types (Table 7.2.3). The total waste amount is reported as the activity data for the Annual Municipal Solid Waste (MSW) at SWDSs in the CRF Table 5.A.

The implied emission factors (IEFs) in the second last column in Table 7.2.5 reflects an aggregated emission factor calculated as the net methane emission divided by the total amount of waste deposited in the current year and corresponds to the reported IEFs in the CRF Table 5.A. This factor is highly effected by the amount of inert waste being reported. Therefore, a significant decrease in IEF is seen in the years 2009-2011 because of the transition from ISAG to ADS waste registration systems. As previously mentioned, ADS registers large amounts of soil, sand and stone from large building sites like e.g. bridge/tunnel construction, which was not reported under ADS. The IEF values in the last column in Table 7.2.5 represents more appropriate IEF values, i.e. calculated as the net methane emission divided by the total accumulated amount of decomposable degradable organic matter, D*DOCm*. The D*DOCm* are provided in the fourth column in Table 7.2.5.

The trend in the total amount of decomposable DOC accumulated at the Danish landfills and amount annual degraded organic matter, provided in the third and fourth column in Table 7.2.5, shows that the percent degraded decreases from 6.3 % in 1990 to 1.6 % in 2021.

Figure 7.2.4 visualises the trend in the annual deposited methane potential, the annual gross emission, the annual amount of recovered methane and the net methane emission with and without methane oxidation.

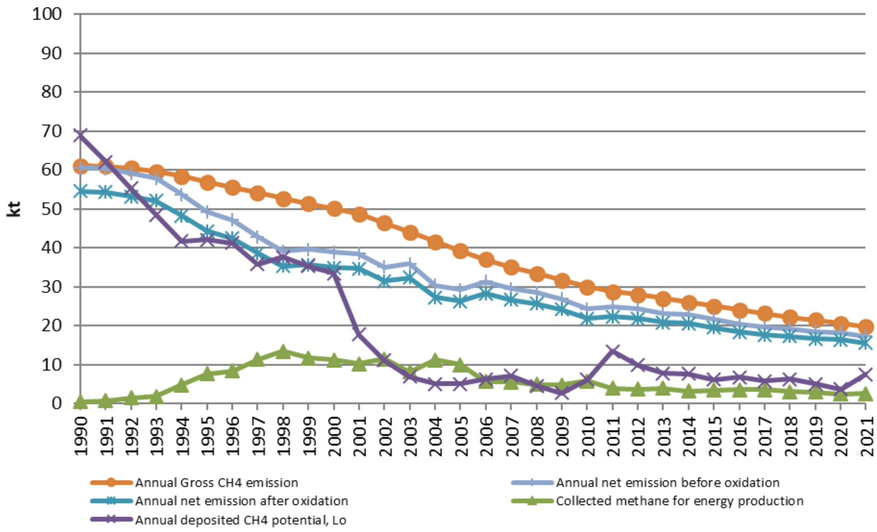

Figure 7.2.4 Time trend in the annual deposited methane potential, gross methane emission, recovered methane, annual net methane emission before and after oxidation.

In total, a reduction in the net methane emission after oxidation from 1990 to 2021 of 72 % is observed. This reduction in the methane emission is accompanied by a decrease in the accumulated amount of decomposable degradable organic matter (D*DOCma*) of 57 % and in the annual amount of deposited methane potential, which is reduced by 89 % in 2021 compared to 1990. The fluctuation in the net methane emission is explained by the fluctuations in the annual amount of deposited methane potential and the amount of recovered methane.

7.3 Biological treatment of solid waste

This sector provides an overview of the Danish greenhouse gas emission from the CRF source category *5.B Biological treatment of solid waste,* which consists of the *sub-categories 5.B.1 Composting* and *5.B.2 Anaerobic digestion at biogas facilities*.

7.3.1 Composting

This section covers the sub-category of biological treatment of solid wastes called composting. Greenhouse gasses that are emitted from this process are CH_4 and N_2O. CO_2 emissions from compost production are biogenic and therefore not relevant for the emission inventories.

Methodological issues

Emissions from composting have been calculated using both IPCC default emission factors and country-specific emission factors, corresponding to a hybrid Tier 1/Tier 2 methodology.

In Denmark, composting of solid biological waste includes composting of:

- Garden and park waste (GPW)
- Organic waste from households and other sources
- Sludge
- Home composting of garden and vegetable food waste.

Composting facilities are categorised in three types. Type 1, treating organic waste mixed with GPW or other organic waste, Type 2, treating only GPW and Type 3, treating GPW mixed with sludge and/or other organic waste.

Table 7.3.1 Composting facilities distributed as the different types.

	1997	2001	2017
Type 1	16	16	9
Type 2	99	123	150
Type 3	11	10	10
Total	126	149	169

According to Petersen & Hansen (2003), 92 % of Danish composting facilities consist entirely of windrow composting. Windrows are a simple technology composting method with access to only natural air. It is assumed that all facilities can be considered using windrow composting.

Composting is performed with simple technology in Denmark; this implies that temperature, moisture and aeration are not consistently controlled or regulated. Temperature is measured but not controlled, moisture is regulated by watering the windrows in respect to weather conditions and aeration is assisted by turning the windrows (Petersen & Hansen, 2003).

During composting, a large fraction of the degradable organic carbon (DOC) in the waste material is converted into CO_2. Even though the windrows are occasionally turned to support aeration, anaerobic sections are inevitable and will cause emissions of CH_4. In the same manner, aerobic biological digestion of N leads to emission of N_2O (IPCC, 2006).

Activity data

All Danish waste treatment plants are obligated to statutory registration and reporting of all waste entering and leaving the plants. All waste streams are weighed, categorised with a waste type and a type of treatment and registered to the national waste data system. For 1995-2009, Denmark used the ISAG waste information system, but since 2010, registration of waste data has gone into the ADS reporting system. Activity data for home composting are estimated separately.

Activity data for each composted waste type, for the whole time series, are provided in Annex Table 3F-3.1. As activity data are not available as dry matter, they not reported in the CRF, as the CRF does not allow to report using wet amounts.

Figure 7.3.1 illustrates the composted amount of waste divided in the four categories mentioned earlier.

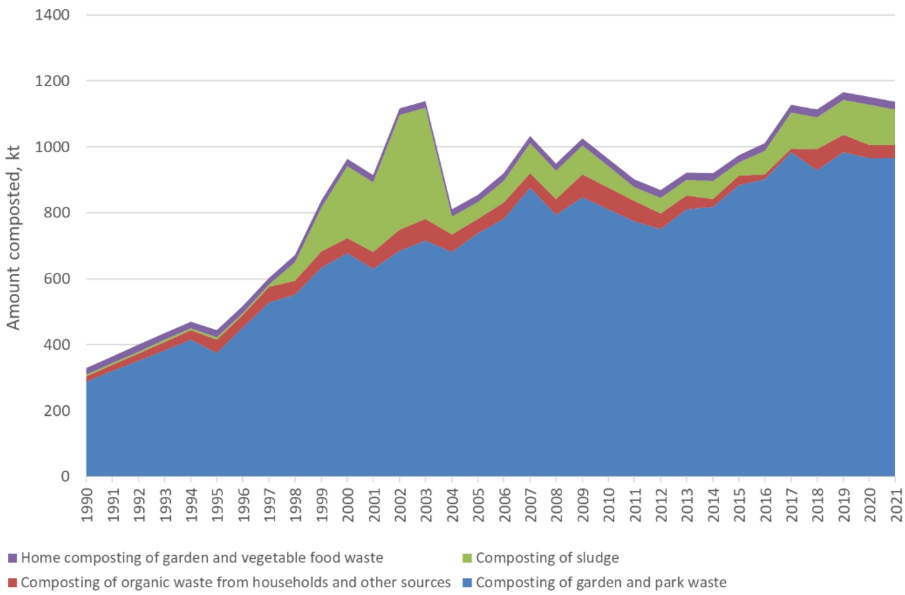

Figure 7.3.1 Trends in the national amount of composted waste.

Activity data for the years 1995-2009 are collected from the Danish waste statistics (DEPA, 2022a) for the categories: GPW, organic waste from households and other sources and sludge. For sludge, activity data are also collected from the waste statistics for 2011-2020 (DEPA, 2022a).

For sludge, activity data in the period 1990-1994 were interpolated based on sludge known to be composted in 1987 (DEPA, 1999). The Danish legislation on sludge (MIM, 2006) was implemented in the summer of 2003. This stated that composted sludge must only be used as a fertilizer on areas not intended for growing foods of any kind for at least 2-3 years. This restriction caused the amount of composted sludge to drop drastically from 2003 to 2004.

The amount of organic waste from households composted in the years 1990-1994 is estimated by multiplying the number of facilities treating this type of waste with the average amount composted per facility in the years 1995-2001 (2.6-3.8 kt per facility per year). The following Table 7.3.2 shows the number of composting sites divided in the three types, where type 1 is mainly receiving source separated organic waste, type 2 receive only garden & park waste, while type 3 receive garden & park waste in combination with other organic waste types (Petersen, 2001 and Petersen & Hansen, 2003).

Table 7.3.2 Number of composting facilities in the years 1990-2001.

Facility type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Type 1	5	6	7	8	9	13	14	13	14	13	11	9
Type 2	38	54	70	86	102	113	108	99	102	111	115	123
Type 3	1	2	2	3	4	9	9	11	10	10	7	10
Total	44	62	79	97	115	136	133	123	130	139	138	142

Type 1 waste treatment sites normally includes biogas-producing facilities, but these have been excluded in Table 7.3.2.

The ISAG activity data for composting of garden and park waste (GPW) include wood chipping. Compost data for GPW provided by Petersen (2001) and Petersen & Hansen (2003) show that for 1997-2001, wood chipping accounts for about 3 % of the total chosen waste statistics activity data for GPW.

Activity data for GPW for the years 1990-1994 are estimated by extrapolating the trend.

Activity data for 2011-2019 for composting of GPW and organic waste are available from DEPA (2022b).

Activity data for 2020-2021 are kept constant on the average 2017-2019 level for GPW and organic waste composting and at the average 2018-2020) level for sludge composting. Activity data for 2010 are interpolated between 2009 and 2011.

The last waste category involved in composting is home composting of garden waste and vegetable waste. The activity data for this category are known from Petersen & Kielland (2003) to be 21.4 kt in 2001. It is assumed that the following estimates made by Petersen & Kielland (2003) are valid for all years in the time series.

- 28 % of all residential buildings with private gardens (including summer cottages) are actively contributing to home composting
- 14 % of all multi-dwelling houses are actively contributing to home composting
- On average, 50 kg waste per year will be composted at every contributing residential building
- On average, 10 kg waste per year will be composted at every contributing multi-dwelling house.

Multi-dwelling houses include apartment buildings. It is quite un-common for people in these types of buildings to compost their bio waste and the average amount of composted waste is therefore lower in spite of the higher number of residents. The total number of occupied residential buildings, summer cottages and multi-dwelling houses are gathered from Statistics Denmark (2022) for the entire time series. The calculated activity data for composting are shown in Table 7.3.3 and in Annex Table 3F-3.2.

Table 7.3.3 Activity data composting, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Composting of garden and park waste	288	376	677	737	811	884	929	983	965	965
Composting of organic waste from households and other sources	16	40	47	45	65	29	64	53	41	41
Composting of sludge	5	7	218	50	65	39	97	106	121	108
Home composting of garden and vegetable food waste	20	21	21	22	23	23	23	23	24	24
Total	329	444	963	854	964	975	1113	1166	1151	1138

Emission factors

The emissions from composting strongly depend on both the composition of the treated waste and on process conditions such as aeration, mechanical agitation, moisture control and temperature pattern (Amlinger et al., 2008).

The emission factors stated in Table 7.3.4 and 7.3.5 are considered the best available for the calculation of Danish emissions from composting and are provided in kg emissions/kt wet weight bio-waste.

Methane emission factors

Table 7.3.4 CH_4 emission factors for composting [kg/t ww].

	Garden and park waste (GPW)	Organic waste from households and other sources	Sludge	Home composting of garden and vegetable food waste
Unit	kg per t	kg per t	kg per t	kg per t
CH_4	3.19	4.00	0.22	4.20
Source	Andersen et al., 2010a	IPCC, 2006	DEPA, 2013b; Kirkeby et al, 2005	Andersen et al., 2010b

The methane emission factors, $EF(CH_4)$, for composting of GPW, sludge and for home composting, are calculated according to equation 7.3.1:

$$EF(CH_4) = E(CH_4\text{-}C) \cdot 16/12 \cdot DOC \cdot f_{degraded} \cdot (1- f_{moisture}) \cdot 1000 \text{ kg/t} \qquad \text{Eq. 7.3.1}$$

where the emissions factor, $EF(CH_4)$, is provided in units of [kg CH_4 per tonne ww bio-waste, $E(CH_4\text{-}C)$ is emissions provided in units of [kg CH_4-C per kg dw degraded C], *DOC* is the content of degradable organic carbon provided in units of [kg DOC per kg dw bio-waste], $f_{degraded}$ is the fraction of *DOC* that are degraded during the composting process and $f_{moisture}$ is the moisture content in composted waste type. *DOC* is quantified as the content of volatile solids (VS) multiplied by the carbon content of the VS.

Garden and park waste

Data from Andersen et al. (2010a) were applied to derive at an $E(CH_4)$ value of 0.027 kg CH_4-C per kg dw degraded C, a DOC value of 0.26 kg DOC per kg dw bio-waste, $f_{degraded}$ equals 0.56 and the dry matter content equals 0.61 kg dw per kg ww; resulting in an $EF(CH_4)$ value of 3.19 kg CH_4 per tonne ww.

Organic waste from households and other sources

For composting of organic waste from households and other sources, the EF value is set equal to the default value of 4 kg CH_4 per tonne ww organic waste (IPCC, 2006, Vol. 5, Chapter 4, Table 4.1).

Sludge

The $E(CH_4)$ value for sludge composting is set equal to 0.003 kg CH_4-C per kg dw degraded C in sludge, which is an average of reported values for composting of anaerobic digested and secondary sludge (Annex 4.6, page 177, DEPA, 2013b).

DOC is derived from reported value on the VS content. DEPA (2013b) provides numbers for loss on ignition (VS) prior to composting in the range of 55 to 70% for anaerobic digested per not digested secondary sludge. As sludge management may consist of anaerobic digestion and composting as post-treatment of the digestate (DANVA, 2009; DEPA, 2013c; Glæsner et al., 2016; Zeng et al., 2016), an average value of 0.625 multiplied by a carbon content of 0.5 result in a *DOC* value 0.313 kg DOC per kg dw sludge. This value is comparable to the reported value of 0.350 kg DOC per kg dw sludge based on an assumption of 70% of loss on ignition (equal to the VS content) and 50% of the VS is carbon (Friedrich et al., 2002; Kirkeby et al., 2005). We applied the highest DOC value of 0.350 kg DOC per kg dw sludge.

The amount of degraded carbon is reported as 50% of *DOC* for anaerobic digested sludge and 65% for secondary (non-digested) sludge. An average value of 0.575 is applied.

The dry matter content of sludge before composting is in the range of 20-30 % and set equal to an average value of 27.5 % for digested and non-digested sludge (Annex 4.6, page 177, DEPA, 2013b). The National waste statistics reports a dry matter content of 33% in sludge applied on agricultural soils (DEPA, 2022a).

As a result, an $EF(CH_4)$ value 0.22 kg CH_4 per tonne ww is applied.

Home composting of garden and vegetable food waste

Values of $E(CH_4\text{-}C)$ for home composting ranges from 0.6 to 4.2 (Table 2 in Andersen et al., 2010b). In the inventory, the highest value reported in Andersen et al. (2010b) is applied in the calculations.

All *DOC* values are within the range of 25-50%, and comparable to the corresponding average value of 0.375 kg DOC per kg dw bio-waste (Table 4.1 in Chapter 4, IPCC, 2006).

The default dry matter content, $1\text{-}f_{moisture}$ for the composted waste is 40% or 0.4 kg dw per kg ww, based on a moisture content of 60% in wet waste (Table 4.1 in Chapter 4, IPCC, 2006). For GPW and sludge, applied values are outside the range provided in the IPCC guidelines; i.e. 0.61 and 0.275 kg dw per kg ww is applied (Andersen et al., 2010a; DEPA, 2013b).

Nitrous oxide emission factors

Table 7.3.5 N_2O emission factors for composting, kg per tonne ww.

	Garden and park waste (GPW)	Organic waste from households and other sources	Sludge	Home composting of garden and vegetable food waste
Unit	kg per t	kg per t	kg per t	kg per t
N_2O	0.23	0.24	0.09	0.20
Source	Boldrin et al., 2009	IPCC, 2006	DEPA, 2013b; Jensen et al., 2015; DEPA, 2001b	Boldrin et al. 2009

Emission factors for nitrous oxide, $EF(N_2O)$, for composting of GPW, sludge and for home composting, are calculated according to equation 7.3.2, while the default IPCC value was applied for composting of organic waste:

$$EF(N_2O) = E(N_2O\text{-}N) \cdot 44/28 \cdot N_{tot} \cdot (1\text{-} f_{moisture}) \cdot 1000 \text{ kg/t} \qquad \text{Eq. 7.3.2}$$

where $EF(N_2O)$ is provided in units of kg N_2O per kg ww bio-waste, $E(N_2O\text{-}N)$ is the emission provided in units of N_2O –N per kg dw total N, 44/28 is the molecular weight ratio between N_2O and N_2, N_{tot} is the total N content in the waste and $f_{moisture}$ is the moisture content in composted waste type.

Garden and park waste

The $EF(N_2O)$ were derived from an $E(N_2O\text{-}N)$ value of 0.012 kg N_2O –N per kg dw total N in central composted GPW (Table 4, Boldrin et al., 2011), a default nitrogen content of 2 % in dry matter, or 0.02 kg total N per kg dw GPW (IPCC, 2006) and a moisture content of 39 %. This results in an emission factors of 0.23 kg N_2O per kg ww.

Organic waste from households and other sources

For composting of organic waste the default value of 0.24 kg N_2O per tonne ww waste is applied (Table 4.1 in Chapter 4, IPCC, 2006).

Sludge

For sludge, emission is reported per total N emission during composting and therefore, the EF value is calculated according to equation 7.3.3

$$EF(N_2O) = E(N_2O) \cdot 44/28 \cdot f_{N\text{-}loss} \cdot N_{tot} \cdot (1 - f_{moisture}) \qquad \text{Eq. 7.3.3}$$

where *EF(N_2O)* is provided in units of kg N_2O per kg ww bio-waste. The *E(N_2O-N)* value is equal to 0.0093 kg N_2O-N per kg N loss, the N-loss set equal to 55 % of the total N content in sludge (DEPA, 2013b). The nitrogen content of sludge, N_{tot}, is equal to 4.3% of the dw sewage sludge; i.e. 0.043 kg N per kg dw sludge (Jensen et al., 2015; DEPA, 2001b). The dry matter content of sludge before composting is in the range of 20-30 % and set equal to an average value of 27.5 % for digested and non-digested sludge (Table 4.6, page 177, DEPA, 2013b).

Home composting of garden and vegetable food waste

As for all waste types, the *E(N_2O-N)* value of 0.0011 kg N_2O-N per kg total N for home composting (Boldrin et al. 2009) is multiplied by 44/28 to provide the emission in units of kg N_2O per kg total N. N_{tot} is set equal to 2 % N per dry matter, 0.02 kg N per kg dw bio-waste, (Table 4.1 in Chapter 4, IPCC, 2006). The dry matter content ($1-f_{moisture}$) in units of kg dw per kg ww is set equal to 0.6 (Boldrin and Christensen, 2010).

Emissions

CH_4 emissions correlates to the pattern in the activity data excluding sludge, this is explained by the minor size of the CH_4 emission factor for sludge compared to the remaining three bio-waste types treated at the Danish composting plants (see Table 7.3.4). The N_2O emissions, however, are explained by the significant increase in the amount of sludge being composted in the period 1999 to 2003 as shown in Figure 7.3.1 (and Annex Table 3F-3.1) and a high N_2O emission factor value for sludge compared to the remaining bio-waste types (Table 7.3.5).

The full time series for emissions related to composting are shown in Annex Table 3F-3.2.

Table 7.3.6 National emissions from composting.

	Unit	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
CH_4	t	1068	1448	2485	2634	2958	3042	3338	3470	3368	3366
N_2O	t	75	101	190	189	212	218	242	253	247	246
CO_2 eqv.	kt	50	67	120	124	139	143	158	164	160	159

The whole time series is visualised in Figure 7.3.2 showing a steady increase in the greenhouse gas emissions.

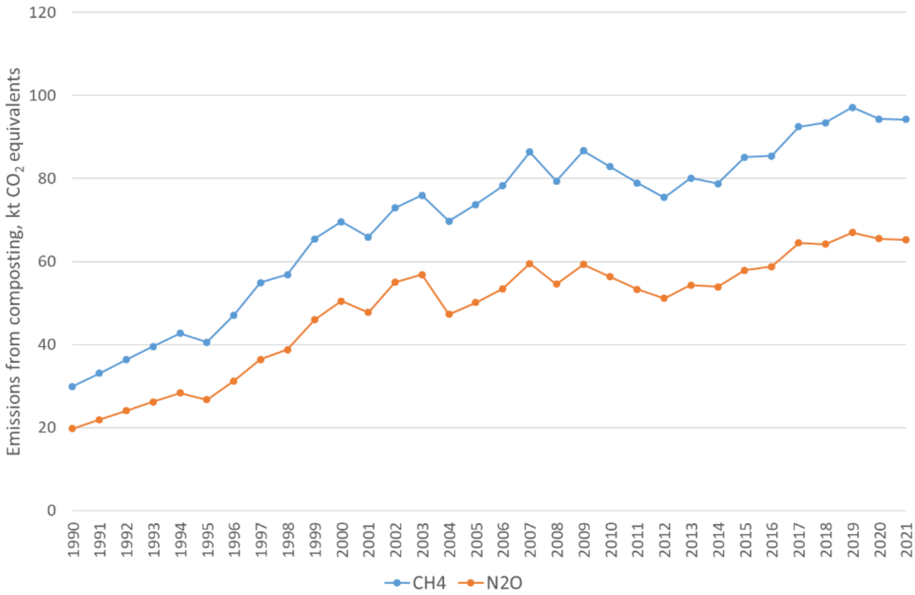

Figure 7.3.2 Time trend for N_2O and CH_4 emissions from composting plants.

For both methane and nitrous oxide emission, garden and park waste (GPW) is the main contributor to emissions from composting, contributing with between 80 % (2002) and 94 % (2017) of GHG emissions.

The emission from composting increases from 50 kt in 1990 to 159 kt CO_2 eq. in 2021; i.e. 221 %.

7.3.2 Anaerobic digestion at biogas plants

Biogas production in this sector covers emissions from the handling of biological waste including garden and park waste, household waste, sludge and manure.

Methodological issues

Methane emission from biogas plants using landfill gas as feedstock is implicitly included in the CRF source category *5.A.1. Managed Waste Disposal Sites*, as the collected biogas is monitored in terms of energy production subtracted from the yearly methane release from SWDS in Denmark (cf. Chapter 7.2).

Methane emissions from sludge-based biogas plants connected to wastewater treatment are included in the CRF category *5.D Wastewater treatment and discharge* (cf. Chapter 7.5).

Emissions from storage of manure are included in the agricultural sector (cf. Chapter 5).

Emissions of CH_4 from biogas plants occur from stacks and ventilation during several stages of the process, e.g. ventilation in the receiving hall of the plant, from the emergency flare and from upgrading units.

Emissions that are more significant occur from leakages in the production equipment and pipelines. These leakages are by nature very variable from plant to plant and as such difficult to quantify at a national level.

The activity data and resulting emissions are estimated according to equation 7.3.4 and shown in Table 7.3.6 below.

$$CH_{4,mbb} = (E : NCV) \cdot EF_{mbb} \qquad \text{Eq. 7.3.4}$$

where $CH_{4,mbb}$ is the methane emission from manure-based biogas, E is energy production included in the annual energy statistics, divided by the net calorific value (NCV) of CH_4 of 50 GJ per tonne (Oiltanking, 2023) and multiplied by the emission factor.

Activity data

The activity data for anaerobic digestion is the energy production from manure based biogas facilities, these are available from the annual energy statistics; DEA (2022). Activity data are presented in Table 7.3.8 below.

Emission factors

The 2006 IPCC Guidelines consider emissions from biogas plants (anaerobic digestion) as part of the waste sector. According to the 2006 IPCC Guidelines, emissions of CH_4 from such facilities due to unintentional leakages during process disturbances or other unexpected events will generally be between 0 and 10 % of the amount of CH_4 generated. In the absence of further information, use 5 percent as a default value for the CH_4 emissions (IPCC, 2006).

A Danish project measured leakages from nine biogas plants in Denmark. The results are reported in DEA (2015). Five of the plants were small farm-based plants while the other four were larger plants. The results were that the CH_4 leakage varied from nil to 10 % of the production. The largest leakage rates were detected for the larger plants. The weighted average for the nine plants was 4.2 % and the adopted emission factor, set equal to 0.042 for 1990-2016 (Eq. 7.3.4).

A voluntary measurement programme was started by the industry in 2017. The voluntary programme consisted of multiple elements including the establishment of own-check programmes, leak detection and quantification of the CH_4 emission (Biogasbranchen, 2019).

In 2019, finances was allocated in the national budget to amongst other things carry out a more comprehensive measuring programme on biogas plants. The programme measured on different types of plants and the results were reported in 2021 (Gudmundsson et al., 2021).

The results are summarised in Table 7.3.7 below.

Table 7.3.7 Results from the measurement programme.

Plant type	Number of plants	Sum measured CH_4 production (kg CH_4/time)	Sum of measured CH_4 emission (kg CH_4/hour)	Emission factor (%)
Large plants	29	26 717	505	1.9 ± 0.3
Single farm plants	15	3246	128	3.9 ± 1.0
Industrial plants	1	467	9	2.0 ± 0.4

The weighted emission factor is 2.1 % for all plants combined.

The measurements cover 64 % of the CH_4 production from these plant types. However, the plants included in the programme did volunteer and hence it cannot be guaranteed that the plants are representative for all plants in Denmark As such, the previously determined emission factor of 4.2 % will be used for the plants not included in the measurement programme.

Therefore, the emission factor used in the inventory from 2020 forward is a weighted emission factor of the plants covered by the measurement programme and the plants not included. For 2020, the weighted emission factor is calculated based on 36 % of the production having an emission factor of 4.2 % and the remaining 64 % having an emission factor of 2.1 % resulting in a weighted emission factor of 2.9 % in 2020 forward.

The attention to the issue of emissions from biogas plants started in 2016/2017 and therefore the emission factor has been interpolated between 2016 (4.2 %) and 2020 (2.9 %) resulting in values of 3.9 %, 3.5 % and 3.2 % for 2017, 2018 and 2019 respectively.

Emissions

Table 7.3.8 an Annex Table 3F-3.3 presents the biogas production and the resulting emissions.

Table 7.3.8 Activity data and emissions from anaerobic digestion of organic waste.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Biogas production, TJ	266	746	1442	2375	3184	5199	12052	15164	19725	24787
CH_4 production, t	5328	14917	28834	47504	63682	103970	241044	303286	394498	495733
CH_4 emission, t	224	627	1211	1995	2675	4367	8437	9705	11440	14376
CO_2 eq emission, kt	6	18	34	56	75	122	236	272	320	403

7.4 Incineration and open burning

The CRF source category *5.C. Incineration and open burning* includes cremation of human bodies and animal carcasses.

Incineration of municipal, industrial, clinical and hazardous waste takes place with energy recovery and therefore the emissions are included in the relevant subsectors under CRF sector 1A. For documentation, please refer to Chapter 3.2. Flaring off-shore and in refineries are included under CRF sector 1B2c, for documentation please refer to Chapter 3.5. No flaring in chemical industry occurs in Denmark.

7.4.1 Emissions

Table 7.4.1 gives an overview of the Danish greenhouse gas emission from the CRF source category *5.C Incineration and open burning* comprised by emission from human and animal cremations. CO_2 emissions from animal and human cremations are considered biogenic.

Table 7.4.1 Methane and nitrous oxide emissions from cremations.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
CH_4 emission from										
Human cremation, t	0.48	0.52	0.49	0.48	0.49	0.51	0.54	0.54	0.55	0.58
Animal cremation, t	0.03	0.04	0.08	0.14	0.26	0.20	0.21	0.20	0.18	0.17
Total, t	0.51	0.55	0.57	0.62	0.76	0.71	0.76	0.75	0.73	0.75
N_2O emission from										
Human cremation, t	0.60	0.64	0.61	0.60	0.62	0.64	0.68	0.68	0.69	0.72
Animal cremation, t	0.03	0.05	0.10	0.17	0.33	0.25	0.26	0.26	0.23	0.21
Total, t	0.64	0.69	0.71	0.77	0.95	0.89	0.95	0.93	0.91	0.93
5C. Waste incineration										
Human cremation, kt CO_2 eqv.	0.17	0.19	0.18	0.17	0.18	0.18	0.20	0.19	0.20	0.21
Animal cremation, kt CO_2 eqv.	0.01	0.01	0.03	0.05	0.09	0.07	0.08	0.07	0.06	0.06
Total, kt CO_2 eqv.	0.18	0.20	0.20	0.22	0.27	0.26	0.27	0.27	0.26	0.27

Emissions from human cremations constitutes 65 % (2010) to 95 % (1990) of the sub-sectoral total CO_2 equivalent emission. The trend in emissions from animal cremations is the most significant with an increase of a factor 5.3 in 2021 compared to 1990. Emissions for the whole time series are provided in Annex Table 3F-4.1.

7.4.2 Human cremation

The incineration of human corpses is a common practice that is performed on an increasing part of the deceased. All Danish crematoria use optimised and controlled cremation facilities with temperatures reaching 800-850 °C, secondary combustion chambers, controlled combustion airflow and regulations for coffin materials.

Methodological issues

During the 1990s, all Danish crematoria were rebuilt to meet new standards. This included installation of secondary combustion chambers and in most cases replacement of old primary combustion chambers (Schleicher et al., 2001). All Danish crematoria are therefore performing controlled incinerations with a good burnout of the gases and a low emission of pollutants.

Following the development of new technology, the emission limit values for crematoria were lowered again in January 2011. These new standards were originally expected from January 2009 but were postponed two years for existing crematoria. Table 7.4.2 shows a comparison of the emission limit values from February 1993 and the new standard limits.

Table 7.4.2 Emission limit values, mg per Nm^3 at 11 % O_2 (Schleicher & Gram, 2008).

Component	Report 2/1993	Standard terms (1/2011)
	Emission limit value mg per normal m^3 at 11 % O_2	
CO	500	500
Other demands:		
Stack height	3 m above rooftop	3 m above rooftop
Temperature in stack	Minimum 150 °C	Minimum 110 °C
Flue gas flow in stack	8 – 20 m/s	No demands
Temperature in after burner	850 °C	800 °C
Residence time in after burner	2 seconds	2 seconds

To meet the new standards, some crematoria have been rebuilt to larger capacity while others are closed (MILIKI, 2006). In 2021, there were 19 operating crematoria in Denmark, some with multiple furnaces. In 2010, there were 31 operating crematoria (DKL, 2022).

Crematoria that are not closed are equipped with flue gas cleaning (bag filters with activated carbon) and use of air pollution control devices. The use of air pollution control devices will however not affect the greenhouse gas emissions.

Around half of the Danish crematoria are currently connected to the district heating system and in addition, a few crematoria produce heat for use in their own buildings. The bag filter cleaning system requires that the flue gas is cooled down to 125-150 °C, and the cheapest way to do so is to use the surplus heat in the district heating system (DKL, 2009). The heat contribution from crematoria is negligible compared to the total district heat production and is not part of the Danish energy statistics. Therefore, it is not included in the Energy sector.

Activity data

Table 7.4.3 shows the time series of total number of nationally deceased persons (Statistics Denmark, 2022), number of cremations and the fraction of cremated corpses in relation to the total number of deceased (DKL, 2022). Annex Table 3F-4.2 presents data for the entire time series 1990-2021.

Table 7.4.3 Activity data for human cremations.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Nationally deceased	60,926	63,127	57,998	54,962	54,368	52,555	55,232	53,958	54,645	57,152
Cremations	40,991	43,847	41,651	40,758	42,050	43,238	46,340	46,126	46,910	48,951
Cremation fraction, %	67.3	69.5	71.8	74.2	77.3	82.3	83.9	85.5	85.8	85.7

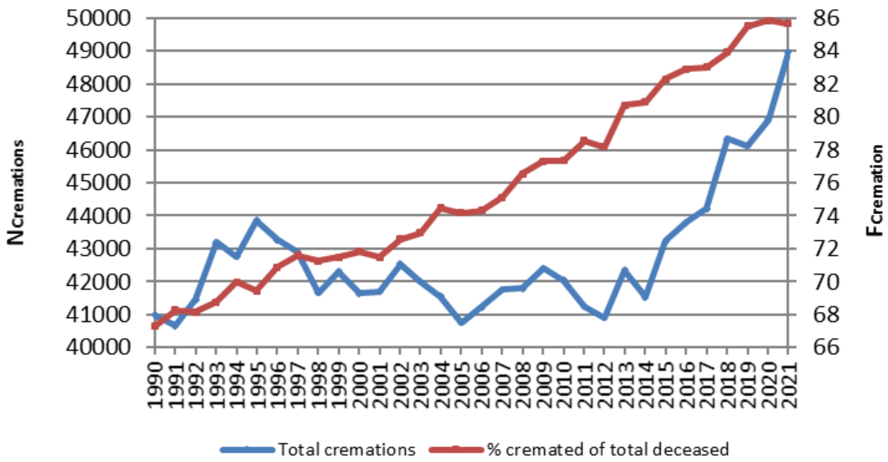

Figure 7.4.1 Visualisation of the development in cremations, where the number of cremation, $N_{cremations,}$ is shown at the left Y-axis. The cremation percentage, $F_{cremations}$, shows the percentage of cremated deceased of the total number of deceased.

Even though the total number of annual cremations is fluctuating, the cremation percentage has been steadily increasing since 1990. The average body weight is assumed to be 65 kg (EEA, 2019).

Figure 7.4.2 presents the trend of the number of deceased persons together with the activity data for human cremation. The figure shows a direct connection between the number of deceased and the activity of human cremation as the two trends are quite similar. Figure 7.4.2 also shows the effect of the increasing fraction of cremations per deceased, as the two lines are nearing each other.

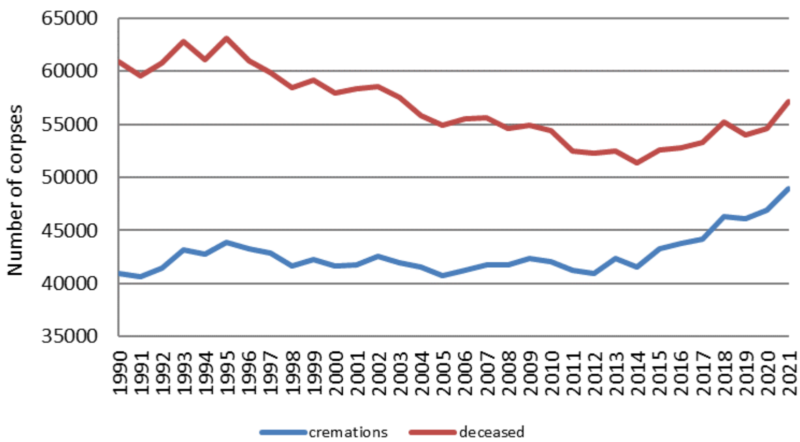

Figure 7.4.2 Trends of the activity data for cremation of human corpses and the national number of deceased persons.

Emission factors

For human cremation, emissions are calculated by multiplying the total number of human cremations by the emission factors. Since there are no continuous measurements available of the annual emission from Danish crematoria, the estimation of emissions is based on emission factors from literature.

A literature search has provided the emission factors shown in Table 7.4.4. It has not been possible to find any additional data to validate the emission factors. It is not clear from the reference, whether the emission factors includes any contribution from the fuel use. However, as the emission factors are originally used in an inventory following the same reporting guidelines, it is assumed that the emission factors only includes the contribution from the corpses and the casket or other storage materials.

Table 7.4.4 Emission factors for human cremation with references.

Pollutant name	Unit	Emission factor	Reference
CH_4	g/body	11.8	Aasestad, 2008
N_2O	g/body	14.7	Aasestad, 2008

7.4.3 Animal cremation

The incineration of animal carcasses in animal crematoria follows much the same procedure as human cremation. Animal crematoria use similar two chambered furnaces and controlled incineration. However, animal carcasses are incinerated in special designed plastic (PE) bags rather than coffins. Emissions from animal cremation are similar to those from human cremation.

Animal cremations are performed in two ways, individually where the owner often pays for receiving the ashes in an urn or collectively, which is most often the case with animal carcasses that are left at the veterinarian.

Methodological issues

Open burning of animal carcasses is illegal in Denmark and is not occurring, and small-scale incinerators are not known to be used at Danish farms. Livestock that is diseased or in other ways unfit for consumption is disposed of through rendering plants. Incineration of livestock carcasses is illegal and these carcasses are therefore commonly used in the production of fat and soap at Daka Bio-industries.

The only animal carcasses that are approved for cremation in Denmark are deceased pets and animals used for experimental purposes, where the incineration must take place at a specialised animal crematorium. There are four animal crematoria in Denmark; one of these is situated at a waste incineration company in northern Jutland called AVV. The specially designed cremation furnaces are at this location connected to the flue gas cleaning equipment of the municipal waste incineration plant with energy recovery and the emission from the cremations are therefore included in the annual inventory from AVV and consequently included under the energy sector in this report. Therefore, only three animal crematoria are included in this section.

Animal by-products are regulated under the EU commission regulation no. 142/2011. This states that animal crematoria must be approved by the authority and comply either with the EU directive (2000/76/EC) (EC, 2000) on waste incineration or with Regulation (EC) No. 1069/2009 (EC, 2009).

The incineration of animal carcasses is, as the incineration of human corpses, performed in special incineration chambers. All Danish animal crematoria have primary combustion chambers with temperatures around 850 ºC and secondary combustion chambers with temperatures around 1100 ºC. The support fuel used at the Danish facilities is natural gas.

Activity data

Activity data for animal cremation are gathered directly from the animal crematoria. There is no national statistics available on the activity from these facilities. The precision of activity data therefore depends on the information provided by the crematoria.

Table 7.4.5 lists the four Danish animal crematoria, their foundation year and provides each crematorium with an id letter.

Table 7.4.5 Animal crematoria in Denmark.

Id	Name of crematorium	Founded in
A	Dansk Dyrekremering ApS	May 2006
B	Ada's Kæledyrskrematorium ApS	Unknown, Has existed for more than 40 years
C	Kæledyrskrematoriet	2006
D	Kæledyrskrematoriet v. Modtage-station Vendsyssel I/S	-

Crematorium D is situated at the AVV municipal waste incineration site and the emissions from this site are, as previously mentioned, included in the annual emission reporting from AVV and consequently included in the energy sector in this report as waste incineration with energy recovery. Therefore, only crematoria A-C are considered in this chapter.

Table 7.4.6 lists the activity data for animal crematoria A-C. Activity data for the entire time series are available in Annex Table 3F-4.3.

Table 7.4.6 Activity data. Source: direct contact with all Danish crematoria.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Total, t	150	200	443	762	1449	1119	1169	1131	995	945

Crematorium B delivered exact annual activity data for the years 1998-2011 and 2013-2021. They were not certain about the founding year but believe to have existed since the early 1980s. Activity data for 1990-1997 and 2012 have therefore been estimated by expert judgement by DCE. It is not possible to extrapolate data back to 1990 because the activity, due to the steep trend line, in this case would become negative.

Emission factors

Concerning the incineration of animal carcasses in animal crematoria there is not much literature to be found.

Emission factors for CH_4 and N_2O are collected from the literature search on human cremation and it is assumed that humans and animals are similar in composition for this purpose. Emission factors from human cremation are recalculated to match the activity data for animal cremation. Table 7.4.7 lists the emission factors and their respective references. As stated in the description of the emission factors for human cremation, it is not clear from the reference, whether a contribution from the fuel has been included.

Table 7.4.7 Emission factors for animal cremation.

Pollutant name	Unit	Emission factor	Reference
CH_4	g/t	182	Aasestad, 2008
N_2O	g/t	226	Aasestad, 2008

7.5 Wastewater treatment and discharge

The Danish wastewater treatment system is characterised by few big and advanced wastewater treatment plants (WWTPs) and many smaller WWTPs. From 1993 to 2020, the amount of wastewater treated at the most advanced technological WWTPs in Denmark has increased from 54 % to above 95 % (DEPA, 1993b and 2021). Improvements of the decentralised wastewater treatment systems as well as the sewer system are on-going in Denmark. For the part of the population, which is not connected to the collective sewer system (i.e. scattered houses), septic sludge is collected and transported for treatment at the centralised WWTPs. Municipal collection of sludge from septic tanks occurs at a frequency set by the local authorities and in general, septic tanks are emptied one time each year.

A presentation of methodological approach, emission factors and activity data are presented in the following sub-chapters.

7.5.1 Source category description

This source category includes an estimation of the emission of CH_4 and N_2O from wastewater handling; i.e. wastewater collection and treatment. CH_4 is produced during anaerobic conditions and treatment processes, while N_2O may be emitted as a by-product from nitrification and denitrification processes under anaerobic as well as aerobic conditions (e.g. Adouani et al., 2010; Kampschreur et al., 2009).

Wastewater streams from households and industries are mixed in the sewer system prior to further treatment at centralised WWTPs. The contribution from the industry to the influent wastewater at the centralised WWTPs has increased from zero in 1987 to around 40 % from 2006 (Table 7.5.4) with the highest influent contribution occurring at the biggest and most advanced technological WWTPs in Denmark (DNA, 2010; Thomsen, 2016).

The number of houses not connected to the sewer system is known from DEPA (2021b) and the total national number is known from Statistics Denmark (2022). From this information, the trend in the fraction of population not connected to the sewer system is calculated. The fraction of the population not connected to the sewer system decreased from 11.5% in 1993 to 7.3% in 2021.

Regarding diffuse emissions from the sewer system, very little data are available (e.g. Lyngby-Taarbæk Kommune, 2014). It is known that centralized wastewater treatment plants are associated with increased residence times, which increases the risk of the occurrence of bottom sediments and thus biological decomposition of organic matter in the sewage system. However. The sewer system is hydraulically designed to prevent the accumulation of bottom sediments and under such conditions, temporary anaerobic processes will be dominated by fermentation and sulphate reduction, which means that the possibility of methane formation may be ignored (DANVA, 2008; DANVA, 2011; Hvitved-Jacobsen, 2001).

The indirect N_2O emissions from separate industries are included, as effluent N-data are available from the National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environments (NOVANA) (DEPA, 2021). The direct N_2O emission from separate industries is calculated by the use of activity data on the amount of N in the effluent wastewater and data on treatment efficiency at industrial wastewater treatment plants. The methodological approach are described in Thomsen (2016) and in chapter 7.5.2.

7.5.2 Methane emission

Fugitive methane emissions from the municipal and private WWTPs have been divided into contributions from 1) the sewer system, primary settling tank and biological N and P removal processes, 2) from anaerobic treatment processes in closed systems with biogas recovery for energy production and 3) septic tanks. The individual contribution to the net methane emission is given in Table 7.5.1, data for the whole time series is provided in Annex Table 3F-5.1.

Table 7.5.1 Produced, recovered and emitted CH_4 from wastewater treatment, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
$CH_{4,\ anaerobic\ digestion,\ gross}$	17.7	23.5	33.3	27.2	27.5	27.4	32.9	31.3	30.8	32.4
$CH_{4,\ recovery}$	9.2	12.0	17.1	18.3	16.8	18.0	22.3	23.1	25.9	25.4
$CH_{4,\ anaerobic\ digestion,\ net}$	0.6	0.8	1.2	1.3	1.2	1.2	1.5	1.6	1.8	1.8
$CH_{4,\ sewers\ +\ MB}$	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
$CH_{4,\ septic\ tanks}$	1.5	1.5	1.5	1.4	1.3	1.2	1.1	1.1	1.1	1.1
$CH_{4,\ total}$	2.4	2.6	2.9	2.9	2.8	2.8	3.0	3.0	3.2	3.1

Regarding the time trend, the net CH_4 emission from anaerobic treatment has increased 177 % from 1990 to 2021, while a less significant increase is observed in the CH_4 emission from the sewer system (incl. mechanical and biological treatment) (12%). Lastly, the CH_4 emission from scattered houses not connected to the collective sewer system has decreased with 28 % reflecting the increase in the number of people connected to the collective sewer system. In total CH_4 emissions quantified as a sum of CH_4 emissions from anaerobic treatment processes, i.e. $CH_{4,\ anaerobic\ digestion,\ net}$, the sewer system, mechanical and biological treatment, i.e. $CH_{4,\ sewers\ +\ MB}$ and scattered houses, i.e. $CH_{4,\ septic\ tanks}$, has increased by 31 % from 1990 to 2021.

7.5.3 Nitrous oxide emission

N_2O formation and releases, both during the treatment processes at the WWTPs and from discharged effluent wastewater, are included.

The emission of N_2O from wastewater handling is calculated as the sum of contributions from wastewater treatment processes at the WWTPs (direct emissions) and from sewage effluents (indirect emissions). The emission from effluent wastewater, i.e. indirect emissions, includes separate industrial discharges, rainwater-conditioned effluents as well as effluents from scattered houses and from aquaculture.

Table 7.5.2 shows the total N_2O emission originating from treatment processes at the Danish WWTPs (direct emissions) and effluents to the Danish surface waters (indirect emissions). The full time series is shown in Annex Table 3F-5.2.

Table 7.5.2 N_2O emissions from wastewater, t.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
N_2O, indirect	200	119	79	55	51	58	45	51	46	46
N_2O, direct, seperate industries	741	408	148	73	56	55	61	39	47	30
N_2O, direct, municipal	194	295	356	426	361	403	400	391	400	402
N_2O, total	1135	822	583	554	468	515	506	482	493	478

Regarding the time trend, the indirect N_2O emission has decreased 77 % from 1990 to 2021, the direct N_2O emission from separate industries has decreased by 96 %, while the direct N_2O emission from municipal wastewater treatment plants has increased by 107 %. The latter is mainly due to the fact that the fraction of industrial wastewater being treated at municipal WWTPs has increased to 40 % during the whole time series. In total, the N_2O emission has decreased 58 % from 1990 to 2021.

7.5.4 Methodology and data

The methodology developed for this submission for estimating emission of methane and nitrous oxide from wastewater handling follows the IPCC Guidelines (IPCC, 2006).

Monitoring data on the influent and effluent resources, i.e. N, P, biological oxygen demand (BOD) and chemical oxygen demand (COD) for the wastewater are available for all WWTPs in Denmark and reported by the Danish Environmental Protection Agency (DEPA), the National Focal Point for point sources. DEPA collects all point source data from the National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environments (NOVANA) (DEPA, 2021). Since the late eighties, annual reports have documented results from the monitoring of point sources; i.e. wastewater treatment plants, industries, rainwater conditioned effluent (storm water), scattered houses, freshwater aquacultures and maricultures.

Data on energy production from Danish wastewater treatment plant with anaerobic sludge digestion are available from the energy statistics (DEA, 2022) and presented in Annex Table 3F-5.1 (Biogas production, TJ). These data do not include any information on venting or flaring, which are however included in the reported gross energy production data (Tafdrup, 2014).

Applied emission factors are presented in Table 7.5.3 below.

Table 7.5.3 Emission factors applied in the Danish inventories for waste water.

Emission factor	Unit	Value	Source
Bo, max. CH_4 producing capacity	kg CH_4/kg COD	0.25	IPCC (2006), V5, C6, Table 6.2
MCF, sewers and plants	-	0.003	Vollertsen (2012)
MCF, anaerobic digester	-	0.8	IPCC (2006) V5, C6, Table 6.3
MCF, septic tanks	-	0.5	IPCC (2006) V5, C6, Table 6.3
CH_4 EF, sewer+MB	kg CH_4/t COD	0.75	Calculated
CH_4 EF, septic tanks	kg CH_4/kg BOD	0.11	Calculated
BOD	g/person/day	62	IPCC (2006), V5, C6, Table 6.4
COD per BOD ratio	-	2.4	IPCC (2006), V5, C6, page 12
DOC_{st}	kg COD/person/yr	54.31	calculated
CH_4 leakage rate at biogas plants	-	6.9%	ENS (2021)
NCV CH_4	MJ/kg	50	Oiltanking (2023)
N_2O EF, direct	t N_2O-N/t N influent	0.0084	DEPA (2020)
N_2O EF, indirect	t N_2O-N/t N influent	0.005	IPCC (2006), V5, C6, page 6.25

Measured data for the methane leakage rate from waste water treatment plants have been obtained from ENS (2021). The leakage rate is 6.9 % of the gross energy production.

The following section is divided into methodological issues related to the CH_4 and N_2O emission calculations, respectively.

Methane emissions from private and municipal WWTPs

The methane emissions from WWTPs are divided into a contribution from the sewer system, primary settling tank and biological N and P removal processes. $CH_{4.\,sewer+MB}$, and from anaerobic treatment processes in closed systems with biogas extraction for energy production, $CH_{4.AD}$.

$$CH_{4,WWTP} = CH_{4,sewer+MB} + CH_{4,AD} \qquad \text{Eq. 7.5.1}$$

Methane emissions from sewer systems

The fugitive emissions from the sewer system, primary settling tank and biological N and P removal processes, $CH_{sewer+MB}$, are estimated as:

$$CH_{4,sewer+MB} = EF_{sewer+MB} \cdot TOW_{inlet}$$
$$\Downarrow \qquad \text{Eq. 7.5.2}$$
$$CH_{4,sewer+MB} = B_o \cdot MCF_{sewer+MB} \cdot TOW_{inlet}$$

where

TOW_{inlet} equals the influent organic degradable matter measured as the chemical oxygen demand (COD) in the influent wastewater flow.

Bo is the default maximum CH_4 producing capacity, i.e. 0.25 kg CH_4 per kg COD (IPCC, 2006).

$MCF_{sewer+MB}$ is the fraction of DOC that is anaerobically converted in sewers and WWTPs. ***$MCF_{sewer+MB}$*** equals 0.003 based on an expert judgement (Vollertsen, 2012) of a conservative estimate of the fugitive methane emission from the primary settling tanks and biological treatment processes is well below 0.1 % of influent COD, while the fugitive emission from the sewer system is judged to be negligible or zero (DANVA, 2008; DANVA, 2011).

The emission factor, $EF_{sewer+MB,}$ for these three processes and systems equals 0.00075 kg CH_4 per kg COD.

Methane emission from anaerobic digestion

The gross methane emission potential from anaerobic processes, $CH_{4.AD.gross}$, is calculated as:

$$CH_{4,AD,gross} = f_{AD} \cdot MCF_{AD} \cdot B_o \cdot TOW_{inlet} \qquad \text{Eq. 7.5.3}$$

where

f_{AD} is the fraction of the COD in the influent wastewater that are conserved in the ingestate set equal to 0.6 (Jensen et al., 2015; DEPA, 2015).

MCF_{AD}, the methane correction factor, adjust the default maximum CH_4 producing capacity or theoretical methane yield to the expected conversion under real operating conditions and is set equal to 0.8 (IPCC, 2006).

TOW_{inlet} equals the influent organic degradable matter measured as the sum of chemical oxygen demand (COD) in the influent wastewater at WWTPs using anaerobic sludge digestion in a digester tank for the production of biogas.

B_o is the default maximum CH_4 producing capacity, i.e. 0.25 kg CH_4 per kg COD (IPCC, 2006). By dividing B_o with the density of methane, i.e. 0.72 kg CH_4 per m^3 t STP (Standard Temperature and Pressure), the theoretical methane yield of 0.35 Nm^3 CH_4 per kg COD is obtained, a value which, as expected, is strongly under matched in real operating conditions (DEA, 2015).

The net methane emission from anaerobic digestion in biogas tanks are at present estimated according to equation 7.5.4:

$$CH_{4,AD,net} = EF_{AD} \cdot CH_{4,AD,recovered} \quad \text{Eq. 7.5.4}$$

where the emission factor, EF_{AD}, has been set equal to 6.9 % (ENS, 2021) of the methane content in the gross energy production at national level reported by the Danish Energy Agency.

At the present stage of verification of activity data, equation 7.5.4 has been applied for estimating the net methane emission from anaerobic digestion of sludge, i.e. the net methane emission from anaerobic digestion equals the methane emissions due to venting (Thomsen, 2016).

Methane emissions from septic tanks

For the part of the population not connected to the collective sewer system, simple decentralised wastewater handling is assumed and modelled as septic tanks. Only little knowledge is available about the frequency of collection and few measurements of the methane emissions from septic tanks and the pumping and management of septate, including its transportation to a wastewater treatment facility exist (Nielsen et al., 2018). The methane emission is calculated as:

$$CH_{4,st} = B_o \cdot MCF_{ST} \cdot f_{nc} \cdot P \cdot DOC_{st} \quad \text{Eq. 7.5.5}$$

$$CH_{4,st} = EF_{st} \cdot f_{nc} \cdot P \cdot DOC_{st}$$

where

f_{nc} is the fraction of the population that is not connected to the sewer system, i.e. scattered houses, which is a time series that steadily decreases from 11.5 % in 1990 to 7.3 % in 2021.

P is the population number.

DOCst is the per capita produced degradable organic matter (DOC) which equals 54.31 kg COD per person per year derived from the default value of 62 g BOD/person/day multiplied by the COD/BOD factor of 2.4 (IPCC, 2006).

The EF_{st} value is equal to $Bo * MCF_{st}$, where the default maximum CH_4 producing capacity, Bo, equals 0.25 kg CH_4 per kg COD (IPCC, 2006) and the methane conversion factor MCF_{st} in earlier NIRs have been set equal 0.5 (IPCC, 2006) assuming that degradation for the settled DOC occurs at 100 % anaerobic conditions. The MCF_{st} value depends on the extent to which COD settles in the septic tanks.

Using the default maximum methane producing capacity, Bo, and a methane conversion factor, MCF_{st}, of 0.5 (IPCC, 2006) results in an emission factor, EF_{st}, equal to 0.125 kg CH_4/kg COD.

However, new measurement have shown that the emission factor value is overestimated (Nielsen et al, 2018; Vollertsen, 2018). From the submission in 2019 an onwards, a country-specific Bo* MCF_{st} has been calculated based on the measured methane emission of 0.695 g CH_4/PE/d (Nielsen et al., 2018), as shown in equation 7.5.6. Based on these measurements, a country-specific emission factor value has been derived as shown below:

$$EF_{st} = \frac{0.695 \text{ g CH}_4\text{/PE/d}}{DOC_{st}} * 10 = 0.047 \frac{\text{kg CH}_4}{\text{kg COD}} \qquad \text{Eq. 7.5.6}$$

where DOC_{st} is set equal to 148.8 g COD/PE/d using the default value of 62 g BOD/person/day (IPCC, 2006) and the default BOD/COD conversion factor of 2.4 (IPCC, 2006).

The country-specific EF_{st} value is derived by applying an uncertainty factor of 10 to account for the fact that the general state of installed septic tanks are of older date and may not be functioning optimal (Vollertsen, 2018). As such, the MCF_{ST}, hence the EF value, is reduced by a factor 2.6 (from 0.125 to 0.047 kg CH_4/kg COD).

Annual activity data and emission factors used for calculation the net methane emission

Monitoring data on the influent BOD and COD are available for mixed industrial and household wastewater, which are used for calculating the total organic waste (TOW) in the influent wastewater. From 1990 to 1997, no BOD or COD data for Danish WWTPs exists. For the years 1998-2014, data on COD and BOD are available.

In the second approach, an average of BOD per COD ratios throughout the time series equal to 2.7 was applied to in place of the default value of Danish monitoring data for BOD and COD. The Danish COD per BOD ratio is on average 2.7 throughout the time series. Based on plant level data on TOW and energy production, the fraction of TOW in units of kt COD at anaerobic WWTPs has been derived. Details on the activity data reported in Thomsen (2016). The time series for activity data on TOW are presented in Table 7.5.4. The full time series is presented in Annex Table 3F-5.3.

Table 7.5.4 Time series for the contribution from industrial wastewater to the influent TOW at Danish wastewater treatment plants, population number, measured BOD and COD data and resulting COD/BOD ratio.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Industrial inlet, %	2.5	22.2	42.0	40.5	40.5	40.5	40.5	40.5	40.5	40.5
Population-estimate (1000)	5135	5216	5330	5411	5535	5660	5781	5806	5823	5840
TOW, kt COD	349	354	382	349	370	387	405	391	388	392
TOW, kt BOD	97	116	149	141	145	168	171	172	173	172
COD/BOD ratio	3.6	3.0	2.6	2.5	2.6	2.3	2.4	2.3	2.2	2.3
$COD_{influent,anaerobic}$ [kt]*	118	157	222	181	183	183	219	209	205	216

*The amount of the influent TOW at Danish WWTP using anaerobic digestion as sludge management strategy.

The TOW data, measured in units of kt COD per year, were used to estimate the fugitive methane emissions from the sewer system, primary settling tank and biological N and P removal processes according to Equation 7.5.2.

For the anaerobic digestion of sludge, the Danish energy statistics were used to quantify the amount of methane lost by venting; i.e. EF_{AD} value of 0.069 (Equation 7.5.4).

For scattered houses, the default IPCC BOD per COD conversion factor of 2.4 was considered most representative, as the average Danish BOD per COD ratio of 2.6 reflects the presence of industrial COD in the influent wastewater at Danish WWTPs (Table 7.5.4).

Overall methane emission time trends

The trends in the CH_4 emission from the Danish WWTPs are summarised in Table 7.5.1, are presented graphically in Figure 7.5.1.

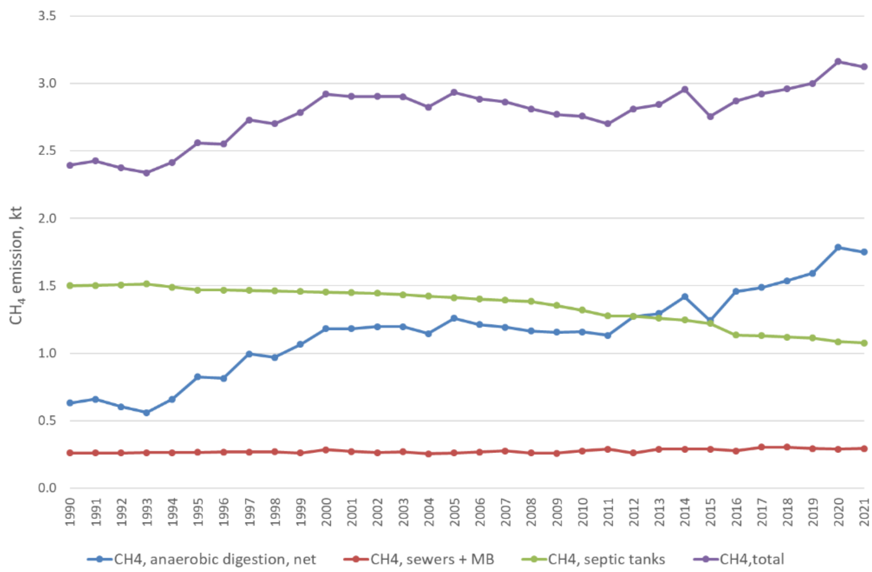

Figure 7.5.1 Time trends for net methane emission, methane emission from sewer systems, mechanical and biological treatment, from septic tanks and from anaerobic treatment processes.

The methane emission due to venting, i.e. $CH_{4.AD.net}$, has increased by 177 % from 1990 to 2021. The methane emission from the sewer system, mechanical and biological treatment, i.e. $CH_{4.sewer+MB}$, has increase by 12 % from 1990 to 2021. The methane emission from scattered houses, i.e. $CH_{4.st}$, has decreased by 28 %.

The total methane emissions, i.e. $CH_{4.total}$, has increased from 2.4 kt in 1990 to 3.1 kt in 2021, corresponding to an increase in the total methane emissions from wastewater handling of 31 %.

N_2O emissions from WWTPs

N_2O may be generated by nitrification (aerobic processes) and denitrification (anaerobic processes) during biological treatment. Starting material in the influent may be urea, ammonia and proteins, which are converted to nitrate by nitrification. Denitrification is an anaerobic biological conversion of nitrate into dinitrogen. N_2O is an intermediate of both processes. A Danish investigation indicates that N_2O is formed during aeration steps in the sludge treatment processes as well as during anaerobic treatments, the former contributing most to the N_2O emissions during sludge treatment (Gejlsbjerg et al., 1999; DEPA, 2015). A review by Kampschreur et al. (2009) documents that around 90 % of the emitted N_2O originates from activated sludge processes. Based on this review an average of two highest EF values, i.e. 0.6 % N_2O (Wicht et al., 1995) and 0.035 % (Czepiel et al., 1995), both reported in units of per cent N load in the influent wastewater, was applied to derive a national emission factor for the direct emission of nitrous oxide of 0.32 % or 0.0032 kg N_2O-N per kg N in the inlet wastewater. The national emission factor value was comparable to earlier reporting's on two WWTPs by Andersen et al. (2010a). However, a newer monitoring campaign running on nine wastewater treatment plants in the period 2018 to 2020, covering a wide range variety of plants in terms of size, nitrogen loading, aeration technology, sludge treatment configuration and reject water handling showed that the Danish emission factor value used until the 2020 inventory submission was underestimated (DEPA, 2020). Since the monitoring campaign is based on a wider amount of data, and its value corresponds with recent studies from the LaGas-project on the biggest WWTP in Denmark (Delre et al., 2017), the newly documented direct N_2O emission factor of 0.0084 kg N_2O-N per kg T-N_{inlet} (DEPA, 2020) was applied from the 2021 inventory submission.

Direct N_2O emission from wastewater treatment

The direct N_2O emission from wastewater treatment processes is calculated according to Equation 7.5.6:

$$E_{N_2O} = EF_{N_2O,direct} \cdot m_{N,\inf luent} \cdot \frac{M_{N_2O}}{2 \cdot M_N} \qquad \text{Eq. 7.5.6}$$

where

$\boldsymbol{EF_{N2O.direct}}$ is equal to a fraction of 0.0084 of the N load in the influent wastewater.

$\boldsymbol{m_{N.influent}}$ is the annually reported N load in the Danish Water Quality Parameter Database provided in Table 7.5.5.

$\boldsymbol{M_{N2O}/M_{N2}}$ is the mass ratio i.e. 44/28 to convert the fraction of N emitted as nitrous oxide from total N.

The country-specific emission factor value of 0.0084 kg N_2O-N per kg T-N_{inlet} (DEPA, 2020) may be expressed as $\boldsymbol{EF_{N2O.direct}}$ = 13.2 g N_2O per kg N load in the influent wastewater by reducing Equation 7.5.6 to:

$$E_{N_2O} = EF_{N_2O,direct} \cdot m_{N,\inf luent} \qquad \text{Eq. 7.5.7}$$

The methodology adopted for estimating the direct N_2O emission only relies on the influent N load as activity data.

Indirect N_2O emission from wastewater treatment

The indirect N_2O emission from WWTPs is calculated according to Equation 7.5.8:

$$E_{N_2O,WWTP,effluent} = D_{N,WWTP} \cdot EF_{N_2O,WWTP,effluent} \cdot \frac{M_{N_2O}}{2 \cdot M_N} \qquad \text{Eq. 7.5.8}$$

where

$D_{N.WWTP}$ is the effluent discharged sewage nitrogen load consisting of contributions from municipal wastewater treatment plants, the separate industry, effluent from aquaculture, rainwater conditioned effluents and scattered houses not connected to the sewage system (cf. Table 7.5.5).

$EF_{N2O.WWTP.effluent}$ is the IPCC default emission factor of 0.005 kg N_2O-N per kg sewage-N produced (IPCC, 2006).

M_{N2O}/M_{N2} is the mass ratio i.e. 44/28 to convert the fraction of discharged N emitted as nitrous oxide from total N.

Annual activity data and emission factors for calculating the nitrous oxide emission

Data on the N content in the influent and effluent wastewater flows are provided in Table 7.5.5. The effluent data provided in the table constitute a sum of the N content in effluent wastewater from municipal wastewater treatment plants, the separate industry, effluent from aquaculture, rainwater conditioned effluents and scattered houses. For the entire time series cf. Annex Table 3F-5.4.

Table 7.5.5 Nitrogen content in the influent and effluent wastewater, t

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Influent, Municipal WWTPs	14,679	22,340	26,952	32,288	27,357	30,509	30,288	29,629	30,301	30,450
Influent, Industrial WWTPs	56,100	30,888	11,225	5,513	4,225	4,141	4,636	2,978	3,533	2,302
Effluent wastewater from WWTPs	16,555	8,938	4,654	3,831	3,578	3,705	3,127	3,654	3,245	3,327
Effluent wastewater, total[1]	25,504	15,152	10,008	7,038	6,513	7,359	5,745	6,520	5,879	5,823

[1]Effluent wastewater, total includes discharges from the separate industry, rainwater conditioned effluent, scattered houses, aquaculture farming and effluents from WWTPs (DEPA, 2021).

The reduction of N in the effluent wastewater from Danish WWTPs compared to in influent wastewater has increased from a reduction efficiency of 30 % in 1990 to a reduction efficiency of 88 % in 2016 (DEPA, 2021). The significant reduction in the effluent wastewater content of nitrogen has been a driver for the increasing direct N_2O emission from WWTPs. However, emerging wastewater treatment technologies may cause an increased N capture in the sludge (Kristensen & Jørgensen, 2008; DEPA, 2015).

The influent N load at industrial WWTPs not collected to the collective sewer systems were estimated from reported N in the effluents from separate industries and knowledge of an N reduction efficiency of 92 % for industrial WWTPs (Thomsen, 2016).

Overall nitrous oxide emission trends

The trends in the direct N_2O emission from WWTPs, the indirect emission from wastewater effluent and the total nitrous oxide emissions, as summarised in Table 7.5.5, are presented graphically in Figure 7.5.2.

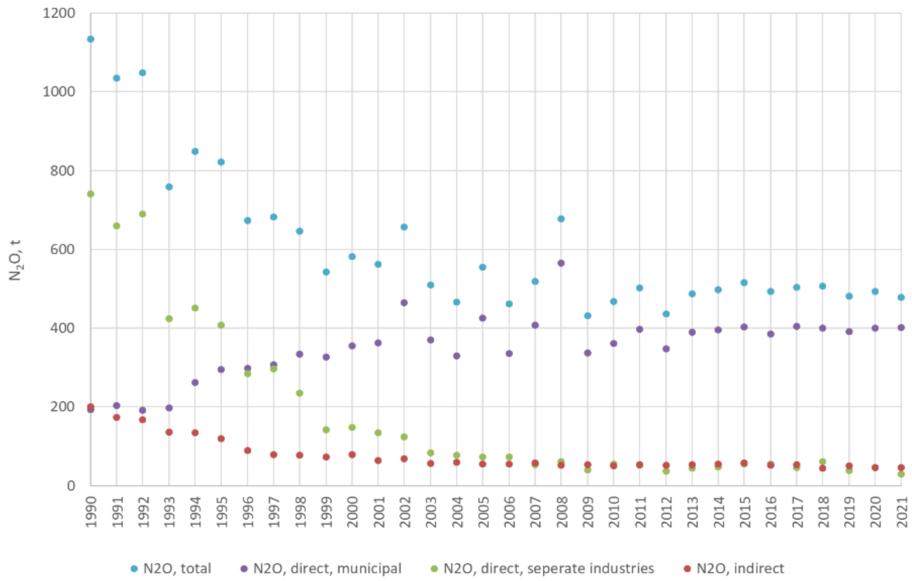

Figure 7.5.2 Time trends for the direct and indirect emission of N_2O (from wastewater effluents) and total N_2O emission.

The annual fluctuations may be caused by several factors, e.g. climatic condition such as variations in precipitation and as a result varying contributions to the influent N and varying characteristics of especially the industrial contributions to the influent. Furthermore, infiltration of groundwater, as well as exfiltration of overload rainwater and wastewater (DEPA, 2021 and Vollertsen et al., 2002), may contribute to the "noise" or fluctuation in the trend of the calculated N_2O emission.

The total N_2O emission shows a decreasing trend from 1135 tonnes in 1990 to 478 tonnes in 2021. Comparing 2021 with the base year 1990, a decrease of 58 % is observed. This trend reflects the sum of indirect N_2O emissions and direct N_2O emissions from municipal and industrial WWTPs.

The direct N_2O emissions from municipal WWTPs are increasing from 194 tonnes in 1990 to 402 tonnes N_2O in 2021 (+107 %), while the direct N_2O emissions from industrial WWTPs are decreasing from 741 tonnes in 1990 to 30 tonnes in 2021 (-96 %). The opposite trends for direct N_2O emissions from industrial WWTPs is partly explained by an increase in the number of industrial WWTPs connected to the collective sewer system as reflected by the increased per cent contribution form industries to the influent wastewater at municipal WWTPs (Table 7.5.4 and Annex Table 3F-5.3). In sum a decrease in the direct N_2O emissions of 54 % is observed in 2021 compared to 1990.

The decrease in the emission from effluent wastewater is due to the technical upgrade and centralisation of the Danish WWTPs following the adoption of the Action Plan on the Aquatic Environment in 1987. The indirect emission from wastewater effluent has decreased from 200 tonnes N_2O in 1990 to 46 tonnes N_2O in 2021 corresponding to a reduction of 77 %.

The direct emission is the major contributor to the emission of nitrous oxide from wastewater treatment and discharge, contributing with between 82 % and 92 % of total N_2O emission from this sub-sector.

7.6 Other

The CRF category *5.E Other* is comprised by the subcategory accidental fires grouped into accidental building fires and accidental vehicle fires as presented in sub-chapter 7.6.1 and 7.6.2. Greenhouse gasses that are estimated from these processes are CH_4 and CO_2 as presented in Table 7.6.1. No emission factors are available for N_2O, wherefore N_2O is reported as Not Estimated in the CRF tables. The full time series for emissions related to accidental fires are shown in Annex Table 3F-6.1.

Table 7.6.1 Overall emission of greenhouse gasses from accidental fires.

		1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Non-biogenic CO_2 emission from											
Accidental building fires	kt	15.8	18.1	15.9	15.3	16.1	16.5	18.2	16.7	16.6	15.2
Accidental vehicle fires	kt	6.0	6.2	6.3	6.2	6.9	5.1	6.3	6.3	6.3	6.4
Total non-biogenic CO_2	kt	21.8	24.3	22.2	21.6	23.1	21.6	24.5	23.0	23.0	21.6
CH_4 emission from											
Accidental building fires	t	96.4	110.7	97.2	93.7	100.1	98.8	109.4	99.5	99.7	91.1
Accidental vehicle fires	t	12.5	12.9	13.0	13.0	14.4	10.7	13.1	13.1	13.2	13.3
Total CH_4	t	108.9	123.5	110.3	106.7	114.5	109.4	122.4	112.6	112.9	104.4
Total 5.E Other											
Total CO_2-eqvivalents	kt	24.8	27.7	25.2	24.5	26.3	24.6	27.9	26.2	26.1	24.5

7.6.1 Accidental building fires

Emissions estimated from building fires are CO_2 and CH_4.

Methodological issues

Emissions from building fires are calculated by multiplying the number of building fires with selected emission factors. Six types of buildings are distinguished with different emission factors: detached house, undetached houses, apartment buildings, industrial buildings, additional buildings and containers.

Activity data

In January 2005, it became mandatory for the local authorities to register every rescue assignment in the online data registration- and reporting system called ODIN (www.odin.dk). ODIN is developed and run by the Danish Emergency Management Agency (DEMA, 2007).

Activity data for accidental building fires are given by ODIN (DEMA, 2022). Fires are classified in four categories: full, large, medium and small. The emission factors comply for full-scale fires and the activity data are therefore recalculated as a full-scale equivalent where it is assumed that a full, large, medium and a small scale fire leads to 100 %, 75 %, 30 % and 5 % of a full-scale fire, respectively.

In practice, a full-scale fire is defined as a fire where more than three firehoses were needed for extinguishing the fire. A full-scale fire is considered as a complete burnout. A large fire is in this context defined as a fire that involves the use of two or three fire hoses for fire extinguishing and is assumed to typically involve the majority of a house, an apartment, or at least part of an industrial complex. A medium size fire is in this context defined as a fire involving the use of only one fire hose for firefighting and will typically involve a part of a single room in an apartment or house. A small size fire is in this context, defined as a fire that was extinguished before the arrival of the fire service, extinguished by small tools or a chimney fire.

The total number of registered fires is known for the years 1989-2022. For the years 2007-2022, the total number of registered building fires is known with a very high degree of detail based on information given in the yearly statistic reports (DEMA, 2022).

Table 7.6.2 shows the occurrence of all types of fires (registered for 1990-2021) and the occurrence of building fires (2007-2021) registered at DEMA. In 2007-2011, the average per cent of building fires, in relation to all fires, was 40 %. The total numbers of building fires 1990-2006 are calculated using this percentage. The full time series is presented in Annex Table 3F-6.2.

Table 7.6.2 Occurrence of all fires and building fires.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
All fires	17,025	19,543	17,174	16,551	16,802	12,777	15,132	12,670	12,538	13,447
Building fires	6,832	7,842	6,891	6,641	7,094	6,245	7,193	6,436	6,534	6,721

The building fires that occurred in the years 2007-2021 are subcategorised into five building types; detached houses, undetached houses, apartment buildings, industrial buildings and additional buildings and in sizes. The average distribution of subcategories and sizes for 2007-2011 are used to estimate the distribution of building fires in 1990-2006. These are shown in Table 7.6.3a.

Table 7.6.3a Average of registered occurrence of building fires, 2007-2011, %. (DEMA, 2022).

Type		Size	
Detached	41	Full	8
Undetached	19	Large	21
Apartment	25	Medium	40
Industry	14	Small	31
Additional	1		

For 2008-2016, the number and sizes of container fires is known. For the years 1980-2007 the number of container fires are based on the average share of all fires for 2008-2011 and for the years 2017-2021 the number is based on the average share of all fires for 2012-2016. In Table 7.6.3b are shown the average share and sizes of container fires for 2008-2011 and 2012-2016.

Table 7.6.3b Average of registered occurrence of container fires, 2008-2011 and 2012-2016, %. (DEMA, 2017).

	Average 2008-2011, %	Average 2012-2016, %
Share of all fires	11.1	8.8
Size:		
Full	0	0
Large	8	11
Medium	84	77
Small	8	12

By applying the damage rates of 100 %, 75 %, 30 % and 5 % corresponding to the damage sizes of full, large, medium and small, a full-scale equivalent can be determined. Table 7.6.4 shows the calculated full-scale equivalents (FSE). The whole time series is shown in Annex Table 3F-6.3.

Table 7.6.4 Number of accidental building fires full-scale equivalent activity data.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Detached house fires	1065	1223	1075	1036	1185	920	1019	907	945	889
Undetached house fires	480	551	484	467	447	398	286	226	242	218
Apartment building fires	726	833	732	706	726	635	1055	885	899	748
Industry building fire	409	470	413	398	408	662	699	702	660	614
Additional building fires	35	40	35	34	25	14	36	36	37	25
Container fires	593	681	598	577	513	331	426	356	353	331

Emission factors

For building fires, emissions are calculated by multiplying the number of full-scale equivalent fires with the emission factors. The emission factors are produced from different measurements and assumptions from literature and expert judgements. When possible, emission factors are chosen that represent conditions that are comparable to Denmark. By comparable is meant countries that have similar building traditions, with respect to the materials used in building structure and interior.

In the process of selecting the best available emission factors for the calculation of the emissions from Danish accidental building fires, a range of different sources has been studied. Unfortunately, it is difficult to perform an interrelated comparison of the different sources because they all establish emission factors on different assumptions and many of these assumptions are not fully accounted for.

Table 7.6.5 lists the emission factors that were chosen as the best reliable and their respective references.

Table 7.6.5 Average emission factors for building fires, per FSE fire. Used for all years.

Compound	Unit /fire	Detached house	Undetached house	Apartment building	Industrial building	Additional building	Container	Reference
CO_2 - total	t	31.3	25.7	14.9	78.1	3.9	1.8	Blomqvist et al., 2002
CO_2 - biogenic	t	25.5	21.0	12.1	67.6	3.2	0.2	Blomqvist et al., 2002
CO_2 - non-biogenic	t	5.8	4.8	2.8	10.5	0.7	1.7	Blomqvist et al., 2002
CH_4	kg	41.5	34.1	19.7	52.0	2.1	0.3*	NAEI, 2009
N_2O		NAV	NAV	NAV	NAV	NAV	NAV	

*Container fires have a different source of CH_4 emission factor than the other five categories. Blomqvist et al. 2002.

Emission factors for detached, undetached and apartment fires depend on the average floor space in 1990 to 2014 (cf. Table 7.6.6). The average emission factors is used for all years. Industrial, additional and container fires on the other hand are assumed to have a constant size/volume throughout the time series. Emission factors for detached, undetached and apartment fires for 1990-2014 are shown in Annex Table 3F-6.4a-c.

Emission factors from Aasestad (2008) are already specified for four of the six building types, detached houses, undetached houses, apartment buildings and industrial buildings (Aasestad. 2008) and all other sources considered were altered to match the six building types. This alternation was performed simply by adjusting the average floor space for each of the building types respectively, whereas factors like loss rate and mass of combustible contents per area are not altered.

The average floor space in Danish buildings is stated in Table 7.6.6. The data are collected from Statistics Denmark and takes into account possible multiple building floors but not attics and basements. For the whole time series see Annex Table 3F-6.5. The average floor space in industrial buildings, schools etc. is estimated to 500 square meters for all years and the average floor space for additional buildings, sheds etc. is estimated to 20 square meters for all years.

Table 7.6.6 The average floor space in Danish buildings (square metre).

	1990	1995	2000	2010	2011	2012	2013	2014
Detached houses	156	155	156	163	164	165	165	165
Undetached houses	129	129	131	134	132	134	133	133
Apartment buildings	75	75	75	77	78	78	78	78

Some emission factors are delivered in mass emission per mass burned. In order to connect these emission factors to the activity data, the total combustible building masses are estimated using the data from Table 7.6.7.

Table 7.6.7 Building mass per building type.

	Unit	Detached house	Undetached house	Apartment building	Industry building	Additional building	Container
Average floor area*	m^2	167	132	78	500	20	-
Building mass per floor area	kg per m^2	40	40	35	30	30	-
Total building mass	t per fire	6.7	5.4	2.7	15.0	0.6	1

* 2014 numbers.

Emission factors for container fires cannot be calculated based on an average floor space but on an average mass. The average mass of a container is set to 1 t and covers all types of containers, from small residential garbage containers to large shipping containers and waste/goods in storage piles.

For more information on the emission factors, please refer to Hjelgaard (2013).

7.6.2 Accidental vehicle fires

Emissions estimated from vehicle fires are CO_2 and CH_4.

Methodological issues

Emissions from vehicle fires are calculated by multiplying the mass of vehicle fires with selected emission factors. Emission factors are not available for different vehicle types, whereas it is assumed that all the different vehicle types leads to similar emissions. The activity data are calculated as an annual combusted mass by multiplying the number of different full scale vehicle fires with the Danish registered average weight of the given vehicle type.

Activity data

DEMA (2017) provides very detailed data for 2008-2016 for passenger cars and heavy duty vehicles. For buses, light duty vehicles (vans and motor homes), motorcycles/mopeds, other transport, caravans, trains, boats, airplanes, bicycles, tractors, combine harvesters and machines detailed data are available for 2008-2012. The remaining years are for all vehicle categories estimated by using surrogate data.

Table 7.6.8 shows the occurrence of fires in general and vehicle fires registered at DEMA. Between 2008 and 2012, the average per cent of vehicle fires, in relation to all fires, was 20 %. The total numbers of vehicle fires in 1990-2007 and 2013-2021 are calculated using this percentage. The full time series is presented in Annex Table 3F-6.6.

Table 7.6.8 Occurrence of all fires* and vehicle fires**.

	1990	1995	2000	2005	2010	2015	2019	2020	2021
All fires	17 025	19 543	17 174	16 551	16 802	12 777	12 670	12 538	13 447
Vehicle fires	3 428	3 936	3 458	3 333	3 454	2 573	2 551	2 525	2 708

*(DEMA, 2022).
**(DEMA, 2017).

There are fourteen different vehicle categories. The activity data are categorised in passenger cars (lighter than 3500 kg), buses, light duty vehicles (vans and motor homes), heavy duty vehicles (trucks and tankers), motorcycles/mopeds, other transport, caravans, trains, boats, airplanes, bicycles, tractors, combine harvesters and machines.

In the same manner as accidental building fires, the 2008-2016 data from DEMA can be divided in four categories according to damage size. It is assumed that a full-scale fire is a complete burnout of the given vehicle, and that a large, medium and small-scale fire corresponds to 75 %, 30 % and 5 % of a full-scale fire respectively. The total number of full-scale equivalent (FSE) fires can be calculated for passenger cars and heavy duty vehicles for 2008-2016 and other vehicle categories for 2008-2012.

The total number of registered vehicles is known from Jensen et al. (2013) and Statistics Denmark (2022). By assuming that the share of vehicle fires in relation to the total number of registered vehicles, of every category respectively, can be counted as constant, the number of vehicle fires is estimated for the years 1980-2007 and 2017-2021 for passenger cars and heavy duty and 2013-2021 other vehicles.

Table 7.6.9 states the total number of national registered vehicles and the number of full-scale equivalent vehicle fires. The whole time series 1990-2021 is shown in Annex Table 3F-6.6.

Table 7.6.9 Number of nationally registered vehicles and full-scale equivalent vehicle fires.

	Passenger Cars		Buses		Light Duty Vehicles		Heavy Duty Vehicles	
	Registered	FSE fires	Registered	FSE fires	Registered	FSE fires	Registered	FSE fires
1990	1 590 345	437	8 109	10	247 563	21	45 678	55
1995	1 675 432	460	14 371	18	286 049	24	48 085	58
2000	1 853 403	509	15 051	19	335 670	28	50 227	61
2005	1 964 057	540	15 132	19	421 019	35	49 311	59
2010	2 147 178	726	14 781	23	447 722	38	45 632	60
2015	2 392 282	454	12 438	16	395 397	33	41 369	38
2019	2 653 640	729	11 557	15	379 871	31	42 445	51
2020	2 725 313	749	10 973	14	376 128	31	42 131	51
2021	2 788 299	766	10 940	14	373 185	31	43 095	52

Continued

	Motorcycles/Mopeds		Caravans		Train		Ship	
	Registered	FSE fires	Registered	FSE fires	Registered	FSE fires	Registered	FSE fires
1990	164 111	55	86 257	22	7 156	8	2 324	25
1995	166 137	55	95 831	25	6 854	7	1 911	20
2000	233 711	78	106 935	28	4 907	5	1 759	19
2005	274 258	91	121 350	32	3 195	3	1 792	19
2010	304 717	83	142 354	37	2 740	2	1 773	16
2015	286 621	95	139 654	36	3 642	4	1 742	19
2019	261 536	87	127 705	33	3 179	3	1 721	18
2020	263 041	87	124 399	32	3 234	3	1 727	18
2021	262 356	87	121 672	32	3 218	3	1 852	20

Continued

	Airplane		Tractor		Combined Harvester		Bicycle	Other transport	Machine
	Registered	FSE fires	Registered	FSE fires	Registered	FSE fires	FSE fires	FSE fires	FSE fires
1990	1 055	1	162 760	108	35 118	58			
1995	1 058	1	151 233	100	29 291	48			
2000	1 070	1	123 432	82	24 128	40			
2005	1 073	1	105 208	70	21 436	35			
2010	1 155	1	95 374	77	16 451	32	4	58	94
2015	1 064	1	89 398	59	12 467	21			
2019	1 008	1	82 716	55	10 475	17			
2020	1 007	1	80 636	53	9 977	16			
2021	1 015	1	78 900	52	9 675	16			

The average weights of a passenger car, bus, light commercial vehicle, truck and motorcycle/moped are known for every year back to 1993 (Statistics Denmark, 2022). The corresponding weights from 1990 to 1992 and the average weight of the units from the remaining categories are estimated by an expert judgment (see Table 7.6.10 and Annex Table 3F-6.7).

Table 7.6.10 Average weight of different vehicle categories, kg.

Year	Cars	Buses	Vans	Trucks	Motorcycles/Mopeds
1990	850	10.000	2.000	15.000	87
1995	923	8.938	2.338	14.855	97
2000	999	9.062	2.479	15.041	103
2005	1.068	9.171	2.524	14.598	116
2010	1.144	9.160	2.517	13.902	133
2015	1.158	9.698	2.502	16.303	143
2019	1.171	9.920	2.539	16.646	156
2020	1 178	9 973	2 558	16 773	158
2021	1 189	10022	2 578	16 933	160

It is assumed that the average weight of a boat equals that of a bus. That tractors and vans weigh the same and that trains, airplanes and combine harvesters have the same average weight as trucks.

Bicycles, machines and other transport can only be calculated for the years 2007-2012 due to the lack of surrogate data (number of nationally registered vehicles). The average weight of a bicycle, caravan, machine and other transport is estimated as 12 kg, 90 % of a car, 50 % of a car and 40 % of a car respectively.

By multiplying the number of full-scale fires with the average weight of the vehicles respectively, the total amount of combusted vehicle mass can be calculated. The result is shown in Table 7.6.11 and in Annex Table 3F-6.8.

Table 7.6.11 Burnt mass of different vehicle categories, tonnes.

Vehicle category	1990	1995	2000	2005	2010	2015	2019	2020	2021
Passenger cars	371	425	509	577	830	526	854	882	911
Buses	102	161	171	174	207	152	144	138	138
Light duty vehicles	41	55	69	88	96	82	80	80	79
Heavy duty vehicles	825	860	910	867	828	621	851	851	865
Motorcycle. moped	5	5	8	11	11	14	14	14	14
Other transport	0	0	0	0	33	0	0	0	0
Caravan	29	35	42	51	63	63	58	57	34
Train	113	107	78	49	28	63	56	57	57
Ship	247	182	170	175	147	180	182	183	187
Airplane	9	9	9	9	8	10	10	10	10
Bicycle	0	0	0	0	0	0	0	0	0
Tractor	216	234	203	176	194	148	139	137	135
Combine harvester	550	495	438	416	398	273	239	230	220
Machine	0	0	0	0	43	0	0	0	0
Total	2 509	2 570	2 606	2 592	2 885	2 131	2 626	2 639	2 650

Emission factors

In the process of selecting the most reliable emission factors for the calculation of the emissions from Danish vehicle fires, a range of different sources have been studied. Unfortunately, it is difficult to make an interrelated comparison of the different sources because they all establish emission factors on different assumptions and many of these assumptions are not fully accounted for. Table 7.6.12 lists the accepted emission factors and their respective references.

Table 7.6.12 Emission factors for vehicle fires, per tonnes.

	Unit	Emission factor	Source
CO_2	t	2.4	Lönnermark et al. (2006)
CH_4	kg	5	NAEI (2009)
N_2O	-	NAV	-

NAV = not available

7.7 Uncertainties and time series consistency

The uncertainty models follow the methodology in the IPCC Guidelines (IPCC, 2006). Tier 1 is based on the simplified uncertainty analysis.

7.7.1 Input data

Solid Waste Disposal

The waste amounts for solid waste disposal are registered in a national database held by the Danish EPA and assessed to be of high quality resulting in the adoption of an uncertainty for reported waste amounts of 10 %.

Input parameter uncertainties for SWDS considered in the Tier 1 uncertainty analysis are based on the IPCC (IPCC 2006, Vol. 5, Chap. 3, Table 3.5) default values and provided in Table 7.7.1.

Table 7.7.1 Tier 1 input parameter uncertainty, %.

Parameter	Parameter ID	Uncertainty %
The Waste amount sent to SWDS	*W*	10
Degradable Organic Carbon	DOC_i	20
Fraction of DOC dissimilated	DOC_f	20
Methane Correction Factor	*MCF*	10
Fraction of CH_4 in landfill gas		**5**
Methane Generation Rate Constant	*k*	100

Based on the uncertain range provided in IPCC (2016, Vol. 5, Chap. 3, Table 3.4), a simple standard deviation assuming normal probability distribution of the half-live times was calculated. The standard deviation of $t_{½}$ was transformed into k-values using eq. 7.2.3, resulting in an uncertainty range for the methane generation constants, k, of -71 % to +166 %. For the Tier 1 uncertainty calculation the uncertainty of k were kept at 100 %. For the remaining parameters, default uncertainties are used. The uncertainty on the implied emission factor, U_{ief}, is based on uncertainty estimates in Table 7.7.1 and is approximated with IPCC (2006, Vol. 3, Chap. 3, Equation 3.1) equals

$$U_{ief}\ \% = \sqrt{20^2 + 20^2 + 10^2 + 5^2 + 100^2} = 104.5\ \%$$

These uncertainties give the combined Tier 1 uncertainty on the emission from SWDS of:

$$U_{total} = \sqrt{10^2 + 104.5^2} = 105\ \%$$

In addition, the average and standard deviation of the half-life times and DOC values and remaining input parameters in Table 7.7.2 (except for the deposited amounts of waste) were derived from the 2006 IPCC guidelines (Chap. 3, Table 3.4 and Chap. 2, Table 2.4) assuming a normal distribution. A Monte Carlo calculation based on random selected values for each of the input parameters within defined 95 % confidence interval uncertainty ranges were run 1000 times returning resulting implied emission factor- and net CH_4 emission values for 1990 and 2017 (Nielsen et al, 2019). The resulting uncertainty of the implied emission factor is 24 % in 1990 and 26 % in 2017 indicating that the Tier 1 uncertainty of the implied emission factor is rather conservative.

Biological treatment of Solid waste - Composting

Table 7.7.2 lists the 95 % confidence interval uncertainties for activity data and emission factors used in this inventory and at the present level of available information. The uncertainties are assumed valid for all years 1990-2021.

Table 7.7.2 Estimated uncertainty rates for activity data and emission factors, %.

95 % confidence interval uncertainties	CO_2	CH_4	N_2O
5.B.1 Composting			
Activity data	-	20	20
Emission factor	-	100	100
5.B.2 Biogas production			
Activity data		5	
Emission factor		20	

Waste Incineration

The uncertainty of the number of human cremations is miniscule, however for the purpose of uncertainty calculation it has been set to 1 %. Table 7.7.3 lists the 95 % confidence interval uncertainties for activity data and emission factors used in this inventory and at the present level of available information.

Table 7.7.3 Estimated uncertainty rates for activity data and emission factors, %.

95 % confidence interval uncertainties	CO_2	CH_4	N_2O
Human cremation			
Activity data	-	1	1
Emission factor	-	150	150
Animal cremation			
Activity data	-	40	40
Emission factor	-	150	150

Wastewater Handling

The uncertainty levels used in the Tier 1 models are shown in Table 7.7.4.

Table 7.7.4 Estimated uncertainty rates for activity data and emission factors, %.

95 % confidence interval uncertainties	CH_4,	N_2O
5.D.1 Domestic wastewater		
Activity	30	30
Emission factor	50	50
5.D.2 Industrial wastewater		
Activity	IE*	30
Emission factor	IE*	50

*Industrial effluent wastewater is send to the collective sewer system for treatment at municipal wastewater treatment plants, where anaerobic treatment at biogas plants take place.

Default IPCC values are assumed to be given at 95 % confidence level. Uncertainties have been derived from IPCC default values and uncertainties in country-specific parameters, respectively.

Other

The uncertainty of the total number of accidental fires is very small, but the division into building and transportation types and also the calculation of full scale equivalents will lead to some uncertainty, partly caused by the category "other". The uncertainty for both building and vehicle activity data is therefore set to 10 % for all years. The uncertainty is however lowest for the most recent years (2008-2021) (Authors expert judgement).

Table 7.7.5 lists the 95 % confidence interval uncertainties for activity data and emission factors used in this inventory and at the present level of available information. The uncertainties are assumed valid for all years 1990-2021.

Table 7.7.5 Estimated uncertainty rates for activity data and emission factors, %.

95 % confidence interval uncertainties	CO_2	CH_4	N_2O
Accidental building fires			
Activity data	10	10	-
Emission factor	300	500	-
Accidental vehicle fires			
Activity data	10	10	-
Emission factor	500	700	-

7.7.2 Tier 1 uncertainty results

The Tier 1 uncertainty estimates for the waste sector are calculated from 95 % confidence interval uncertainties, results are shown in Table 7.7.6.

The overall uncertainty interval for greenhouse gases (GHG) is estimated to be ±40 % and the decreasing trend in GHG emission, calculated as the per cent change in GHG emissions in 2021 compared to 1990, is -37 % ± 29 %-point.

Table 7.7.6 National Tier 1 uncertainty estimates for the waste sector.

Pollutant	National 2021 emission, kt CO_2 eq.	2021 emission uncertainty, %	Trend* 1990-2021, %	Trend uncertainty, %
GHG**	1210	±40	-37	±29
CO_2	23	±300	-1	±14
CH_4	967	±47	-37	±34
N_2O	220	±50	-40	±30

*Per cent change in emission in 2021 with respect to the base year 1990.
**GHG emissions are calculated in units of CO_2 equivalents.

7.7.3 Time series consistency and completeness

Solid Waste Disposal

Registration of the amount of waste has been carried out since the beginning of the 1990s in order to measure the effects of action plans. Therefore, the activity data are considered to be consistent through the time series to make the activity data input to the FOD model reliable.

The consistency of the emissions and the implied emission factors is a result of the same methodology and the same model used for the whole time series. The parameters in the FOD model are the same for the whole time series. The use of a model of this type is recommended in IPCC (2006).

As regards completeness, waste amounts for the whole time series, i.e. 1940-2021, have been allocated according to 20 waste types as described in Chapter 7.2.3.

Biological treatment of solid waste

For compost production, activity data are not consistent as data are only available for 1995-2020. Data for 1990-1994 and 2021 along with data for home composting are estimated through linear regression and with surrogate data respectively. Emission factors and calculation method are consistent throughout the time series. For 2010-2020, improved quality of the composting data has been achieved through detailed data on the waste type garden and park waste, sludge and organic waste (Nissen, 2017a).

Emissions from compost production are believed to be complete; calculations include composting at all nationally registered sites and best available estimated data for home composting.

Waste Incineration

Activity data for human cremation is considered to be consistent, as these data have been collected by DKL throughout the time series. Activity data for animal cremation on the other hand is not fully consistent. Data for 1998-2021 are gathered directly from the crematoria and data for 1990-1997 are estimated by the author's expert judgement, no surrogate data or data regression is possible.

Emission factors and calculation method are consistent throughout the time series for both human and animal cremation.

Cremation of both corpses and carcasses is considered to be complete. Open burning of carcasses is illegal and therefore not occurring in Denmark, and small-scale incinerators are not known to be used at Danish farms.

Wastewater Handling

Consistency and completeness have been improved by integrating plant level data from the Danish Energy Statistics with plant level COD data from the Danish monitoring program and plant level environmental reports (Thomsen, 2016).

Data regarding industrial on-site wastewater treatment processes have been achieved and included.

Waste Other

For accidental fires, DEMA provides detailed data for 2007-2020 and the total number of nationally registered fires for 1990-2020 (DEMA, 2022). Activity data for accidental fires are there for believed to be consistent. Both emission factors and calculation method are also consistent throughout the time series.

Emissions from accidental fires are believed to be complete. Field burning of agricultural residue is included in Chapter 5 Agriculture.

7.8 QA/QC and verification

In general terms, for this part of the inventory, the Data Storage (DS) Level 1, 2 and 4 and the Data Processing (DP) Level 1 can be described as follows.

7.8.1 Data Storage Level 1

The external data level refers to the placement of the original input data used for estimating annual activity and emission factors in the waste sector. Data references in terms of reports and databases used for deriving input for the emission calculations. Reports and a list of links to external data sources are stored in a common data storage system including all sectors of the annual NIR.

Table 7.8.1 Overview of annually stored external data sources at DS level1.

http. file or folder name	Description	AD or EF	Reference	Contact	Data agreement/ Comment
DCE data-exchange folder: O:\Tech_ENVS-Luft-Emi\Inventory\2021\6_Waste\Level_1b_Processing	Inventory data storage system	AD and EF	DCE		
O:\Tech_ENVS-Luft-Emi\Waste\5D Waste water treatment and discharge\References\Punktkilde rapporter	Report series published by the DEPA (Danish Environmental Protection Agency) (1994-2005; 2018-2021), DNA (Danish Nature Agency) (2011-2015), City- and Landscape Agency (2007-2010) and Water and Nature Management Agency (2017). Available from the DNA www.nst.dk and DEPA www.mst.dk		Report series: "*Point sources*" (1993-2021)	MST Østjylland Lisbeth Nielsen (linie@mst.dk)	Public available reports
O:\Tech_ENVS-Luft-Emi\Waste\5D Waste water treatment and discharge\References\Punktkilde rapporter	Report series published by the DEPA (Danish Environmental Protection Agency) in 1990, 1992 and 1993		Report series "Vandmiljø"		Public available reports
Danish Water Quality parameter Database	Annually reported wastewater characteristics at plant level which includes all years 1990-2015	AD	www.miljoeportal.dk	MST Østjylland Lisbeth Nielsen (linie@mst.dk)	Authorised access
DCE data-exchange folder: O:\Tech_ENVS-Luft-Emi\Inventory\2021\6_Waste\Level_1a_Storage	Raw data extracts from the Danish Waste Reporting System	AD	The Danish Environmental Protection Agency. Database on all registered Danish waste. Available at: www.ads.mst.dk	Maja Hornung Thorndahl, Unit of Circular Economy and Waste (mahot@mst.dk)	The amounts are registered due to statutory requirements
DCE data-exchange folder: O:\Tech_ENVS-Luft-Emi\Energy\2021	Basic data DS1 Dataset for energy-producing SWDS and WWTPs. CH_4 recovery data		The Danish Energy Agency (DEA)		Prepared due to the obligation of DEA
DCE data-exchange folder: O:\Tech_ENVS-Luft-Emi\Inventory\2021\5_Waste\Level_1b_Processing\5A Solid Waste Disposal	Access file with the FOD model: "waste.accdb"	AD, EF, Model	IPCC 2006		
http://www.dkl.dk	Number for cremations	AD	Association of Danish Crematories		Public access
http://www.statistikbanken.dk	Statistics for population. buildings and vehicles	AD	Statistics Denmark		Public access

Continued

http. file or folder name	Description	AD or EF	Reference	Contact	Data agreement/ Comment
DCE data-exchange folder: O:\Tech_ENVS-Luft-Emi\Inventory\2021\5_Waste\Level_1a_Storage	Cremated animal carcasses	AD	Dansk Dyre-kremering ApS	Knud Ribergaard info@danskdyrekremering.dk	Personal contact
DCE data-exchange folder: O:\Tech_ENVS-Luft-Emi\Inventory\2021\5_Waste\Level_1a_Storage	Cremated animal carcasses	AD	Ada's Kæledyrs-krematorium ApS	Anders Oxholm anders@adakrem.dk	Personal contact
O:\Tech_ENVS-Luft-Emi\Inventory\2021\5_Waste\Level_1a_Storage	Cremated animal carcasses	AD	Kæledyrskrematoriet	Annette Laursen springbjerglund@gmail.dk	Personal contact
https://statistikbank.brs.dk	Categorized fires	AD	The Danish Emergency Management Agency	Steen Hjere Nonnemann shn@beredskabsstyrelsen.dk	Public access
DCE data-exchange folder: O:\Tech_ENVS-Luft-Emi\Inventory\2021\5_Waste\Level_1a_Storage	Waste categories for composting	AD	Danish Environmental Protection Agency (DEPA). Waste Statistics		Public access

7.8.2 Data Processing Level 1

This level comprises a stage where the external data extracted from the waste data system are processed internally.

For CRF category 5.A, data are prepared for the DCE First Order of Decay model by allocation of the reported waste amounts according to the European Waste Codes (EWC) as presented in Chapter 7.2. The model runs in Microsoft Access and the output data is stored in Access and Excel files.

For the CRF category 5.B.1 composting, data are delivered by the Danish Environmental Protection Agency for the period 2010-2020 at plant level. Total amount of composted bio-waste is extracted from the waste reporting system (www.ads.mst.dk). Regarding the derivation of emission factors used in the model calculations, improvements are documented in Chapter 7.3.1.

For the CRF category 5.C, activity data are used directly and for category 5.E., the activity data and emission factors are recalculated to match each other by using national average data like the average floor space in houses etc. Calculations are carried out and the output stored in a not editable format each year. The DP at level 1 has been improved to fit into a more uniform and easily accessible data reporting format.

For CRF category 5.D, data are prepared for the input to the country-specific models. The plant level data for WWTPs using anaerobic sludge digestion, i.e. biogas production, have been integrated with plant level energy recovery data from the Energy Statistics and a mass balance for the CH_4 potential in the influent TOW, the ingestate, the digestate, the amount of recovered and lost CH_4 by flaring and venting. Status for the improvements are presented Chapter 7.5 and in Thomsen (2016). Calculations are carried out and the output stored in a not editable format each year. The DP at level 1 has been improved to fit into a more uniform and easily accessible data reporting format. Regarding the derivation of activity data and emission factors used in the model calculations, improvements are documented in Chapter 7.5.

7.8.3 Data Storage Level 2

Data Storage Level 2 is the placement of selected output data from the calculation of emissions as inventory data on sub-category levels in the Access (CollectER) database.

7.8.4 Data Storage Level 4

Data Storage Level 4 is the placement of the calculated output data from the calculation of emissions as data on sub-category levels in the CRFs.

7.8.5 Points of measurement

The present stage of QA/QC for the Danish emission inventories for the waste sector is described below for DS level 1, 2 and 4 and DP level 1 Points of Measurement (PMs). This is to be seen in connection with the general QA/QC description in Section 1.6 and, especially, 1.6.10 on specific description of PMs common to all sectors, general to QA/QC.

Data Storage level 1	1. Accuracy	DS.1.1.1	General level of uncertainty for every dataset including the reasoning for the specific values

The sources of data described in the methodology sections and in DS.1.2.1 and DS.1.3.1 are used in this inventory. Thus, it is the accuracy of these data that define the uncertainty of the inventory calculations.

With regard to the general level of uncertainty for SWDS, the amounts in waste fractions/categories are reasonably certain (per cent uncertainty set equal to 10 %. cf. Table 7.7.1. Due to the statutory environment for these data, while the distribution of waste fractions according to waste type and their content of *DOC* are more uncertain (per cent uncertainty set equal to 20 %. cf. Table 7.7.1). It is generally accepted that FOD models for CH_4 emission estimates offer the best and the most certain way of estimation. The half-life and methane generation rates constant in the FOD model are important parameters with some uncertainty (cf. Table 7.7.1).

For the *CRF category 5.B Biological Treatment of Solid Waste, 5.C Incineration and open burning* and *5.E Other* the level of uncertainty is generally low for activity data but higher for emission factors, cf. Table 7.7.2. Table 7.7.3 and Table 7.7.5. Expert judgments are used whenever default uncertainties are not available.

The input parameter uncertainties for CRF category *5.D Wastewater Treatment and Discharge* have been derived from standard deviations between activity data extracted from national databases and reported national statistics as shown in Table 7.7.4. Uncertainty of activity data are based on simple standard deviations accompanying the annual reported monitoring data.

Data Storage level 1	2.Comparability	DS.1.2.1	Comparability of the emission factors/calculation parameters with data from international guidelines and evaluation of major discrepancies.

Comparison of Danish data values from external data sources with corresponding data from other countries has been carried out in order to evaluate discrepancies.

Comparison of Danish data values with data sources from other countries has been carried out as presented in the national verification report by Fauser et al. (2013).

Data Storage level 1	3.Completeness	DS.1.3.1	Ensuring that the best possible national data for all sources are included, by setting down the reasoning behind the selection of datasets.

SWDS

- Danish Environmental Protection Agency (DEPA). ISAG database and ADS waste data system: amounts of the various waste fractions deposited (refer to Chapter 7.2).
- A Danish investigation and verification of the overall mass balance upon allocating waste fractions within the ISAG (1994-2009) and the ADS (2010-present) waste data systems into 20 well-defined waste types as described in Chapter 7.2.
- Danish Energy Agency (DEA): Official Danish energy statistics: CH_4 recovery data.

The selection of sources is obvious. The ISAG database is based on statutory registrations and reporting from all Danish waste treatment plants for all waste entering or leaving the plants. Information concerning waste in the previous year must be reported to the DEPA no later than 31st of January each year. Registration is made by mass according to EAK codes, which are automatically reallocated into 20 waste types of which 10 are characterised as inert. The individual waste type characteristics have been documented in Chapter 7.2.

For recovery data, the DEA registers the energy produced from plants where installations recover CH_4 in the national energy statistics. For the parameters of the FOD model, references are made to IPCC (2006).

Composting

- ISAG waste database
- ADS waste reporting system

All Danish waste treatment plants are obligated to statutory registration and reporting of all waste entering and leaving the plants. All waste streams are weighed, categorised with a waste type and a type of treatment and registered to the ISAG waste information system, which contain data for 1995-2009 (ISAG). For 2010-2021 data from the new waste reporting system are delivered by the Danish EPA according to the three compost types (Exclusive home composting).

Waste Incineration

- Tables from Association of Danish Crematories available online
- Direct contact with the Danish animal crematories
- Emission factors from literature.

Data from the Association of Danish Crematories is based on annual reporting from all Danish crematories. Specific reported data are available for the complete time series.

WWTP

- Integrated TOW-Energy recovery database
- The Danish Water Quality Parameter Database (www.miljoeportal.dk)

Data on plant level on energy recovery has been integrated with plant level data on influent TOW, which have made it possible to quantify the amount of TOW in the influent at plants using anaerobic digestion as sludge management strategy as reported in Table 7.5.4.
Knowledge of the amount of sludge treated at WWTPs with anaerobic sludge digestion has been used as input parameter for calculation of the gross methane emission from anaerobic treatment. It constitutes a major improvement of the activity data for CRF category 5.D, while the energy statistics have been used to quantify the amount of methane lost via venting and flaring.

Other

- Statistics Denmark
- Danish Emergency Management Agency (DEMA) database (DEMA, 2022)
- Emission factors from literature

The DEMA database is the only provider of data on accidental fires, data for newer years (2007-2021) are extremely detailed.

Data Storage level 1	4.Consistency	DS.1.4.1	The original external data has to be archived with proper reference.

Data are predominantly extracted from the internet and databases (The Danish Waste Reporting System. the Water Quality Parameter database, Statistics Denmark, DEMA database, human cremation). The origin of external activity data has been preserved as much as possible by saving them as original copies in their original form. Files are saved for each year of reporting; in this way changes to previously received data and calculations are reflected and explanations are given. Specific information from reports, industries and experts are saved as e-mails and pdf files.

Data Storage level 1	6.Robustness	DS.1.6.1	Explicit agreements between the external institution holding the data and DCE about the conditions of delivery.

As stated in DS.1.4.1 most data are obtained from the internet. It is a statutory requirement that amounts of waste are reported annually to DEPA, no later than 31st of January for the previous year. No explicit agreements have been made with external institutions.

Data Storage level 1	7.Transparency	DS.1.7.1	Listing of all archived datasets and external contacts.

Contact persons related to the delivery of specific data are provided in Table 8.7.1.

For a listing of all archived external data sets the reader is referred to DS 1.3.1.

Data Processing level 1	1. Accuracy	DP.1.1.1	Uncertainty assessment for every data source not part of DS.1.1.1 as input to Data Storage level 2 in relation to type and scale of variability.

No data are used in addition to those included in DS.1.1.1. Uncertainties are reported in Section 7.7.

Data Processing level 1	2.Comparability	DP.1.2.1	The methodologies have to follow the international guidelines suggested by UNFCCC and IPCC.

The methodological approach is based on the detailed methodology as outlined in the Emission Inventory Guidebook. The calculation used for SWDS is a Tier 2 methodology from IPCC (2006). For WWTP the calculations follow the IPCC (2006). Exemptions have been documented whenever occurring. The inventory calculations for Waste Incineration and Waste Other are a simple multiplication of activity data and emission factors (See also DS.1.3.1).

Data Processing level 1	3.Completeness	DP.1.3.1	Identification of data gaps with regard to data sources that could improve quantitative knowledge.

Emission factors for cremation and accidental fires are gathered from literature studies. There is no Danish literature or measurements available on greenhouse gas emissions from these categories.

Data Processing level 1	4.Consistency	DP.1.4.1	Documentation and reasoning of methodological changes during the time series and the qualitative assessment of the impact on time series consistency.

There is no change in calculation procedure during the time series and the activity data are, as far as possible, kept consistent for the calculation throughout the time series. Any changes in calculation procedures are noted for each year's inventory in the individual chapters for each CRF category.

Data Processing level 1	5.Correctness	DP.1.5.1	Verification of calculation results using time series

The time series of activities and emissions from the model output in the subcategories and in the CRF format have been prepared. The time series are examined and significant changes are checked and explained. A comparison is made with the previous year's estimates and any major changes are verified.

Data Processing level 1	5.Correctness	DP.1.5.2	Verification of calculation results using other measures

The correct interpretation in the model/calculation of the methodology and the parameterisation has been checked as far as possible.

Data Processing level 1	7.Transparency	DP.1.7.1	The calculation principle. The equations used and the assumptions made, must be described.

The calculation principle and equations are described in Chapter 7.2 to 7.6 for each CRF category in the waste sector.

Data Processing level 1	7.Transparency	DP.1.7.2	Clear reference to dataset at Data Storage level 1

Refer to the table at the start of this Section and DS.1.1.1 (Table 7.8.1).

The calculation principle and equations are described in Chapter 7.2 to 7.6 for each CRF category in the waste sector.

Data Processing level 1	7.Transparency	DP.1.7.3	A manual log to collect information about recalculations.

Recalculation and changes in the emission inventories are described in the NIR whenever occurring. The logging of the changes takes place in the annual model file.

Data Storage level 2	5.Correctness	DS.2.5.1	Check if a correct data import to level 2 has been made

The transfer of emission data from level 1, storage and processing, to data storage level 2 is manually checked. This check is performed, comparing model output and report files made by the CollectER database system.

Data Storage level 4	4. Consistency	DS.4.4.3	The IEFs from the CRF are checked regarding both level and trend. The level is compared to relevant emission factors to ensure correctness. Large dips/jumps in the time series are explained.

See DP.1.5.1 and DP.1.5.2.

7.9 Source specific recalculations

Table 7.9.1 presents the recalculations to the waste sector for this year's inventory.

Recalculations have occurred for sector 5.A in the whole time series 1990 to 2020 due to a thorough assessment of both activity data and emission factors applied in the sector. Recalculations have occurred for the whole time series 1990-2020 for sector 5.B1 Composting due to updating of activity data, the most significant of which is composting of sludge. For 5.B2 Biogas productions, recalculations occur for 2011-2020 due to updates in activity data for CH_4 production. 5.D Wastewater and discharge has also been subject to a thorough assessment resulting in updates in several emission factors and activity time series.

The joint effect of these recalculations is a decrease in the GHG emissions between -85.4 kt CO_2 eq. (-4%) in 1990 and -252.6 kt CO_2 eq. (-18%) in 2004. Detailed information about recalculations for the individual sub-sector may be found in sub-chapter 7.91 to 7.9.5 below.

Table 7.9.1 Changes in emissions from the waste sector compared with last year´s submission.

	Unit	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
5.A. Solid Waste Disposal											
CH_4. previous inventory	kt	61.5	53.2	42.9	36.4	30.9	26.1	23.7	23.1	21.4	21.5
CH_4. recalculated	kt	54.5	44.3	34.9	26.3	21.8	19.5	17.7	17.3	16.6	16.4
Change. CO_2 equivalents	kt	-194.4	-250.2	-223.3	-281.3	-253.2	-185.6	-169.1	-162.2	-133.2	-142.8
Change	-	-11.3%	-16.8%	-18.6%	-27.6%	-29.3%	-25.4%	-25.5%	-25.1%	-22.3%	-23.8%
5.B. Biological treatment of Solid Waste											
5.B1 Composting											
CH_4. previous inventory	t	1068.2	1448.0	2485.0	2634.6	2959.5	3037.6	3290.8	3327.8	3448.8	3405.6
CH_4. recalculated	t	1068.2	1448.0	2485.0	2634.4	2957.8	3041.7	3303.3	3337.8	3469.8	3368.1
N_2O. previous inventory	t	74.6	100.9	190.9	189.2	213.5	217.5	239.3	239.5	245.8	244.5
N_2O. recalculated	t	74.5	100.8	190.4	189.1	212.5	218.4	243.2	242.2	252.8	247.2
Change. CO_2 equivalents	t	-2.5	-3.7	-115.5	-33.3	-319.8	336.6	1366.8	992.7	2458.4	-337.8
Change	-	-0.005%	-0.01%	-0.10%	-0.03%	-0.2%	0.2%	0.9%	0.6%	1.5%	-0.2%
5.B2 Biogas											
CH_4. previous inventory	kt	0.2	0.6	1.2	2.0	2.7	4.3	7.7	8.5	9.8	11.6
CH_4. recalculated	kt	0.2	0.6	1.2	2.0	2.7	4.4	7.5	8.4	9.7	11.4
Change. CO_2 equivalents	kt	NA	NA	NA	NA	NA	0.8	-4.7	-1.4	-2.0	-3.4
Change	-	NA	NA	NA	NA	NA	0.7%	-2.2%	-0.6%	-0.7%	-1.1%
5.C. Incineration and open burning of waste											
CH_4. previous inventory	t	0.5	0.6	0.6	0.6	0.8	0.7	0.7	0.8	0.7	0.7
CH_4. recalculated	t	0.5	0.6	0.6	0.6	0.8	0.7	0.7	0.8	0.7	0.7
N_2O. previous inventory	t	0.6	0.7	0.7	0.8	0.9	0.9	0.9	0.9	0.9	0.9
N_2O. recalculated	t	0.6	0.7	0.7	0.8	0.9	0.9	0.9	0.9	0.9	0.9
Change. CO_2 equivalents	t	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Change	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5.D. Wastewater treatment and discharge											
CH_4. previous inventory	kt	1.6	1.7	1.9	1.9	1.9	2.0	2.0	2.0	2.1	2.1
CH_4. recalculated	kt	2.4	2.6	2.9	2.9	2.8	2.8	2.9	3.0	3.0	3.2
N_2O. previous inventory	kt	0.8	0.8	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
N_2O. recalculated	kt	1.1	0.8	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
Change. CO_2 equivalents	kt	109.0	23.3	30.0	28.7	22.9	22.3	25.5	26.1	25.4	29.3
Change	-	42.2%	8.8%	14.6%	14.3%	12.9%	11.7%	13.5%	13.7%	13.6%	15.4%
5.E. Other											
CO_2. previous inventory	kt	21.8	24.3	22.2	21.6	23.1	21.6	23.8	24.5	23.0	23.0
CO_2. recalculated	kt	21.8	24.3	22.2	21.6	23.1	21.6	23.8	24.5	23.0	23.0
CH_4. previous inventory	kt	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
CH_4. recalculated	kt	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Change. CO_2 equivalents	kt	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Change	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

7.9.1 Solid waste disposal on land

Prior to this year's submission, all aspects of the sub-sector of Solid waste disposal on land has gone through a thorough assessment. Among the changes made are:

- Extrapolation of activity data for 1940-1969 is now based on population and GDP, rather than kept constant.
- The number of waste fractions in the FOD model (DCE categories) was changed from 18 to 20. Among the new categories are "Degradable chemicals". Some categories have been divided into two new ones, e.g. "Textile, fur & leather" into "Textiles" and "Rubber & leather".

- Historical data for 1970 and 1985 were revised, resulting in increased degradable waste; +0.4 % in 1970 and +4.7 % in 1985.
- The link between waste types reported in the ISAG waste database (1994-2009) and DCE categories was revised and updated. The distribution of e.g. "combustible waste" into DCE categories is now the same in all years covered by ISAG (i.e. 1994-2009).
- The link between EWCs and DCE categories was revised and updated, resulting in changes for 2010-2020.
- Revision of several half-life times and content of degradable organic matter, e.g. the DOC for degradable sludge of 15 % to 5 % and 9 % for degradable domestic sludge and degradable industrial sludge respectively.
- Updated activity data from DEPA on deposited waste for 2010-2020.
- Inclusion of the inert secondary waste from the ISAG database 1994-2009. This does however not affect the GHG emission calculations.

The resulting overall recalculation for sub-category 5.A is between -4.8 kt CH_4 (-8 %) in 2019 and -10.2 kt CH_4 (-17 %) in 2003.

7.9.2 Biological treatment of solid waste

Composting

Activity data for 2020-2021 are not available for composting of Garden & park waste and Organic waste, and are therefore estimated. Activity data for 2020 have in this submission been calculated as the average of 2017-2019 for both waste categories, resulting in an increase for 2020.

Activity data for composting of sludge was updated by DEPA (2022) for 2008-2020, resulting in decreases for 2008-2010 and increases for 2014-2020.

In last year's submission, activity data for home composting was kept constant for 2010-2020. In this submission, the methodology from 1990-2009 is applied to all years in the time series.

Recalculations for 1990-2007 are strictly due to rounding of activity data.

The resulting overall recalculation for sub-category 5.B1 is between -0.7 kt CO_2 eq. (-0.4 %) in 2009 and +2.5 kt CO_2 eq. (+1.5 %) in 2019.

Anaerobic digestion at biogas facilities

Emissions have been recalculated for 2011 to 2020 due to updates in the activity data for the same years. Recalculations are between +0.5 t CH_4 (+0.02 %) in 2011 and -169.4 t CH_4 (-2.2 %) in 2017.

7.9.3 Waste incineration and open burning

No recalculations have occurred.

7.9.4 Wastewater treatment and discharge

The Wastewater and discharge sub-sector has since last submission been subject to a thorough assessment resulting in updates in several emission factors and activity time series. Among the changes made are:

- Measured data for the CH_4 leakage rate from waste water treatment plants have become available, and the leakage rate is therefore updated to 6.9 %. This update results in significant recalculations in the entire time series, as this factor was only 1.3 % in last year's submission.

- Changing the fraction of population not connected to sewage systems from a constant 10 %, to a time series decreasing from 11.5 % in 1990 to 7.3 % in 2021.
- Minor changes in the point source data for total-N influent, total-N effluent, and wastewater amounts.

The resulting overall recalculation for sub-category 5.D is an increase between 19.3 kt CO_2 eq. (8 %) in 1993 and 109.0 kt CO_2 eq. (+42 %) in 1990.

7.9.5 Other

No recalculations have occurred.

7.10 Source specific improvements

7.10.1 Response to the review process

The table below contains the recommendations of the most recent UNFCCC review of the Danish greenhouse gas inventory. The table details the status of implementation of the recommendations as well as references to where improvements have been implemented in this report.

A review of the Danish 2021 submission took place in September 2021. The table below lists the issues relevant for the waste sector from the report from this most recent review.

Table 7.10.1 Recommendations of the most recent UNFCCC review of the Danish greenhouse gas inventory.

Para	CRF	ERT Comment	Denmark's response	Reference
2021 submission (Review report: https://unfccc.int/sites/default/files/resource/arr2021_DNK.pdf)				
W.2	5.A Solid waste disposal on land – CH_4	Correct the erroneous entry of DOCf in CRF table 5.A.	In the 2021 submission, the correct value was reported, but as fraction (0.5) rather than percentage (50 %). This was corrected in the 2022 submission.	See CRF.
W.3	5.A Solid waste disposal on land – CH_4	Recalculate CH_4 emissions from solid waste disposal in Greenland using the correct values of DOC for dry and wet paper/cardboard in line with the 2006 IPCC Guidelines (vol. 5, chap. 2, table 2.4)	This was addressed in the 2022 submission.	See Chapter 16.
W.6	5.A.1 Managed waste disposal sites – CH_4	Ensure that the references to NIR tables relating to CH_4 recovered from solid waste disposal are correct in the NIR.	This was corrected in the 2022 submission.	See Chapter 7.2.
W.7	5.A.1 Managed waste disposal sites – CH_4	Correct the equation used for estimating the CH_4 generation potential by using the correct value for the coefficient (0.33).	This was corrected in the 2022 submission.	See Chapter 7.2.2.
W.8	5.A.2 Unmanaged waste disposal sites – CH_4	Estimate and report the amount of CH_4 for energy recovery in CRF table 5.B rather than reporting it as "NO".	This was corrected in the 2022 submission.	See CRF
W.9	5.B.1 Composting – CH_4 and N_2O	Accurately report the methodological tiers used to estimate CH_4 and N_2O emissions from composting in CRF summary table 3s2, ensuring consistency with the NIR.	This was corrected in the 2022 submission.	See CRF.
Continued				
W.10	5.B.1 Composting – CH_4 and N_2O	Correct the reference in the NIR to the GHGs emitted from composting by clarifying that only CH_4 and N_2O emissions are estimated for composting.	This was corrected in the 2022 submission.	See Chapter 7.3.1.
W.14	5.B.1 Composting – CH_4 and N_2O	Explain why CH_4 and N_2O emissions from biological treatment of waste (category 5.B) are not estimated and reported for Greenland in the NIR.	This was addressed in the 2022 submission.	See Chapter 16.
Continued				
W.15	5.B.1 Composting – CH_4 and N_2O	Estimate CH_4 and N_2O emissions from waste composting for the Faroe Islands.	This was addressed in the 2022 submission.	See Annex 7.

Table 7.10.1 Recommendations of the most recent UNFCCC review of the Danish greenhouse gas inventory.

Para	CRF	ERT Comment	Denmark's response	Reference
W.16	5.B.2 Anaerobic digestion at biogas facilities – CH_4	Ensure that the correct EF value is given in the equation used to estimate emissions from anaerobic digestion of organic waste at biogas facilities.	This was corrected in the 2022 submission.	See Chapter 7.3.2.
W.18	5.C.1 Waste incineration – CH_4 and N_2O	Include in the NIR information on how the CH_4 and N_2O EFs for human and animal cremation were derived, including whether the contribution of any emissions from the fuels used was considered when deriving the EFs.	This was addressed in the 2022 submission.	See Chapter 7.4.2 and 7.4.3.
W.19	5.C.1 Waste incineration – CO_2, CH_4 and N_2O	Report the AD on the amount of waste incinerated for human cremation as "NE" instead of "NO" in CRF table 5.C and provide a corresponding explanation in a documentation box.	This was corrected in the 2022 submission as the Notation Key has been changed to NE. There are some technical difficulties in adding the explanation in the documentation box, but we trust that the documentation provided in this report is sufficient.	See CRF.
W.22	5.D.1 Domestic wastewater – CH_4	Enhance the transparency of the reporting by correcting the units of measurement for the EF (EFst) presented in NIR equation 7.5.6 (kg CH_4/kg COD instead of kg CH_4/kg DOC).	This was corrected in the 2022 submission.	See equation 7.5.6.
W.26	5.E Other (waste) – CH_4	Report N_2O emissions from accidental fires as "NE" instead of "NA" in CRF tables 5 and summary 2, and correct the reporting in the NIR accordingly.	This was addressed in the 2022 submission.	See CRF.
W.27	5.B.1 Composting – CH_4 and N_2O	The Party reported in CRF table 5.B AD for composting of food and garden waste as "NO" despite reporting emissions related to the activity (e.g. 3.46 kt CH_4 and 0.25 kt N_2O for 2019) and including AD in its NIR (figure 7.3.2 and annex 3F, table 3.2). During the review, the Party clarified that the incorrect notation key was entered in CRF table 5.B. In response to the draft review report, the Party explained that it was unable to report the AD for dry matter, as required by the CRF table, and it will therefore correct the notation key to "NE" in the next annual submission. The ERT recommends that the Party report in CRF table 5.B the correct AD for composting of food and garden waste. If AD are not available, the ERT recommends that the Party report AD as "NE".	The notation key "NE" was applied for the 2023 submission.	See CRF.

7.10.2 Planned improvements

There are no planned improvements for the waste sector.

7.11 References

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8 Other

In CRF Sector 6, there are no activities and emissions for the inventories of Denmark.

9 Recalculations and improvements

Explanations for the recalculations of the Danish inventory are included in the sectoral chapters of the NIR.

The overall impact of recalculations is shown in Table 9.1. A more detailed overview is provided in Tables 9.2 – 9.5.

9.1 Explanations and justifications for recalculations

Explanations and justifications for the recalculations performed in this submission, since the previous submission of data to the UNFCCC for Denmark, are given in the individual sector chapters. As this submission has been prepared using GWPs from the IPCC Fifth Assessment Report, changes in emissions have occurred also for categories where no other changes have occurred.

9.2 Implications for emission levels

For the national total CO_2 equivalent emissions without Land-Use, Land-Use Change and Forestry, the general impact of the improvements and recalculations performed is somewhat significant and the changes for the whole time-series are between 0.47 % (1991) and 2.66 % (2020). The implications of the recalculations on the level and on the trend, 1990-2020, of the national total are small, see Table 9.1. The information presented in this chapter is based directly of the CRF tables and therefore in the case of f-gases also includes the impact of the change in GWP values from AR4 to AR5.

For the national total CO_2 equivalent emissions with Land-Use, Land-Use Change and Forestry, the general impact of the recalculations is similar, see Table 9.1.

Table 9.1 Recalculation performed in the 2023 submission for 1990-2020. Differences in pct. of CO_2 equivalents between this submission and the April 2022 submission for Denmark, excluding Greenland and the Faroe Islands.

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total CO_2 eqv. Emissions with Land-Use Change and Forestry	0.54	0.47	0.62	0.60	0.61	0.72	0.65	0.61	0.73	0.60	0.79
Total CO_2 eqv. Emissions without Land-Use Change and Forestry	0.56	0.47	0.64	0.62	0.62	0.74	0.65	0.61	0.74	0.60	0.80
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total CO_2 eqv. Emissions with Land-Use Change and Forestry	0.80	0.87	0.89	1.01	1.19	1.07	1.14	1.23	1.36	1.38	1.38
Total CO_2 eqv. Emissions without Land-Use Change and Forestry	0.80	0.88	0.90	1.03	1.22	1.09	1.15	1.22	1.34	1.34	1.50
	2012	2013	2014	2015	2016	2017	2018	2019	2020		
Total CO_2 eqv. Emissions with Land-Use Change and Forestry	1.68	1.63	1.75	1.56	1.51	1.59	1.63	1.94	2.46		
Total CO_2 eqv. Emissions without Land-Use Change and Forestry	1.62	1.56	1.70	1.47	1.48	1.53	1.66	1.93	2.66		

9.3 Implications for emission trends, including time series consistency

It is a high general priority in the considerations leading to recalculations back to 1990 to have and preserve the consistency of the activity data and emissions time-series. As a consequence activity data, emission factors and methodologies are carefully chosen to represent the emissions for the time-series correctly. Often considerations regarding the consistency of the time-series have led to recalculations for single years when activity data and/or emission factors have been changed or corrected. Furthermore, when new sources are considered, activity data and emissions are as far as possible introduced to the inventories for the whole time-series based on preferably the same methodology.

The implication of the recalculations is further shown in Tables 9.2-9.5.

Table 9.2 Recalculation for CO_2 performed in the 2023 submission for 1990-2020. Differences in kt CO_2 equivalents between this and the April 2022 submission for Denmark. Excluding Greenland and Faroe Islands.

CO_2 kt	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Total National Emissions and Removals	-108	-96	-64	-64	-25	39	31	-31	0	0	0	-1	-1	-2	-2	1
1. Energy	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
1.A. Fuel Combustion Activities	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.A.1. Energy Industries	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.A.2. Manufacturing Industries and Construction	155	159	154	155	152	163	160	158	161	165	166	179	177	187	191	192
1.A.3. Transport	-32	-35	-38	-41	-45	-49	-52	-56	-60	-64	-69	-74	-78	-82	-87	-88
1.A.4. Other Sectors	-122	-124	-115	-113	-107	-114	-108	-102	-101	-101	-97	-106	-99	-104	-104	-104
1.A.5. Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.B. Fugitive Emissions from Fuels	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
2. Industrial Processes and product use	-108	-95	-64	-63	-25	39	31	-31	-	-	-	-	-	0	0	0
2.A. Mineral industry	-108	-95	-64	-63	-25	39	31	-31	-	-	-	-	-	-	-	-
2.B. Chemical industry	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.C. Metal industry	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.D. Non-energy products from fuels and solvent use	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
2.G. Other product manufacture and use	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3. Agriculture	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3. G. Liming	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3.H. Urea application	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3.I. Other carbon-containing fertilizers	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4. Land Use, Land-Use Change and Forestry (net)	0	0	0	0	0	0	0	0	0	0	-1	-1	-2	-2	-3	0
4.A. Forest Land	0	0	0	0	0	0	0	0	0	0	-1	-1	-2	-2	-3	0
4.B. Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.C. Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.D. Wetlands	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.E. Settlements	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.F. Other Land																
4.G. Harvested wood products	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5. Waste	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.E. Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total National Emissions and Removals	13	12	12	14	-3	1	3	2	6	-105	-117	-101	-114	10	-30
1. Energy	13	0	0	0	-14	-11	-10	-10	-6	-117	-117	-118	-117	-5	19
1.A. Fuel Combustion Activities	0	0	0	0	-14	-12	-10	-10	-7	-118	-117	-118	-117	-5	19
1.A.1. Energy Industries	0	0	0	0	-14	-12	-10	-9	-8	-7	-6	-6	-8	-7	-10

Continued	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1.A.2. Manufacturing Industries and Construction	186	185	175	146	149	140	130	124	118	117	119	123	127	124	148
1.A.3. Transport	-88	-88	-87	-85	-86	-83	-80	-80	-80	-191	-190	-191	-191	-79	-78
1.A.4. Other Sectors	-98	-97	-88	-61	-63	-54	-45	-40	-32	-33	-35	-39	-40	-38	-36
1.A.5. Other	-	-	0	0	0	-3	-5	-5	-5	-5	-5	-5	-5	-5	-5
1.B. Fugitive Emissions from Fuels	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2. Industrial Processes and product use	0	0	0	0	0	0	0	0	0	0	0	2	1	-1	-2
2.A. Mineral industry	-	-	-	-	-	-	-	-	-	-	0	2	1	1	0
2.B. Chemical industry	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-
2.C. Metal industry	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.D. Non-energy products from fuels and solvent use	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1
2.G. Other product manufacture and use	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0
3. Agriculture	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3. G. Liming	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3.H. Urea application	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3.I. Other carbon-containing fertilizers	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4. Land Use, Land-Use Change and Forestry (net)	0	12	12	14	11	12	13	12	12	12	0	14	2	16	-48
4.A. Forest Land	0	1	1	2	-1	0	0	0	0	0	0	0	-1	0	0
4.B. Cropland	0	11	10	12	12	13	13	13	12	12	0	14	-16	-5	-29
4.C. Grassland	0	0	0	0	-	-	-	-	-	-	-	-	18	21	-53
4.D. Wetlands	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34
4.E. Settlements	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-
4.F. Other Land															
4.G. Harvested wood products	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5. Waste	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.E. Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 9.3 Recalculation for CH_4 performed in the 2023 submission for 1990-2020. Differences in kt CO_2 equivalents between this and the April 2022 submission for Denmark. Excluding Greenland and Faroe Islands.

CH4, kt CO_2 equivalents	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Total National Emissions and Removals	252	271	297	321	307	308	317	334	358	350	425	401	419	434	453	446
1. Energy	18	21	21	25	25	27	31	31	29	28	27	31	28	30	27	30
1.A. Fuel Combustion Activities	17	20	21	24	25	27	31	29	29	29	28	30	28	30	30	30
1.A.1. Energy Industries	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.A.2. Manufacturing Industries and Construction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.A.3. Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1
1.A.4. Other Sectors	18	21	21	25	25	27	31	29	30	30	28	30	29	31	31	30
1.A.5. Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.B. Fugitive Emissions from Fuels	0	0	0	0	1	0	0	2	0	-1	-1	1	0	0	-3	0
2. Industrial Processes and product use	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3. Agriculture	408	431	465	498	496	504	515	535	568	563	581	609	632	646	666	648
3.A. Enteric Fermentation	-35	-36	-36	-36	-35	-35	-35	-34	-34	-33	-32	-33	-31	-30	-28	-27
3.B. Manure Management	444	467	502	536	531	540	550	571	603	597	614	644	665	677	696	677
3.F. Field Burning of Agricultural Residues	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
4. Land Use, Land-Use Change and Forestry (net)	0	-1	0	1	2	3	5	6	8	10	11	13	14	16	18	19
4.A. Forest Land	0	-1	0	1	2	3	5	6	8	10	11	13	14	16	18	19
4.B. Cropland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.C. Grassland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.D. Wetlands	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5. Waste	-173	-180	-190	-203	-215	-227	-234	-239	-247	-251	-193	-252	-256	-258	-258	-252
5.A. Solid waste disposal	-194	-201	-210	-222	-236	-250	-256	-265	-273	-278	-223	-281	-285	-287	-285	-281
5.B. Biological treatment of solid waste	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	0
5.C. Incineration and open burning of waste	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.D. Waste water treatment and discharge	21	22	20	19	21	23	23	26	26	27	30	29	29	29	27	29
5.E. Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total National Emissions and Removals	416	420	402	402	429	321	438	432	451	450	462	464	487	487	609
1. Energy	29	28	28	28	32	29	29	28	25	27	30	31	33	36	36
1.A. Fuel Combustion Activities	29	27	27	27	32	28	28	28	24	26	29	30	33	35	33
1.A.1. Energy Industries	0	-	0	0	0	0	0	2	3	2	4	6	7	9	8
1.A.2. Manufacturing Industries and Construction	0	0	0	0	0	0	0	1	0	0	0	0	1	1	2
1.A.3. Transport	-1	0	0	0	-1	0	0	0	0	0	0	0	0	0	0
1.A.4. Other Sectors	29	27	27	28	32	28	28	25	22	24	26	25	25	25	24
1.A.5. Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Continued	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1.B. Fugitive Emissions from Fuels	0	1	1	1	1	1	1	1	1	1	1	1	1	1	2
2. Industrial Processes and product use	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
3. Agriculture	615	615	590	584	600	597	581	564	570	563	566	559	570	538	670
3.A. Enteric Fermentation	-28	-30	-31	-29	-29	-30	-30	-31	-31	-30	-30	-29	-28	-27	-5
3.B. Manure Management	645	646	621	615	630	627	612	596	602	594	596	588	599	567	676
3.F. Field Burning of Agricultural Residues	-2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-2	-2	-2
4. Land Use, Land-Use Change and Forestry (net)	21	22	24	25	25	-84	24	23	23	22	22	22	22	21	22
4.A. Forest Land	21	22	24	25	25	24	24	23	23	22	22	22	22	21	21
4.B. Cropland	-	-	-	-	-	-109	-	-	-	-	-	-	-	-	-
4.C. Grassland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.D. Wetlands	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
5. Waste	-249	-245	-239	-235	-229	-220	-196	-183	-167	-162	-157	-148	-137	-109	-118
5.A. Solid waste disposal	-277	-272	-266	-260	-253	-243	-221	-207	-196	-186	-178	-169	-162	-133	-143
5.B. Biological treatment of solid waste	0	0	0	0	0	0	0	-1	2	1	-2	-4	-1	-1	-4
5.C. Incineration and open burning of waste	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.D. Waste water treatment and discharge	28	27	27	25	24	22	25	25	27	22	24	26	26	25	29
5.E. Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 9.4 Recalculation for N_2O performed in the 2023 submission for 1990-2020. Differences in kt CO_2 equivalents between this and the April 2022 submission for Denmark. Excluding Greenland and Faroe Islands.

N_2O, kt CO_2 equivalents	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Total National Emissions and Removals	237	152	154	85	92	102	72	42	63	-37	12	5	35	61	70	115
1. Energy	-50	-97	-100	-87	-86	-67	-74	-106	-78	-166	-109	-117	-101	-102	-113	-81
1.A. Fuel Combustion Activities	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
1.A.1. Energy Industries	-	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0
1.A.2. Manufacturing Industries and Construction	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
1.A.3. Transport	0	0	0	0	0	0	0	0	0	-1	-1	-1	-1	0	0	-1
1.A.4. Other Sectors	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
1.A.5. Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.B. Fugitive Emissions from Fuels	-47	-94	-97	-84	-83	-64	-71	-103	-75	-163	-106	-114	-98	-99	-111	-78
2. Industrial Processes and product use	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3. Agriculture	199	186	180	172	177	169	145	148	136	129	120	123	136	162	183	196
3.B. Manure Management	0	2	4	6	8	10	12	14	17	23	24	21	17	17	17	18
3.D. Agricultural soils	199	184	176	166	170	159	134	134	119	107	97	102	120	146	167	179
3.F. Field Burning of Agricultural Residues	0	0	0	0	0	0	0	0	-1	-1	-1	-1	0	-1	-1	-1
4. Land Use, Land-Use Change and Forestry (net)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.A. Forest Land	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.B. Cropland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.C. Grassland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.D. Wetlands	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.E. Settlements	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5. Waste	88	63	74	0	0	0	0	0	4	0	0	-1	0	0	0	-1
5.B. Biological treatment of solid waste	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.C. Incineration and open burning of waste	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.D. Waste water treatment and discharge	88	63	74	0	0	0	0	0	4	0	0	-1	0	1	0	-1

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total National Emissions and Removals	132	152	191	228	194	225	214	221	223	181	216	206	211	196	291
1. Energy	-79	-80	-58	-38	-51	-35	-31	-40	-38	-41	-44	-41	-39	-33	-21
1.A. Fuel Combustion Activities	-3	-2	-2	-2	-1	-2	-1	-3	-2	-3	-3	-3	-2	-3	-2
1.A.1. Energy Industries	-	-	0	0	0	0	0	0	0	0	0	0	0	-1	-2
1.A.2. Manufacturing Industries and Construction	1	2	2	1	2	2	2	0	1	1	1	1	1	1	2
1.A.3. Transport	-1	-1	-1	-1	0	-1	-1	-1	-1	-2	-2	-2	-2	-1	-1
1.A.4. Other Sectors	-3	-3	-3	-3	-3	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
1.A.5. Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.B. Fugitive Emissions from Fuels	-77	-78	-56	-36	-50	-33	-30	-37	-36	-38	-41	-39	-37	-30	-19

Continued	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
2. Industrial Processes and product use	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
3. Agriculture	211	232	249	267	246	260	246	260	261	222	259	247	249	227	314
3.B. Manure Management	17	16	13	12	5	4	5	4	5	5	5	5	6	7	24
3.D. Agricultural soils	195	217	237	255	242	256	242	256	257	218	255	242	244	221	290
3.F. Field Burning of Agricultural Residues	-1	-1	0	-1	0	0	0	-1	0	0	0	0	-1	-1	-1
4. Land Use, Land-Use Change and Forestry (net)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2
4.A. Forest Land	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.B. Cropland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-2
4.C. Grassland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.D. Wetlands	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.E. Settlements	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5. Waste	0	0	0	-1	-1	0	0	0	0	0	1	1	1	2	1
5.B. Biological treatment of solid waste	0	0	0	-1	0	0	0	0	0	0	1	1	1	2	1
5.C. Incineration and open burning of waste	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.D. Waste water treatment and discharge	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0

Table 9.5 Recalculation for f-gases performed in the 2023 submission for 1990-2020. Differences in kt CO_2 equivalents between this and the April 2022 submission for Denmark. Excluding Greenland and Faroe Islands.

f-gases kt CO_2 eqv	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
HFCs			0	-9	-13	-20	-29	-25	-31	-35	-38	-40	-39	-37	-39	-38
PFCs					0	0	0	0	0	0	0	0	0	0	0	0
SF_6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
HFCs	-38	-39	-38	-38	-31	-27	-29	-25	-22	-17	-20	-16	-20	-16	-17	
PFCs	0	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	
SF_6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

9.4 Recalculations, including those in response to the review process, and planned improvements to the inventory (e.g. institutional arrangements, inventory preparations)

The review on the submissions in 2007 and 2008 was finalised and the report was published 15 April, 2009. For the 2009 submission the review report was finalised and published 15 April, 2010. The review report of the in-country review of the 2010 submission was published 3 March, 2011. The draft review report for the review of the 2011 submission was available 9 February, 2012. The final review report was published 30 April, 2012. The draft review report of the 2012 submission was made available 30 April, 2013 and the final review report was dated 2 August, 2013. The draft review report of the 2013 submission was made available April 28, 2014 and the final review report was dated 23 June, 2014. The draft of the review report from the centralised review carried out in September 2014 was received on December 9, 2014. The final report was published on February 4, 2015. No review took place in 2015. The review of the 2016 submission took place as an in-country review in September 2016. The final report was published on 9 August, 2017. No review took place in 2017. The review of the 2018 submission took place in October 2018. The final report was published on 5 February, 2019. No review took place in 2019. The review of the 2020 submission took place in November 2020 and the final report was published 5 May 2021. The review of the 2021 submission took place in September 2021 and the final report was published 17 August 2022.

The review of the 2022 submission took place in September 2022. At the time of preparing this report, no draft review report has been provided and hence Table 9.6 has not been updated to reflect the review of the 2022 submission.

The status of the implementation of review recommendations from the latest published review is for the general recommendations included in Table 9.6. For the sector specific recommendations, please refer to the individual sector chapters.

Table 9.6 General recommendations from the latest UNFCCC review.

Para.	CRF	ERT Comment	Denmark's response	Reference
No recommendations related to the general issues was identified during the review of the 2021 submission.				

10 Indirect CO_2 and N_2O emissions

10.1 Description of sources of indirect emissions in GHG inventory

The estimation of indirect CO_2 and N_2O emissions is based on the official Danish inventories for the precursor gases (CO, NMVOC, NH_3 and NO_x) reported under the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP) and the CH_4 emissions reported to the UNFCCC.

For an in-depth description of the Danish inventories for the precursor gases, please see the Danish Informative Inventory Report submitted to the UNECE (Nielsen et al., 2023).

10.2 Methodological issues

The activity data used to estimate the emissions of the precursors and hence the indirect emissions are the same as it used to estimate direct greenhouse gas emissions. Therefore, the information provided in Chapters 3-7 on the activity data is valid also for the reporting of the indirect emissions.

The emission factors used to estimate the emissions of the precursors are for CH_4 documented in this report; see Chapter 3-7. For emissions of CO, NMVOC, NO_x and NH_3, the emission factors are based on a very large selection of data sources. All emission factors are documented in the annual documentation report (Informative Inventory Report – IIR) produced by Denmark and reported as part of the reporting commitments under the Convention on Long-Range Transboundary Air Pollution under the United Nations Economic Commission for Europe; see Nielsen et al. (2023).

The structure of the IIR is very similar to the structure of the NIR, so it is easy for interested parties to get the information on the methodologies and emission factors used to estimate emissions of CO, NMVOC, NO_x and NH_3 in Denmark.

Indirect emissions are generally calculated using the methodology described in the 2006 IPCC Guidelines (IPCC, 2006). However, for some sources a more detailed calculation is performed.

The indirect CO_2 emission from CH_4 is calculated as the emission of CH_4 multiplied by 44/16, the indirect CO_2 emission from CO is calculated as the emission of CO multiplied by 44/28 and the indirect CO_2 emission from NMVOC is calculated as the emission of NMVOC multiplied with the carbon content multiplied by 44/12. The default carbon fraction as per the 2006 IPCC Guidelines is 0.6. This fraction is used for all other sources than solvent use, where the inventory is based on a chemical specific approach and hence the exact carbon fraction is known. For more information on the estimation of CO_2 emissions from solvent use, road paving with asphalt and asphalt roofing, please see Chapter 4.5.

In order for consistency with the reporting done by Denmark under the first commitment period of the Kyoto Protocol, the indirect CO_2 emissions from solvent use, road paving with asphalt and asphalt roofing are reported in category 2D3 of the CRF tables in accordance with the reporting guidelines (UNFCCC, 2013) that allows for the use of these categories in a drop-down list within this category.

For other sources of indirect CO_2, the emissions are reported in CRF Table6. In the calculation of indirect CO_2, only fossil carbon has been considered, hence indirect CO_2 is not calculated for precursors originating from biomass combustion, nor from other biogenic sources, e.g. agriculture and waste disposal on land. In addition, indirect CO_2 has not been calculated for fuels in the combustion sector where an oxidation factor of 1 is already assumed, i.e. for the IPCC default CO_2 emission factors. Denmark only uses the IPCC default emission factors for fuels with a very low consumption; see Chapter 3 for more information.

The precursor emissions used in the calculation of indirect CO_2 therefore differs from the emissions reported in the CRF. Table 10.1 below shows the precursor emissions on which the calculation of indirect CO_2 is based.

Table 100.1 Emissions of precursors used in the calculation of indirect CO_2 for 2021, kt.

	CH_4	CO	NMVOC
Energy	6.17	120.69	17.33
Industrial processes and product use	0.01	0.27	0.11

The resulting indirect emissions are shown in Table 10.2 below.

Table 100.2 Indirect CO_2 emissions for 1990 and 2021, kt CO_2e.

	1990	2021
Indirect CO_2 from solvent use	93.73	70.42
Indirect CO_2 from road paving with asphalt	0.58	0.83
Indirect CO_2 from asphalt roofing	0.02	0.03
Indirect CO_2 from other sources	1120.06	245.42
Total GHG emission excluding all indirect CO_2	77198.04	45954.49
Total GHG emission consistent with CP1	77292.37	46025.77

For indirect N_2O the emissions resulting from ammonia emissions in agriculture and LULUCF are covered in the sectoral tables for agriculture and LULUCF. The indirect N_2O emissions resulting from NO_x emissions in these sectors are included in CRF Table 6. The indirect N_2O emissions are calculated using the below equation.

$$N_2O = (NO_X - N + NH_3 - N) * EF * 44/28$$

The default emission factor of 0.1 kg N_2O-N per kg NH_3-N or NO_x-N emitted is used for all sources.

10.3 Uncertainties and time-series consistency

Uncertainties for the precursors are estimated using a simple error propagation method similar to the IPCC Approach 1.

Please see Nielsen et al. (2023) for further information on the uncertainties and time-series consistency for the Danish inventories of indirect greenhouse gases.

10.4 Category-specific QA/QC and verification

Please see Nielsen et al. (2023) for further information on the QA/QC for the Danish inventories of indirect greenhouse gases.

10.5 Category-specific recalculations

A large number of recalculations are carried out annually to take into account new data, updated knowledge, new sources and correction of errors. The recalculations for 1990 and 2020 are shown in Table 10.3 and 10.4 below. Only short explanations are provided in this report as the number of recalculations are vast and it is beyond the scope of this report to include them here.

Please see Nielsen et al. (2023) for further information on the recalculations for the Danish inventories of indirect greenhouse gases.

Table 100.3 Recalculations of indirect emissions and precursors for 1990, kt.

	Source emissions					Indirect emissions	
	CH_4	CO	NMVOC	NO_x	NH_3	CO_2	N_2O
Total	-8.99	1.65	0.56	3.17	0.00	-0.22	0.02
Energy	-0.63	0.29	0.48	3.12	0.00	-0.22	0.01
Industrial processes and product use	-	-	-	-	-	-	-
Agriculture	-14.57	1.37	0.08	0.05			0.00
LULUCF	0.01	-	-	-			-
Waste	6.19	0.00	0.00	-	0.00		0.00

The recalculations in 1990 are generally small. For CH_4, the largest recalculation is in the waste and agricultural sector. The recalculations for agriculture and waste do not affect the indirect CO_2 emission, as they are biogenic. For explanations on the recalculations for the recalculations of CH_4, please refer to the sectoral chapters of this report.

The recalculations of CO are small compared to the total CO emission in 1990 (approximately 719 kt). The small recalculations are mainly due to changes in the estimate from non-road machinery. A major revision of the Danish non-road emission model has been made based on new stock data from the Danish motor register for tractors used in agriculture, forestry, industry (building and construction, manufacturing industries) and commercial/institutional non road sectors. The stock data consist of fuel type, new sales year, vehicle weight, engine size and branch registration of each tractor, thus enabling a regrouping of the tractors used into the above mentioned inventory sectors.

The NMVOC emissions have decreased mainly due to recalculations in the energy and agricultural sectors. For agriculture, the recalculation is due to a correction of an error. The recalculation for agriculture do not affect the indirect CO_2 emission, as they are biogenic. For the energy sector, the main recalculation was related to non-road transport as described under CO.

For NO_x, the only major change is related to mobile combustion. The main reason is the mentioned update to the model for non-road mobile combustion. This also affected the CH_4 emission and is documented in Chapter 3.5.

The changes for NH_3 are minor and are not further discussed here.

The total indirect CO_2 emission has increased slightly as a consequence of the increased emissions of CH_4 from the energy sector.

Table 100.4 Recalculations of indirect emissions and precursors for 2020, kt.

	Source emissions					Indirect emissions	
	CH_4	CO	NMVOC	NO_x	NH_3	CO_2	N_2O
Total	-21.76	1.29	0.11	-0.37	-0.01	-4.80	0.00
Energy	-1.28	-1.41	-0.09	-0.20	0.01	-4.83	0.00
Industrial processes and product use	0.00	0.03	0.13	0.00	0.00	0.04	0.00
Agriculture	-23.93	2.67	-0.08	-0.16			0.00
LULUCF	-0.77	-	-	-			-
Waste	4.22	0.00	0.16	-	-0.02		-0.01

The main recalculations for CH_4, CO, NMVOC and NO_x in 2020 are to a large extent caused by the same improvements as mentioned for 1990.

The total indirect CO_2 emission has increased slightly as a consequence of the increased emissions of CH_4 and CO and the smaller increase in NMVOC from the energy sector.

Please see Nielsen et al. (2023) for further information on the recalculations for the Danish inventories of indirect greenhouse gases. For the recalculations of CH_4, please see the relevant sector chapter of this report.

10.6 Category-specific planned improvements

Please see Nielsen et al. (2023) for further information on the planned improvements for the Danish inventories of indirect greenhouse gases.

10.7 References

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11 Methodology applied for the greenhouse gas inventory for Greenland

11.1 Introduction

This chapter is Greenland's National Inventory Report (NIR) 2023 for submission to the United Nations Framework Convention on Climate Change and the Kyoto Protocol.

The following sections contain detailed information on Greenland's inventories for all the years from 1990 to 2021. The structure of the report follows the UNFCCC guidelines on reporting and review.

The issues addressed in this report are trends in greenhouse gas emission, a description of each IPCC category, uncertainty estimates, recalculations, planned improvements and procedures for quality assurance and control.

The annual emission inventories for the years 1990-2021 are reported in the Common Reporting Format (CRF) as requested in the reporting guidelines. The CRF-spreadsheets contain data on emissions, activity data and implied emission factors for each year. Emission trends are given for each greenhouse gas and for the total greenhouse gas emission in CO_2 equivalents.

According to the instrument of ratification, the Danish government has ratified the UNFCCC on behalf of Denmark, Greenland and the Faroe Islands.

The information in this chapter relates to Greenland only.

This report does not contain the full set of CRF Tables. However, the full set of CRF tables is available at the EIONET, Central Data Repository, kept by the European Environment Agency:
http://cdr.eionet.europa.eu/dk/Air_Emission_Inventories/Submission_UNFCCC

The greenhouse gas inventory submitted in 2023 is completed by Statistics Greenland with technical support from the Danish National Center of Environment and Energy (DCE). This report on methodology is written by Statistics Greenland with documental support by DCE.

11.1.1 Greenhouse gas

The greenhouse gases to be reported under the Climate Convention are:

- Carbon dioxide — CO_2
- Methane — CH_4
- Nitrous Oxide — N_2O
- Hydrofluorocarbons — HFCs
- Perfluorocarbons — PFCs
- Sulphur hexafluoride — SF_6
- Nitrogen triflouride — NF_3

According to the IPCC and their Fifth Assessment Report, which UNFCCC has decided to use as reference, the global warming potentials for a 100-year time horizon are:

- Carbon dioxide (CO_2) 1
- Methane (CH_4) 28
- Nitrous Oxide (N_2O) 265

Based on weight and a 100-year period, methane is thus a 28 times more powerful greenhouse gas than CO_2, and nitrous oxide is 265 times more powerful. Some of the other greenhouse gases (hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) have considerably higher global warming potential values.

The indirect greenhouse gases reported are nitrogen oxides (NO_x), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and sulphur dioxide (SO_2).

11.1.2 A description of the institutional arrangement for inventory preparation

All calculations and reporting in this 2023 submission has been conducted by Statistics Greenland. This includes reporting the Greenlandic national emission inventory to DCE in the Common Reporting Format in accordance with the UNFCCC guidelines.

DCE is responsible for reporting the national inventory for the Kingdom of Denmark to the UNFCCC. The inventory for LULUCF is carried out by DCE and the documentation of the inventory (Sections 11.6) is completed by the Danish LULUCF experts with data supplied by Statistics Greenland.

The work concerning the annual greenhouse gas emission inventory is carried out in cooperation with Greenlandic ministries, research institutes, organisations and companies.

Statistics Greenland

Statistics Greenland conducts an annual energy statistics in a format suitable for the emission inventory work and fuel-use data for the large combustion plants. Since 2009, annual surveys on emissions of F-gas have been conducted.

Agricultural Advisory Service (Ministry for Agriculture, Self-Sufficiency, Energy and Environment)

Background data on forestry, cropland and grassland, and statistics on livestock (sheep and reindeer).

Former Ministry of Nature and Environment

Data on waste and emission of F-gas. Annual Survey carried out by the former Ministry of Domestic Affairs, Nature and Environment until 2008 and by Statistics Greenland from 2009 and onwards.

Greenland Airport Authority (Ministry of Housing and Infrastructure)

Statistics on domestic and foreign flights to and from Greenland.

11.1.3 Brief description of the process of inventory preparation - data collection, data processing, data storage

The background data (activity data and emission factors) for estimation of the Greenlandic emission inventories is collected and stored in central databases at Statistics Greenland. The databases are in SAS/WPS format and handled with the World Programming System (WPS) software. The WPS programs are designed by Statistics Greenland. The methodologies and data sources used for the different sectors are described briefly in Section 11.1.4 and more in depth in Sections 11.3 to 11.7.

For each submission, databases and additional tools and submodels are frozen together with the resulting CRF-reporting format. The material is placed on servers at Statistics Greenland. The servers are subject to routine backup services. Material, which have been backed up is archived safely.

11.1.4 Brief general description of methodologies and data sources used

Greenland's air emission inventories are based on the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000), the Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC, 2003) and the CORINAIR methodology.

CORINAIR (COoRdination of INformation on AIR emissions) is a European air emission inventory programme for national sector-wise emission estimations, harmonised with the IPCC guidelines. To ensure estimates are as timely, consistent, transparent, accurate and comparable as possible, the inventory programme has developed calculation methodologies for most subsectors and software for storage and further data processing (EMEP/CORINAIR, 2007).

A thorough description of the CORINAIR inventory programme used for Danish emission estimations is given in Illerup et al. (2000). The CORINAIR calculation principle is to calculate the emissions as activities multiplied by emission factors. Activities are numbers referring to a specific process generating emissions, while an emission factor is the mass of emissions per unit activity. Information on activities to carry out the CORINAIR inventory is largely based on official statistics. The most consistent emission factors have been used either as national values or as default factors proposed by international guidelines.

A list of all subsectors at the most detailed level is given in Illerup et al. (2000) together with a translation between CORINAIR and IPCC codes for sector classifications.

The greenhouse gas inventory for Greenland includes the following sectors:

- Energy
- Industrial Processes and Product Use
- Agriculture
- Land Use, Land-use Change and Forestry
- Waste

The applied methodologies follow the IPCC Guidelines and IPCC Good Practice Guidance. In some cases the methodology is identical to the methodology applied in the Danish inventory, however, the availability of data – especially site specific data – do not allow the same methodology to be used for all the sectors. The brief methodological description is included below for the different sectors. Descriptions that are more thorough are included in Sections 11.3-11.7.

Energy

Fuel Combustion

The Greenlandic emission inventory for fuel combustion has been performed according to the IPCC tier 1 methodology. The inventory is based on activity data from the Greenlandic energy statistics and on emission factors for different fuels, plants and sectors.

Total fuel combustion is based on data from Polaroil, Air BP (earlier Statoil) and Malik Supply A/S. Polaroil imports fuel and distributes fuel in all parts of Greenland. Air BP imports and distributes fuel in Kangerlussuaq. Malik Supply A/S, a Danish company, re-distributes fuel bought from Polaroil to Greenlandic trawlers, ships etc. By using detailed data from Polaroil, Statoil and Malik Supply A/S it is possible to determine total import, total export, total international bunkers and total domestic fuel combustion.

Total domestic fuel combustion is divided into sectors and private households by using data from a survey on energy consumption, company specific sales data from Polaroil and local fuel distributors, relevant tax accountings and by estimation.

Fuel combustion in private households is estimated using detailed information from a number of local fuel distributors. Fuel deliveries are registered by buildings. In Greenland, each building has a unique number registered in the Greenlandic Area Register (NIN). By combining the NIN-register and the Danish Business Register (CVR) with statistics on housing and population, each building is labelled *private household* or located to a sector describing the main activity in the building. This new building-sector register, completed annually, is used extensively to determine the buyer of fuel delivered by Polaroil or local fuel distributors.

Fuel combustion in road traffic is based on a model designed by Statistics Greenland. The model contains data on the vehicle stock obtained from the Greenland Police Department's register on engine data. The vehicles are divided into broad categories of type e.g., personal car, lorry, taxi, truck, ambulance, motorbike etc. Each category is assigned with ratios on fuel type and mileage. Input data on mileage is derived from an annual survey among businesses and private road traffic since 2008. Each vehicle is divided in business categories or labelled *private vehicle* according to the owner. For each group the emissions are estimated by combining vehicle and annual mileage numbers with standard emission factors according to the type of fuel. However, the model does not take cold start or hot engines into account.

For air traffic annual emissions are based on activity data from Air Greenland A/S and sales data from the Greenland Airport Authority. For navigation, ferries and freight, annual emissions are based on activity data from Royal Arctic Line A/S (freight), Royal Arctic Tankers A/S (freight), and Arctic Umiaq Line A/S (passengers).

For further information please refer to Section 11.3.

Memo Items

International Aviation Bunkers

Previously, emissions from international aviation bunkers have been considered to be of neglible importance in terms of Greenland. For that matter the annual amount of jet fuel loaded into foreign aircrafts has been included as part of the IPCC category 1A3a Domestic Aviation. However, some misunderstanding has taken place and this assumption seems to be incorrect! New data has emerged regarding the distinction between domestic and international flights, and it seems possible that combustion of jet fuel in international bound aircrafts taking off from Greenland can be determined and reported as international aviation bunkers as from the coming 2024 submission. However, in this 2023 submission jet fuel loaded into foreign aircrafts is still included as part of the IPCC category 1A3a Domestic Aviation.

International Navigation Bunkers

Emissions from international marine bunkers are included from 2004 and onwards. Before 2004, international marine bunkers are considered to be of negligible importance.

Fugitive emissions

Greenland has no coal mines, no off-shore activities, no oil refineries, no natural gas transmission or distribution. For that reason, there have been no fugitive emissions from such activities in 1990-2009. However, in 2010 a Scottish company initiated a search for oil along the westcoast of Greenland. Three wells were drilled and tested in 2010. Five wells in 2011. There has been no oil exploration since 2011.

In the 2014 National Inventory Report calculation of fugitive emission was based on the annual number of drilled and tested wells and IPCC Guideline emission factors. Since the 2015 National Inventory report fugitive emission is to be based on the amount of drilled oil and gas and IPCC Guideline emission factors.

However, the Scottish company has not been able to provide the Government of Greenland with any information on the amount of oil and gas picked up during drillings in 2010 and 2011. To our knowledge, the Scottish company only discovered a few minor kicks with some minor inflow of water or gas during drillings.

With no data available, activity data in 2010 and 2011 has been marked with the notation key Not Applicable (NA). Since no amounts could be estimated, all fugitive emissions are assumed to be zero, and also marked with the notation key Not Applicable (NA). This decision has been made in agreement with the DCE.

Aside from energy production, some fugitive emission occurs in the distribution of fuel e.g., when refuelling from ships to on-shore tanks, onshore loading of fuel to ships and offshore loading of ships. The emission would only be in the form of NMVOC. The fugitive emission from loading/unloading of ships is currently not estimated.

Industrial Processes and Product Use

Mineral Industry

CO_2 emissions occur from limestone and dolomite use. Import statistics of limestone are used as activity data for estimating the emissions.

Chemical Industry
Greenland has no chemical industry.

Metal Industry
Greenland has no metal industry.

Non-energy Products from Fuels and Solvent Use
CO_2 emissions occur from paraffin wax use, road paving with asphalt and asphalt roofing. Import statistics of paraffin wax and asphalt are used as activity data for estimating the emissions.

The emission estimates for solvent use are also prepared by using import statistics of pure chemicals that fits the criteria for being considered a NMVOC compound. Additionally, import statistics are used for products containing NMVOC's. The NMVOC emission is then calculated in to a CO_2 emission by using a standard value for carbon content in the NMVOC's. For further information, see Section 11.4.

Electronics Industry
Greenland has no electronics industry.

Product Uses
Greenland has no production of halocarbons or SF_6. Data on consumption of F-gas (HFCs and SF_6) are obtained from an annual survey on consumption of halocarbons and SF_6 conducted by the Ministry of Industry and Labour. Information on emission of industrial gases is available from 1995 onwards. Greenland has no consumption of PFCs.

Product Uses as Substitutes for ODS
Consumption of halocarbons for refrigeration

Other Product Manufacture and Use
Consumption of SF_6 in electrical equipment.

Other Production
There are several manufacturers of fish products and one tannery. Emissions of NMVOC are estimated, but there are no emissions of greenhouse gases occurring.

For further information on the methodology for calculating emissions from industrial processes, please refer to Section 11.4.

Agriculture
Livestock, Enteric Fermentation and Manure Management
Agriculture is sparse in Greenland due to climatic conditions. However, sheep and reindeer are considered to contribute to emission of greenhouse gases. Enteric fermentation and manure management is assumed to contribute to emission of CH_4, and nitrogen excretion is assumed to contribute to emission of N_2O.

Activity data for livestock is on a one-year average basis from the agriculture statistics published by Statistics Greenland. Data concerning the land use and crop yield is obtained from the Agricultural Advisory Service.

Data concerning the feed consumption and nitrogen excretion from sheep is based on information from the Agricultural Advisory Service supplemented by data on imported feed. Data concerning the feed consumption and nitrogen excretion from reindeer is based on information from the Agricultural Advisory Service and information from an article on reindeer management in Greenland.

Emission of N_2O is closely related to the nitrogen balance. Thus, quite a lot of the activity data is related to the calculation of ammonia emission. National standards are used to estimate the amount of ammonia emission. When estimating the N_2O emission the IPCC standard value is used for all emission sources. The emission of CO_2 from Agricultural Soils is included in the LULUCF sector.

For a more thorough description of the methodology for the agricultural sector, please refer to Section 11.5.

Land Use, Land-Use Change and Forestry

Greenland is the world's largest non-continental island on the northern American continent between the Arctic Ocean and the North Atlantic Ocean, northeast of Canada. The northernmost point of Greenland, Cape Morris Jesup, is only 740 km from then North Pole. The southernmost point is Cape Farewell, which lies at about the same latitude as Oslo in Norway. Greenland is covering approx. 2,166,086 km^2. It has been estimated that 81 % is covered permanently with ice leaving only 410,449 km^2 ice free. The climate is Arctic to sub arctic with cool winters and cold summers. The capitol Nuuk is having an average temperature of 1.4°C.

Due to its cold climate the LULUCF sector is of minor importance in relation to the emission of green house gases. Only a very minor area is covered by forest of which the major part has been planted within the last 50 years. Cropland was introduced in year 2000 and grassland management within the last 30 years. The cold climate slows down the biological processes making all growth rates very low.

In total, the emission from the LULUC sector in 2021 has been estimated to a net source of 1.38 kt CO_2 equivalent or 0.2 % of the total Greenlandic emission.

Forest land

Greenland has a few forests, which may qualify to the FAO criteria of forest definitions. The major forest areas are:

A natural forest in the Qinngua valley of 45 ha consisting mainly of Betula Pubescens ssp. Czerepanovii, which in the period 1990 to 2021 has had an average height of six meters and approx. 100 trees per ha. It is thus assumed that it has had the same biomass for the whole period.

An additional 187 ha other planted forest. The largest of this is an arboretum (a research area) where different species and origins of trees are investigated which are adaptable to the harsh climate.

Cropland

In 1990, no annual crops were grown in Greenland. In 2021, 10.5 ha of cropland were used for annual crops. The primary production is potatoes. Potato fields are mainly managed by hand and primarily fens with a high content of organic matter, which is used for this purpose. It is thus assumed that the IPCC standard emission factor for boreal/cold areas of five tonnes C pr ha can be used although it is probably an overestimation due to the cold climate and the current management practice.

Grassland

In total is 242,000 hectares reported as grassland. The grasslands are located in mountainous areas used for grazing of sheep. Due to the global warming, there are some smaller areas, which have become improved fertilised grassland. The total area with improved grassland has increased from 490 ha in 1990 to 1,167 ha in 2021.

Wetlands

Reported area with wetlands consists only of water-reservoirs. Due to lack of methodology for methane emissions under arctic conditions, no emission estimates have been made, which is in accordance with the IPCC Good Practice Guidance guidelines.

Settlements

The few settlements are mainly built on cliffs with very sparse vegetation. Hence, it is assumed that no changes in C stock occur.

Other land

No emission estimates has been made since no data is available which is in accordance with IPCC Good Practice Guidance guidelines.

Harvested wood products

Due to an only marginal area with slowgrowing forests it is assumed that no national changes in the carbon stock in Harvested Wood Products (HWP) have taken place.

For a more thorough description of the methodology applied for LULUCF please refer to Section 11.6.

Waste

Solid Waste Disposal

The solid waste disposal in Greenland can be divided in the following processes:

- Managed waste disposal sites, anaerobic.
- Unmanaged waste disposal sites.

Biological Treatment of Solid waste

Greenland has no biological treatment of solid waste.

Incineration and Open Burning of Waste

Waste incineration with or without energy recovery and open burning of waste is both divided in the following processes:

- Waste incineration/Open burning, biogenic.
- Waste incineration/Open burning, non-biogenic.

Waste incineration with energy recovery is according to IPCC Guidelines included under the energy sector.

Information on amount of waste produced per year, amount of waste treated in the different processes, distribution between household and commercial waste, composition of the household waste and commercial waste, respectively, are provided by the Ministry of Environment and Nature.

Wastewater Treatment and Discharge

N_2O emission from human sewage is estimated. The calculation of the N_2O emission uses population data from Statistics Greenland website and an estimate for average protein consumption combined with default values from the IPCC Guidelines. No emissions of CH_4 are assumed to occur.

For more information, please refer to Section 11.7.

11.1.5 Brief description of key categories

A key category analysis (KCA) for year 1990 and 2021 has been carried out in accordance with the IPCC Good Practice Guidance.

The categorisation used results in a total of 39 categories. In the level KCA for the inventory for 1990, five key categories were identified. In the KCA for 2021, seven categories were identified as key categories due to the level whereas ten categories were key categories due to the trend.

Of the seven key sources due to level for the reporting year 2021 five are in the energy sector, of which CO_2 from liquid fuels excluding transport in the analysis contributes most with 74.2 % of the national total (this contribution and the percentage contributions in the following are results from the level KCA based on the absolute values of the emissions; this contribution as percentages may differ somewhat from the percentage used in the sectoral chapters). Of the remaining level key categories in the energy sector three are CO_2 from the transport sector and one is CO_2 from combustion of other fuels excluding transportation. Road transportation, domestic aviation and domestic navigation comprise respectively 6.7 %, 5.5 % and 4.7 % of the national total. The last two key categories are HFCs from the consumption of HFCs and CH_4 from enteric fermentation.

The trend assessment shows that N_2O from wastewater treatment and discharge, CO_2 from incineration and open burning of waste, CO_2 from grassland remaining grassland and N_2O from agricultural soils are key categories to the trend. Further five sources from the energy sector are also key categories to the trend as well as HFCs from the consumption of HFCs.

The categorisation used, results, etc. are included in Section 11.10 (Annex 1).

11.1.6 Information on QA/QC plan including verification

A number of measures are in place to ensure the quality of the Greenlandic greenhouse gas inventory.

The general QC activities include:

- Check that data are correctly moved between data processing steps e.g., it is ensured that the data are imported correctly from the emission spreadsheets/databases to the CRF Reporter.
- The time series are analysed. Any large fluctuations are investigated and explained/corrected.
- The recalculations are analysed, and the consistency of the emission estimates are verified.
- The completeness of the inventory is checked utilising the completeness checker incorporated in the CRF Reporter as well as expert knowledge from the inventory compilers.
- All references are checked, and it is ensured that the citations are correct.

These types of QC checks are recommended as tier 1 QC checks in the IPCC Good Practice Guidance (IPCC, 2000).

The Greenlandic emission inventory is reviewed by Danish emission experts, who provide input to the Greenlandic inventory compilers on necessary improvements etc. This is done as a QA procedure. When the emission estimates are transferred to DCE, the quality control system of the Danish emission inventory is applied to the Greenlandic data.

All information related to the Greenlandic emission estimates are documented and archived securely annually. This is done in order to ensure that any part of the inventory can be reproduced at a later stage if necessary.

In addition, source specific QA/QC activities are conducted; please see the associated paragraphs in the sectoral chapters.

11.1.7 General uncertainty evaluation

The uncertainty estimates are based on the Tier 1 methodology in the IPCC 2006 Guidelines (IPCC, 2006). Uncertainty estimates for the following sectors are included in the current year: fuel combustion, industrial processes and product use, solid waste, wastewater treatment and waste incineration, agriculture and LULUCF.

The uncertainties for the activity rates and emission factors are shown in Table 11.1.4. The estimated uncertainties for total GHG and for CO_2, CH_4, N_2O and F-gases are shown in Table 11.1.3. The base year for F-gases is 1995 and for all other sources, the base year is 1990. The total Greenlandic GHG emission is estimated with an uncertainty of ± 4.3 %. The trend in the GHG emission (since 1990) has been estimated with an uncertainty of -7.2 % ± 3.8 %-age points. The GHG uncertainty estimates do not consider the uncertainty of the GWP factors.

Regarding uncertainty the largest sources in the Greenlandic GHG Inventory are CO_2 and N_2O from liquid fuels in fuel combustion, N_2O emission from wastewater treatment, CH_4 emission from enteric fermentation, CH_4 emission from solid waste disposal and HFC from consumption of HFC. However, the result is skewed by the fact that more than 90 % of the Greenlandic Greenhouse gas emission is from fuel combustion of liquid fuels.

Table 11.1.3 Uncertainties 1990-2021.

	Uncertainty [%]	Trend [%]	Uncertainty in trend [%-age points]
GHG	± 4.3	-7.2	± 3.8
CO_2	± 3.5	-9.1	± 3.8
CH_4	± 55.7	-11.1	± 8.9
N_2O	± 119	-8.1	± 26.1
F-gases	± 51	+19 204	± 7 425

Table 11.1.4 Uncertainty rates for each emission source.

IPCC Source category	Gas	Base year emission	Year t emission	Activity data uncertainty	Emission factor uncertainty
		Gg CO_2 eqv.	Gg CO_2 eqv.	%	%
1A Liquid fuels	CO_2	620	553	3	2
1A Municipal waste	CO_2	2	9	3	25
1A Liquid fuels	CH_4	1	1	3	100
1A Municipal waste	CH_4	0	0	3	100
1A Biomass	CH_4	0	0	3	100
1A Liquid fuels	N_2O	2	2	3	500
1A Municipal waste	N_2O	0	0	3	500
1A Biomass	N_2O	0	0	3	200
1B2 Oil exploration	CO_2	0	0	3	1000
1B2 Oil exploration	CH_4	0	0	3	1000
1B2 Oil exploration	N_2O	0	0	3	1000
2A4 Limestone and dolomite use	CO_2	0	0	5	5
2D2 Paraffin wax use	CO_2	0	0	5	25
2D2 Paraffin wax use	N_2O	0	0	5	25
2D2 Paraffin wax use	CH_4	0	0	5	25
2D3 Solvent use	CO_2	0	0	5	25
2D3 Road paving with asphalt	CO_2	0	0	5	25
2D3 Road paving with asphalt	CH_4	0	0	5	25
2D3 Asphalt roofing	CO_2	0	0	5	25
2F Consumption of HFC	HFC	0	13	10	50
2G Consumption of SF6	SF_6	0	0	10	50
3A Enteric Fermentation	CH_4	8	6	10	100
3B Manure Management	CH_4	0	0	10	100
3B Manure Management	N_2O	1	1	10	100
3D Agricultural soils	N_2O	1	2	20	50
3G Liming	CO_2	0	0	5	50
4A Forest	CO_2	0	0	5	50
4A Forest	CH_4	0	0	5	50
4A Forest	N_2O	0	0	5	50
4B Cropland	CO_2	0	0	5	50
4C Grassland	CO_2	0	1	5	50
4C Grassland	CH_4	0	0	5	50
5A Solid Waste Disposal	CH_4	5	5	10	100
5C Incineration and open burning of waste	CO_2	3	3	10	25
5C Incineration and open burning of waste	CH_4	3	2	10	50
5C Incineration and open burning of waste	N_2O	1	1	10	100
5D Wastewater treatment and discharge	N_2O	7	5	30	100

11.1.8 General assessment of completeness

The present Greenlandic greenhouse gas emission inventory includes all major sources identified by the Revised IPCC Guidelines.

11.1.9 References

Agricultural Advisory Service: Statistics on livestock (sheep and reindeer) and background data on land use (cropland and grassland).

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11.2 Trends in Greenhouse Gas Emissions

11.2.1 Description and interpretation of emission trends for aggregated greenhouse gas emission

The GHG emissions are estimated according to the IPCC guidelines and are aggregated into five main sectors; Energy incl. Transport, Industrial Processes and Product Use, Agriculture, LULUCF, and Waste, see Figure 11.2.3 and Figure 11.2.4.

The greenhouse gases include CO_2, CH_4, N_2O, HFCs, PFCs and SF_6. However, Greenland has no consumption of PFC. In 2021 total emission of greenhouse gases excluding LULUCF was 606.55 Gg CO_2 equivalent, and 605.17 Gg CO_2 equivalent including LULUCF.

Figure 11.2.1 shows total greenhouse gas emission in CO_2 equivalents from 1990 to 2021. The emissions are not corrected for temperature variations. CO_2 is the most important greenhouse gas. In 2021 CO_2 contributed to the total emission in CO_2 equivalent excluding LULUCF with 93.6 %, followed by CH_4 with 2.4 %. N_2O and F-gases (HFCs and SF_6) contributed with 1.8 % and 2.1 %.

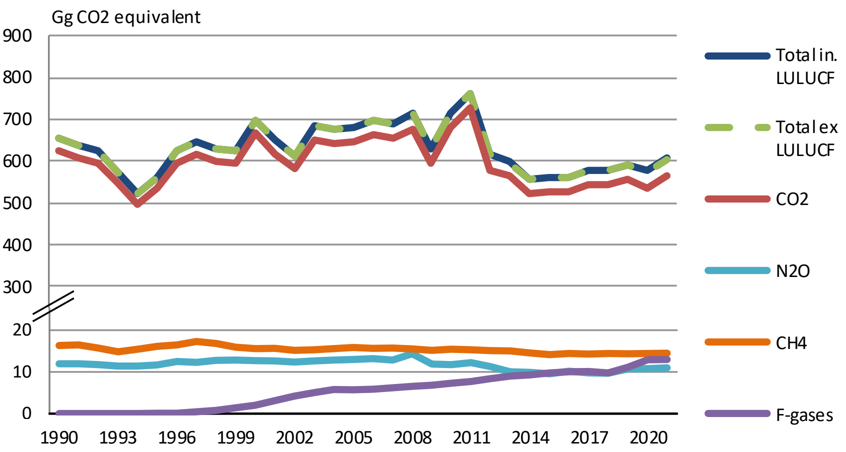


Figure 11.2.1 GHG- emission in CO_2 equivalents, time series 1990-2021.

Stationary combustion plants and transport represent the largest categories. Energy excluding transport contributed to the total emission in CO_2 equivalents excluding LULUCF with 76.4 % in 2021; see Figure 11.2.2. Transport contributed with 17.2 %. Industrial processes and product use, agriculture and waste contributed to the total emission in CO_2 equivalents all together with 6.4 %.

The net CO_2 emission forestry etc. is 0.2 % of the total emission in CO_2 equivalents in 2021. Total GHG emission in CO_2 equivalents excluding LULUCF has decreased by 7.3 % from 1990 to 2021 and decreased 7.1% including LULUCF. Comments on the overall trends etc. seen in Figure 11.2.1 and Figure 11.2.2 are given in the sections below on the individual greenhouse gases.

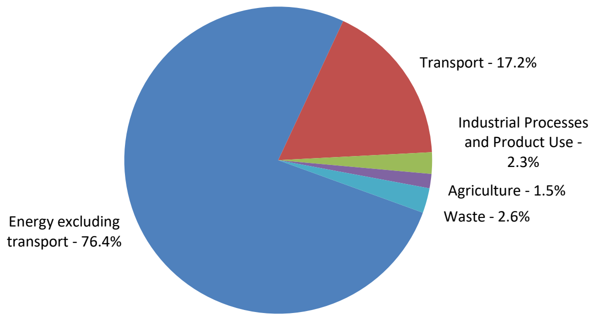


Figure 11.2.2 GHG- emission in CO_2 equivalents distributed on main sectors for 2021.

11.2.2 Description and interpretation of emission trends by gas

Carbon Dioxide

Emission of CO_2 accounted for 93.6 % of the total GHG emission in 2021. The largest source to emission of CO_2 is the energy sector comprising Fuel Combustion (Sectoral Approach). In 2021, the energy sector contributed to 99.3 % of the total CO_2 emission.

In Figure 11.2.3 and Figure 11.2.4 CO_2 emissions are split into several subcategories e.g., Energy Industries, Manufacturing Industries and Construction, Transport, Other energy sectors consisting of the subcategories Commercial and Institutional, Residential, Agriculture and Fishing. All remaining sectors are included in the subcategory *Other* including Agriculture, Industrial Processes and Product Use, and Incineration and Open Burning of waste.

The largest source to the emission of CO_2; the energy sector includes combustion of fossil fuels like gasoil, gasoline, jet kerosene etc. From this sector Agriculture, Forestry and Fisheries (AFF) contributes with 27.5 % making AFF the largest contributor in 2021 followed by Residental and Transports, both accounting for 18.1 %. Energy Industries accounted for 17.6 %.

Emissions from Energy Industries have been reduced a great deal in later years due to massive investments in hydro power plants. However, in 2010 and 2011 oil explorations were initiated along the west coast increasing fuel combustion and thus caused emissions in the Energy Industries to rise to the highest point ever. Since 2011, there has been a standstill in the oil exploring activities; see the blue curve in Figure 11.2.3.

Commercial and Institutions contributes with 10.0 % of the total CO_2 emission and Manufacturing Industries and Construction with 7.0 %. The category *Other* (containing the remaining sectors) contributed with 1.6 % of the CO_2 emissions in 2021.

Overall CO_2 emissions excluding LULUCF increased by 5.5 % from 2020 to 2021. In 2021, the actual CO_2 emission was 9.3 % lower than the emission in 1990 excluding LULUCF.

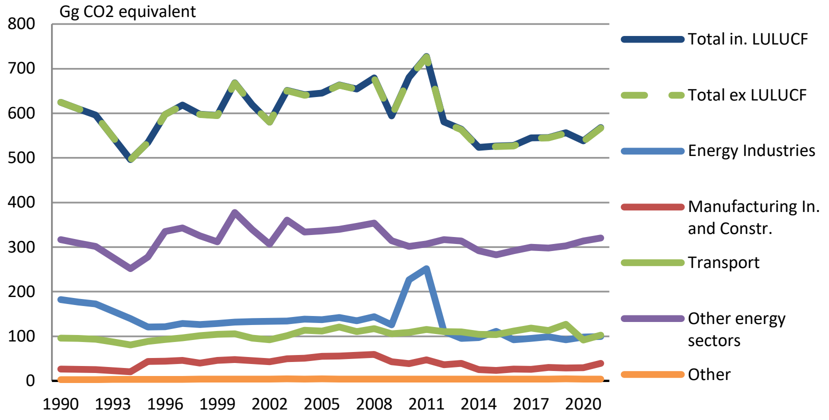


Figure 11.2.3 CO_2 emissions, time series for 1990-2021.

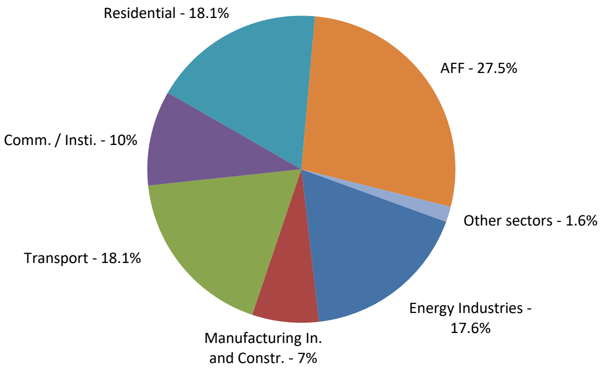


Figure 11.2.4 CO_2 emissions, distribution according to the main sectors for 2021.

Nitrous oxide

Waste, particularly wastewater treatment and discharge is the most important N_2O emission source in 2021 contributing 51.5 % to the total N_2O emissions, see Figure 11.2.6. Agricultural activities contributed 24.3 % to the total N_2O emissions in 2021. Fuel combustion including transport contributed 24.1 %. Since 1990, total emission of N_2O has decreased by 8.1 % excluding LULUCF.

Besides from a temporary increase in 2011 total N_2O emission has mostly been reduced in later years, 2009-2010 and 2011-2015 due to a fall in the amount of wastewater from industrial fishing plants and reduced use of inorganic fertilisers in agricultural activities, see Figure 11.2.5.

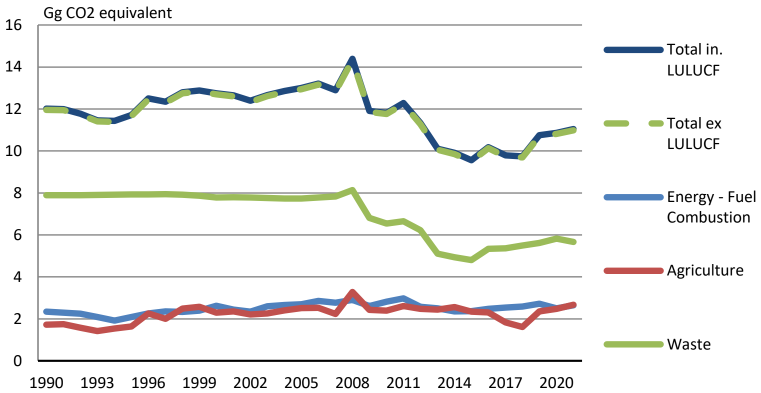


Figure 11.2.5 N_2O emissions, time series for 1990-2021.

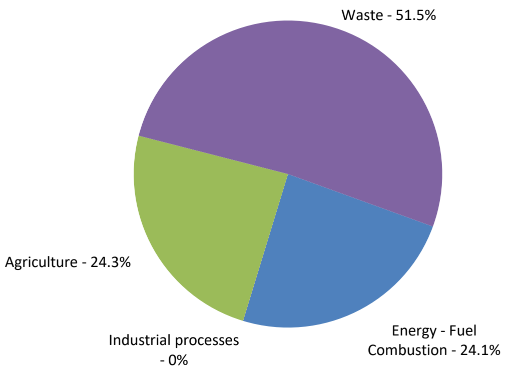


Figure 11.2.6 N_2O emissions, distribution according to the main sectors in 2021.

Methane

The largest sources of anthropogenic CH_4 emissions are waste handling activities contributing with contributing with 46.2 % of total CH_4 emission in 2021, see Figure 11.2.8. Agriculture contributes to 44.5 % of total emission and the energy sector with 9.2 % of total CH_4 emission in 2021.

The emission from agriculture derives from enteric fermentation (97.6 %) and management of animal manure (2.4 %). Since 1990, the number of sheep and reindeer has decreased. From 1990 to 2021, the emission of CH_4 from agricultural activities has decreased by 17.4%.

The emission of CH_4 from waste derives from solid waste disposal (70.7 %) and incineration and open burning (29.3 %). From 1990 to 2021, the emission of CH_4 from solid waste disposal has increased by 4.0 %, while emissions from waste incineration have decreased by 27.1 %. Overall emission of CH_4 from waste handling has decreased by 7.6 % from 1990 to 2021.

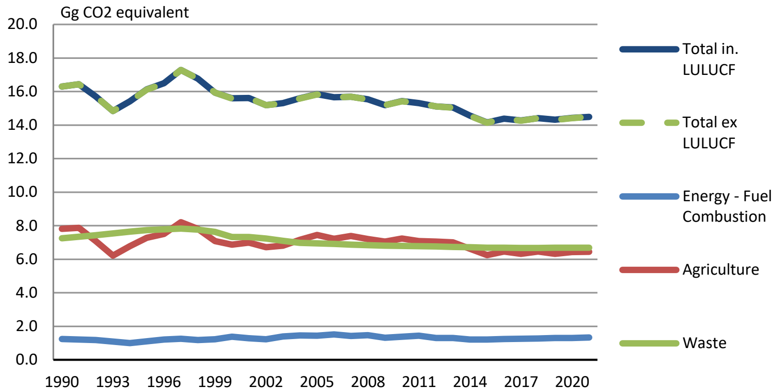


Figure 11.2.7 CH_4 emissions, time series for 1990-2021.

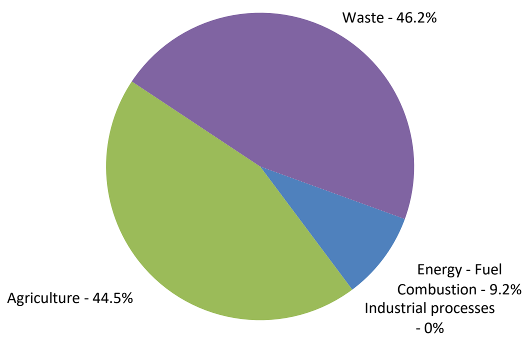


Figure 11.2.8 CH_4 emissions, distribution according to the main sectors in 2021.

HFCs, PFCs and SF_6

This part of the Greenlandic inventory only comprises a full data set for HFCs and SF_6 from 1995. Greenland has no consumption that leads to emission of PFCs. Since 1995 there has been a continuous and substantial increase in the contribution from F-gases calculated as the sum of emissions in CO_2 equivalents, see Figure 11.2.9.

This increasing emission from 1995 to 2020 is caused by an increase in the emission of HFCs. For the years 2004-2021, the relative increase is lower than for the years 1995 to 2004. The increase from 1995 to 2004 is 8,517 %. From 2004 to 2021 total emission increased by 124.0 %. SF_6 contributed to the F-gas sum in 1995 with 50.9 %. Environmental awareness and regulation of this gas under Danish law has reduced its use considerably since 1995. In 2021, the contribution from SF_6 to the emission of F-gases was only 0.02 %.

The use of HFCs has increased to a great extent. Today HFCs are by far the dominant F-gas, comprising 49.1 % in 1995, but 99.98 % in 2021. HFCs are mainly used as a refrigerant.

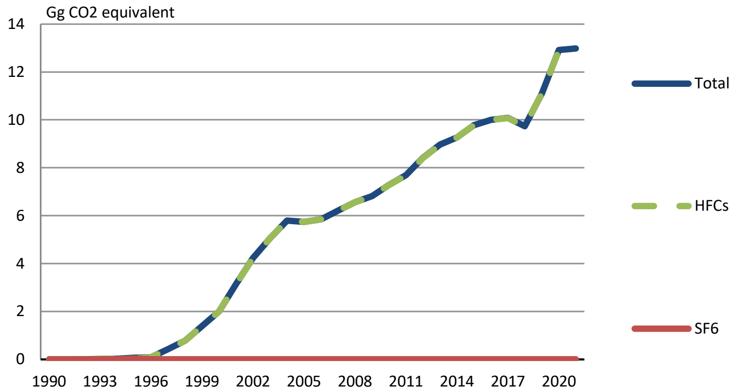


Figure 11.2.9 F-gas emissions, time series for 1990-2021.

11.2.3 Description and interpretation of emission trends by category

Energy

The emission of CO_2 from energy has decreased by 9.5 % from 1990 to 2021. Emissions decreased from 1990 until 1994 due to the implementation of the first hydro power plant. However, since 1994 combustion of fuel increased continuously causing emissions to increase as well. The reason for this increase was primarily higher demand for transportation and heating. Combustion of fuel may decrease in certain years due to milder temperatures. However, in 2010 and 2011, emissions increased significantly due to the initation of oil exploration, which caused CO_2 emission from energy to rise abrupt in 2010 and 2011. However, since 2011 oil exploration activities came to a standstill. At the same time, Greenlands fifth hydro power plant went into operation. In later years, the increasing supply in hydro power has let to a decrease in CO_2 emissions from energy.

Overall emission of CH_4 from energy has increased by 7.5 % from 1990 to 2021. However, emission of CH_4 from transportation has increased by 105.3 % from 1990 to 2021, mainly due to an increase in domestic aviation.

Emission of N_2O has increased by 13.4 % from 1990 to 2021.

Industrial processes and product use

Emissions from industrial processes and product use (consumption of halocarbons and SF_6) other than fuel combustion amount to 2.3 % of the total emission in CO_2 equivalents excluding LULUCF in 2021. The main source is consumptions of HFCs. Emission of F-gases have increased considerable since 1990.

Agriculture

The agricultural sector contributes with 1.5 % of the total GHG emissions excluding LULUCF in 2021, 44.5 % of the total CH_4 emission and 24.2 % of the total N_2O emission. The total emission from this sector has decreased by 4.4 % from 1990 to 2021. This decrease is due to a fall in the number of reindeer from 6,000 heads in 1990 to 3,000 heads in 2021 and a fall in the number of sheep from 19,929 in 1990 to 18,184 in 2021. The use of inorganic fertilisers has overall increased since 1990. CH_4 emission has decreased by 17.4 % from 1990 to 2021, primarily due to the fall in the number of livestock, both sheep and reindeer. In the same period N_2O emission has increased by 54.8 % due to a significantly increase in the use of fertilizers.

LULUCF

Emission from the LULUCF sector amount to just 0.2 % of total emission in 2021 of 1.37 kt CO_2 equivalent. Forests are assumed to be a source for the period 1990-2016. Since 2017 the Greenlandic forests has turned into a small net sink due to a reported slightly higher average height in two forests. In 2021 the net forest sink was 21.1 tonnes CO_2 equivalent. The emission from cropland is estimated to zero in 1990 (as there were no cropland in Greenland at the time) and a net source in 2021 of 25.2 tonnes CO_2 equivalent. The emission from grassland has been estimated to 211 tonnes CO_2 in 1990 increasing to 1,366 tonnes CO_2 equivalent in 2021.

Waste

The waste sector contributes with 2.6 % of the total greenhouse gas emissions in 2021, 46.2 % of the total CH_4 emission and 51.3 % of the total N_2O emission. Total emission from this sector has decreased by 10.5 % from 1990 to 2021. This decrease is caused by a drop in the CH_4 emission from incineration and open burning by 27.1 %, a decrease in the N_2O emission from incineration and open burning by 21.9 % and a decrease in N_2O emission from wastewater handling by 28.9 %.

Total GHG emission from waste incineration without energy recovery has decreased by 10.5 % from 1990 to 2021 due to an increasing amount of waste incineration with energy recovery and a continuous decrease in wastewater from industrial fishing plants in 2021. Emission from incinerated waste used for heat production is included in the 1A1 IPCC category Energy Industries.

11.2.4 Description and interpretation of emission trends for indirect greenhouse gases and SO_2

NO_X

The largest sources to emission of NO_X are AFF (Agriculture, Forestry and Fisheries) followed by Transport and combustion in Energy Industries (public power and district heating plants). The AFF-sector is the most contributing sector to the emission of NO_X. In 2021, 57.8 % of the Greenlandic emission of NO_X came from AFF-related activities. The emission of NO_X from AFF varies from year to year. The emissions from transport obtain 25.5 % of total emissions in 2021.

From 1990 to 2021, emission of NO_X from AFF has increased by 50.6 %, while emissions from transport have increased by 16.2 %. In the same period, total emission of NO_X has increased by 18.7 %.

The emissions from energy industries obtain 6.2 % of total emission in 2021. The emission from energy industries have decreased by 44.6 % from 1990 to 2021. The decrease is due to a continuous substitution from fossil fuels to hydro power.

Emission of NO_X from waste handling obtains 1.0 % of total emission in 2021, see Figure 11.2.10.

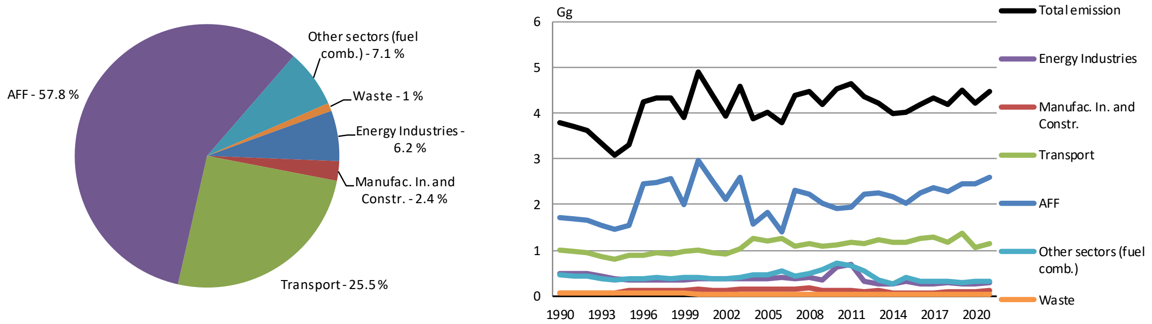


Figure 11.2.10 NO_X emissions. Distribution according to the main sectors (2021) and time series (1990-2021).

CO

Mobile sources like transport and AFF (agriculture, forestry and fisheries) contribute significantly to the total emission of this pollutant. In 2021 Transport is the largest contributor to the total CO emission, see Figure 11.2.11.

Total CO emission has increased by 50.5 % from 1990 to 2021, largely due to increasing emissions from road transportation and civil aviation. Emissions from energy industries have been cut by 46.0 % since 1990, while emissions from transport have increased by 133.0 %.

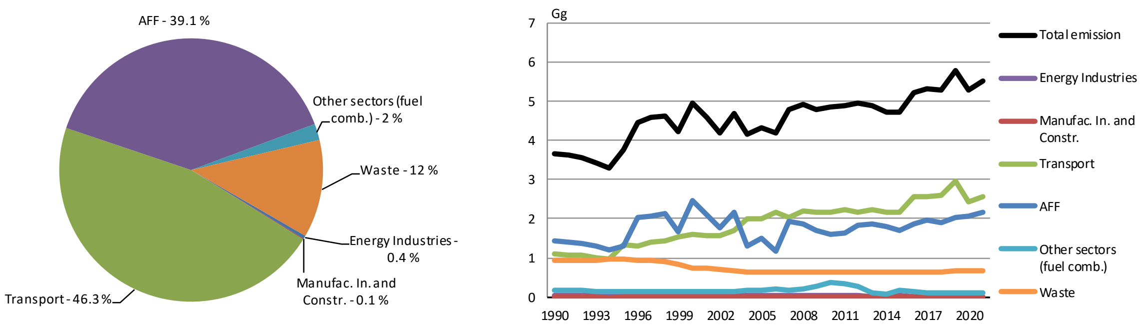


Figure 11.2.11 CO emissions. Distribution according to the main sectors (2021), and time series (1990-2021).

NMVOC

The emissions of NMVOC originate from many different sources and can be divided into two main groups: incomplete combustion and evaporation. Road vehicles and other mobile sources such as national navigation vessels fishing vessels and off-road machinery are the main sources of NMVOC emissions from incomplete combustion processes. Road transportation and fishing vessels are the main contributors to this pollutant. Road transportation is included under transportation, which obtain 45.4 % of total NMVOC emission in 2021.

Fishing vessels are included under AFF (agriculture, forestry and fisheries), which obtain 38.9 % of total NMVOC emission in 2021, see Figure 11.2.12.

The evaporative emissions mainly originate from the use of solvents and the extraction, handling and storage of oil. Emissions from solvent and other product use are included under Industrial Processes and Product Use. The emission from this sector has increased by 7.2 % from 1990 to 2021.

Total anthropogenic emission of NMVOC has increased by 56.7 % from 1990 to 2021, largely due to the increase in road transportation and AFF activities.

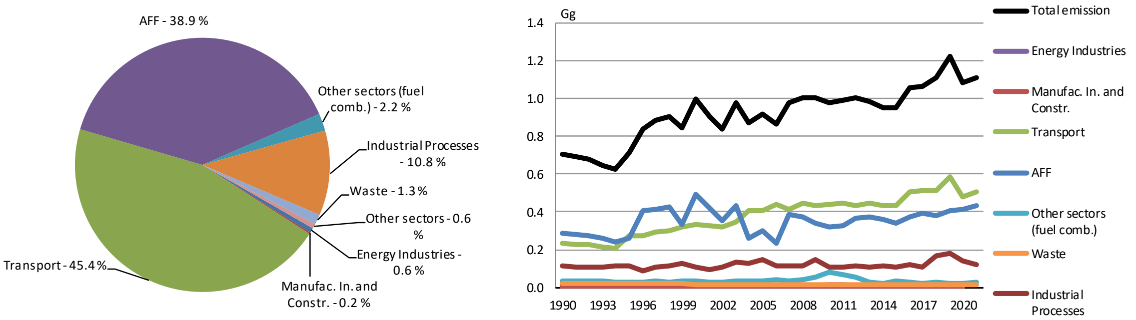


Figure 11.2.12 NMVOC emissions. Distribution according to the main sectors (2021), and time series (1990-2021).

SO_2

The main part of the SO_2 emission originates from the combustion of fossil fuels mainly gasoil in public power and district heating plants. From 1990 to 2021, total emission of SO_2 decreased by 11.9 %.

Emissions from AFF (Agriculture, Forestry and Fisheries) obtain 26.4 % of total SO_2 emission in 2021 followed by Energy Industries obtaining 21.5 %. Emissions from other industrial combustion plants, non-industrial combustion plants and mobile sources are likewise important. Transportation contributed with 11.8 % of total SO_2 emission in 2021.

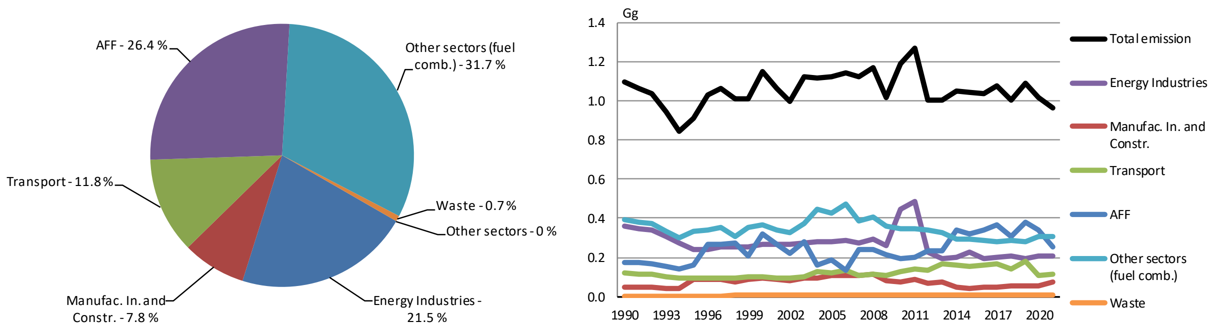


Figure 11.2.13 SO_2 emissions. Distribution according to the main sectors (2021), and time series (1990-2021).

11.3 Energy (CRF sector 1)

11.3.1 Overview of sector

The emission of greenhouse gases from energy activities includes CO_2, CH_4 and N_2O emission from fuel combustion. In 2010 fugitive emission of CO_2, CH_4 and N_2O occurred for the first time due to the initiation of well drilling and testing for oil and gas. However, since it has been impossible to obtain any information on the amount of oil and gas picked up during drillings in 2010 and 2011, fugitive emissions have been labelled with the notation key NA.

Emissions from the energy sector are reported in CRF Tables 1.A(a), 1.A(b), 1.A(c), 1.A(d) and 1.B. Furthermore, the emission of non-methane volatile organic compounds (NMVOC), NO_X, CO and SO_2 from fuel combustion is given in CRF Table 1.

Summary tables for the energy sector are shown in Table 11.3.1.

Table 11.3.1 Emission of CO_2 from the Energy Sector.

Greenhouse gas source and sink categories	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
						Gg					
1. Energy	621.6	606.8	592.7	542.8	492.7	531.1	593.6	614.2	593.0	590.7	664.0
A. Fuel Combustion (Sectoral Approach)	621.6	606.8	592.7	542.8	492.7	531.1	593.6	614.2	593.0	590.7	664.0
1 . Energy Industries	182.2	177.0	172.8	156.4	139.9	120.8	121.6	128.6	126.5	128.7	132.1
2 . Manufacturing Industries and Construction	26.5	25.7	25.1	22.6	20.2	43.8	44.5	46.2	40.0	45.8	48.1
3 . Transport	96.1	95.6	93.6	87.2	80.8	88.8	92.7	96.7	101.2	104.5	105.9
4 . Other Sectors	308.7	300.6	293.5	269.5	245.5	271.1	328.1	336.2	318.7	305.1	371.2
5 . Other	8.2	8.0	7.8	7.0	6.3	6.6	6.6	6.6	6.6	6.6	6.6
B . Fugitive Emissions from Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
C . CO_2 Transport and Storage	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1. Energy	614.5	576.2	646.2	636.4	640.5	658.8	649.7	674.3	589.4	675.4	722.0
A. Fuel Combustion (Sectoral Approach)	614.5	576.2	646.2	636.4	640.5	658.8	649.7	674.3	589.4	675.4	722.0
1 . Energy Industries	133.2	133.9	134.5	138.5	137.1	142.4	135.1	144.0	126.0	226.5	251.8
2 . Manufacturing Industries and Construction	45.7	43.2	49.8	50.7	55.1	55.7	57.4	59.4	43.2	38.7	47.3
3 . Transport	96.1	92.4	101.4	113.6	111.9	121.2	110.4	117.1	105.9	108.5	115.5
4 . Other Sectors	332.9	300.1	354.0	326.2	329.1	330.0	339.1	343.9	298.3	277.4	286.0
5 . Other	6.6	6.6	6.6	7.5	7.3	9.7	7.7	10.0	16.0	24.4	21.3
B . Fugitive Emissions from Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
C . CO_2 Transport and Storage	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
continued	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	
1. Energy	575.6	558.9	518.4	521.5	522.5	539.7	540.3	551.0	532.9	562.5	
A. Fuel Combustion (Sectoral Approach)	575.6	558.9	518.4	521.5	522.5	539.7	540.3	551.0	532.9	562.5	
1 . Energy Industries	111.2	95.5	96.9	111.2	92.2	95.3	99.2	92.4	98.1	99.8	
2 . Manufacturing Industries and Construction	36.5	39.3	25.2	23.4	26.5	26.0	30.3	29.1	29.3	39.7	
3 . Transport	110.7	110.1	104.7	104.1	111.8	118.6	112.7	126.7	91.9	102.8	
4 . Other Sectors	301.4	309.0	289.1	273.0	286.1	295.1	293.0	298.5	309.4	315.3	
5 . Other	15.6	4.9	2.4	9.7	6.0	4.7	5.1	4.3	4.1	5.0	
B . Fugitive Emissions from Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
C . CO_2 Transport and Storage	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	

Table 11.3.2 Emission of CH_4 from the Energy Sector.

Greenhouse gas source and sink categories	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
					Gg						
1. Energy	0.05	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.06
A. Fuel Combustion (Sectoral Approach)	0.05	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.06
1 . Energy Industries	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
2 . Manufacturing Industries and Construction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 . Transport	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.01
4 . Other Sectors	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.04
5 . Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B . Fugitive Emissions from Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1. Energy	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06
A. Fuel Combustion (Sectoral Approach)	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06
1 . Energy Industries	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
2 . Manufacturing Industries and Construction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 . Transport	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4 . Other Sectors	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03
5 . Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B . Fugitive Emissions from Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NA	NA

continued	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
1. Energy	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
A. Fuel Combustion (Sectoral Approach)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1 . Energy Industries	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
2 . Manufacturing Industries and Construction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 . Transport	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4 . Other Sectors	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
5 . Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B . Fugitive Emissions from Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table 11.3.3 Emission of N_2O from the Energy Sector.

Greenhouse gas source and sink categories	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
						Gg					
1. Energy	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
A. Fuel Combustion (Sectoral Approach)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1 . Energy Industries	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 . Manufacturing Industries and Construction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 . Transport	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4 . Other Sectors	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5 . Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B . Fugitive Emissions from Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1. Energy	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
A. Fuel Combustion (Sectoral Approach)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1 . Energy Industries	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 . Manufacturing Industries and Construction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 . Transport	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4 . Other Sectors	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5 . Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B . Fugitive Emissions from Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NA	NA
continued	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	
1. Energy	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
A. Fuel Combustion (Sectoral Approach)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
1 . Energy Industries	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2 . Manufacturing Industries and Construction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
3 . Transport	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
4 . Other Sectors	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
5 . Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
B . Fugitive Emissions from Fuels	NA	NA	NO	NO	NO	NO	NO	NO	NO	NO	

11.3.2 Source category description

In this section emission source categories, fuel consumption data and emission data are presented.

Activity data on fuel consumption is based on the same methology that Statistic Greenland has used to the annual statistics on energy previously published by Statistics Greenland and information on waste incineration with energy recovery. Annual statistics on energy is divided into sectors according to the Greenlandic Business Register (GB2018). The register comprises 745 business categories. Official statistics on energy is published by aggregation into 34 categories.

In the Greenlandic emission data, all activity rates and emissions are based on the official statistics on energy. However, in order to fit the new CRF format fuel consumption from the official statistics on energy is further aggregated into 19 sectors.

Fuel combustion

In 2021, total fuel combustion was 7,855 TJ of which 7,635 TJ was liquid fossil fuels.

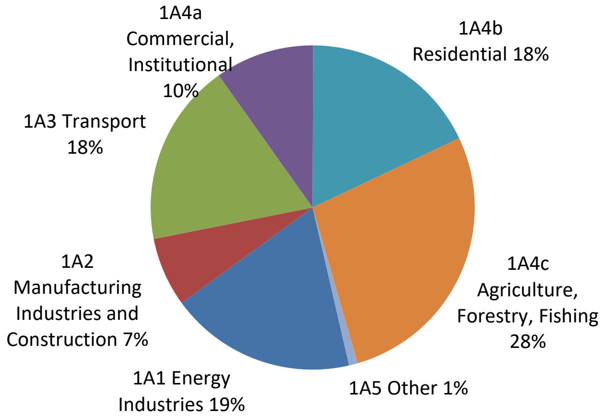


Figure 11.3.1 Fuel combustion rates, fossil fuels 2021 (Statistics Greenland).

In Greenland gasoil, kerosene and gasoline are used in fuel combustion. Fueloil was imported from 2010 to 2019 and combusted in ships. Gasoil and kerosene are the most utilised fuels. Gasoil is used in power plants to produce electricity and heat, as well as in district heating, private households, industries and for transportation. In 2010 and 2011 the combustion of gasoil increased significantly due to oil explorations. Due to a standstill in oil explorations total fuel combustion dropped again in 2012.

Kerosene is primarily used in aviation as jetfuel, but also for heating in minor settlements.

Activity data on the consumption of Liquid Petrol Gas (LPG) exists for the full period 1990-2021. However, consumption of LPG amount to less than 1 % of total fuel combustion, see Figure 11.3.2.

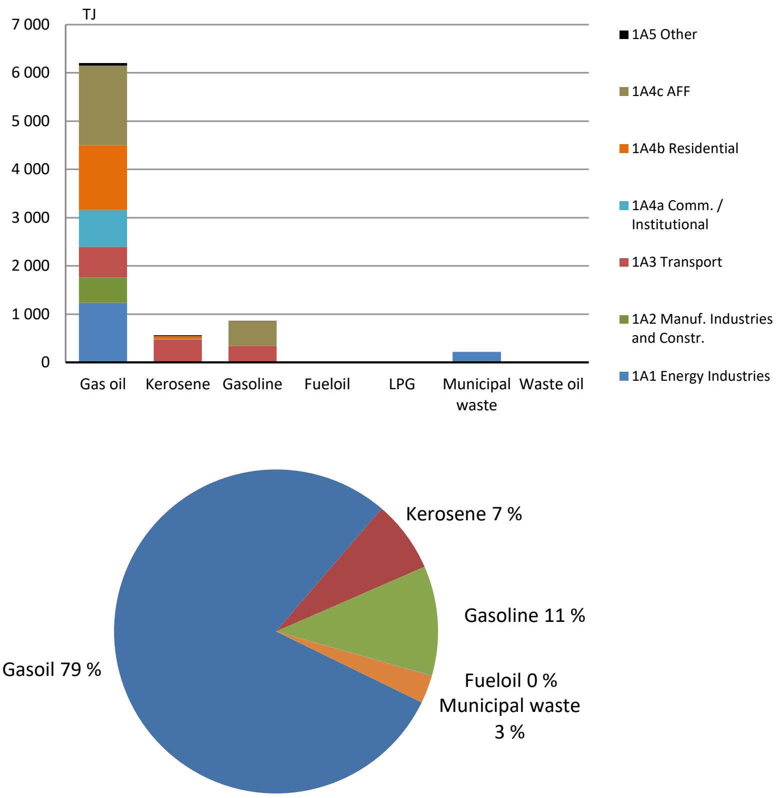
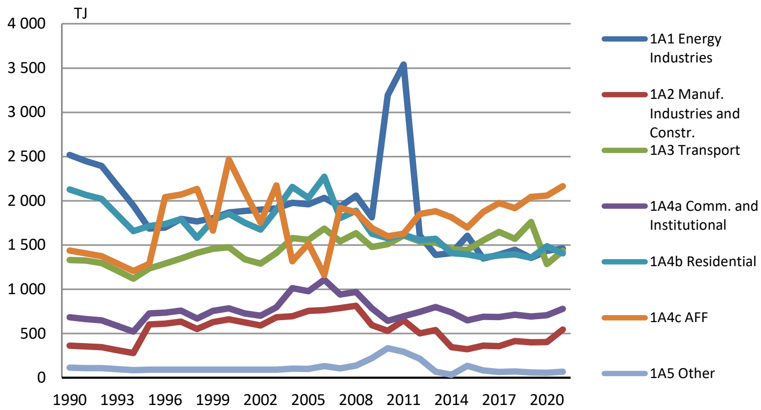


Figure 11.3.2 Fuel combustion, 2021 (Statistics Greenland).

Time series on fuel consumption are presented in Figure 11.3.3. Total fuel consumption has decreased by 8.4 % from 1990 to 2021. This overall decrease in fuel consumption is caused by a drop in the consumption of liquid fossil by 10.5 %. Consumption of renewable waste-energy has increased continuously with a total increase of 385.9 % from 1990 to 2021. The dropping fuel consumption in 2011-2014 was caused by an overall recession in the Greenlandic economy and the continuous substitution of liquid fuel with electricity from hydro power in the energy sector. In 2021, fuel consumptions increased by 5.8 %.



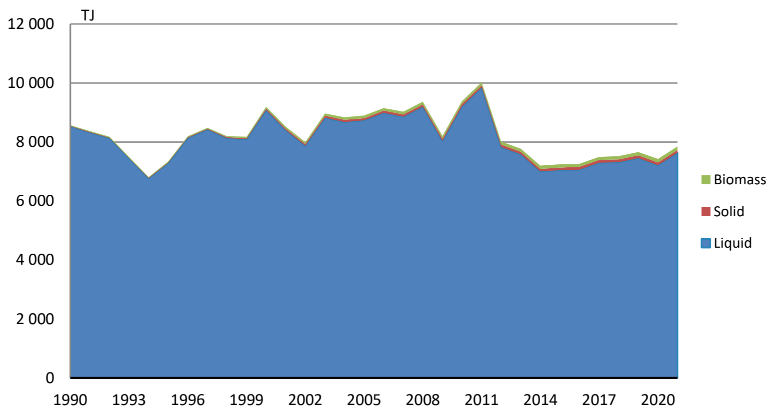


Figure 11.3.3 Fuel consumption time series 1990-2021 (Statistics Greenland).

Fuel consumption is dominated by liquid fuels e.g., gasoil, kerosene and gasoline. In 2021 total fuel consumption consists of 97.2 % liquid fuels, 1.5 % biomass and 1.3 % solid fuels.

Fuel consumption regarding Agriculture, Forestry and Fisheries (AFF) accounted for 27.6 % of total fuel sonsumption in 2021 making AFF the largest energy consuming sector. Before 2004, time series on fuel combustion in this sector varied a great deal due to fluctuations in fishing activities from year to year. However, some uncertainty is expected in the 1990-2003 time series on fuel consumption in Agriculture, Forestry and Fisheries.

Fuel consumption in Energy Industries accounted for 18.6 % of total fuel consumption in 2021 making Energy Industries the second largest energy consuming sector. Fluctuations in fuel consumption are largely a result of variation in outdoor temperatures from year to year, which also causes fluctuations in fuel consumption in Energy Industries.

Fuel consumption in Transport accounted for 18.3 % of total fuel consumption in 2021, while Residentials accounted for 17.9 %.

For 2004-2021 Statistics Greenland has conducted statistics on energy including detailed information on fuel consumption in businesses and private households; see Section 11.3.3. Compared to the new statistics on energy the historic construction of time series on fuel consumption in 1990-2003 was based on a much simpler method. Some uncertainty is therefore to be expected in the 1990-2003 time series on sector-divided fuel consumption.

Fugitive Emissions from Fuels

Greenland has no coal mines, no offshore activities, no oil refineries, no natural gas transmission or distribution. For that reason, there have been no fugitive emissions from such activities in 1990-2009. However, in 2010 a Scottish company initiated a search for oil along the westcoast of Greenland. Three wells were drilled and tested in 2010. Five wells in 2011. There has been no drilling activitiy since 2011.

In the 2014 National Inventory Report calculation of fugitive emission was based on the annual number of drilled and tested wells and IPCC Guideline emission factors. As from the 2015 National Inventory report fugitive emission is to be based on the amount of drilled oil and gas and IPCC Guideline emission factors.

However, the Scottish company has not been able to provide the Greenland Government with any information on the amount of oil and gas picked up during drillings in 2010 and 2011. To our knowledge the Scottish company only discovered a few minor kicks with some minor inflow of water or gas during drillings.

With no data available, activity data in 2010 and 2011 has been marked with the notation key Not Applicable (NA). Since no amounts could be estimated, all fugitive emissions are assumed to be zeo, and marked with the notation key Not Applicable (NA). This decision has been made in agreement with the DCE.

Besides energy production some fugitive emission occurs in the distribution of fuel e.g., when refuelling from ships to on-shore tanks, onshore loading of fuel to ships and offshore loading of ships. The emission would only be in the form of NMVOC. The fugitive emission from loading/unloading of ships is currently not estimated.

International bunker fuels

International Aviation Bunkers

Emissions from international aviation bunkers are considered to be of neglible importance. The Greenland Airport Authority has reported the annual amount of jet fuel loaded into foreign aircrafts including Danish aircrafts. However, it is still not possible to distinguish between Danish aircrafts and other aircrafts. Since most foreign aircrafts by far are Danish the annual amount of jet fuel loaded into foreign aircrafts are therefore included as part of the IPCC category 1A3a Domestic aviation.

International Navigation Bunkers

Emission from international marine bunkers is included from 2004 and onwards. Before 2004 international marine bunkers are considered to be of neglible importance.

Feedstocks, reductants and other non-energy use of fuels

At the moment, Greenland has no production or use of feedstocks. Emissions from non-energy use of fuels (e.g., bitumen and solvents) are included in the sector Industrial Processes and Product Use (CRF sector 2).

11.3.3 Methodological issues

Activity data

The Greenlandic emission inventory for fuel combustion has been performed according to the IPCC tier 1 methodology. The inventory is based on activity data from the Greenlandic energy statistics and on emission factors for different fuels, plants and sectors.

Total fuel combustion is based on data from Polaroil, Air BP and Malik Supply A/S. Polaroil imports and distributes fuel in all parts of Greenland. Air BP imports and distributes fuel in Kangerlussuaq. Malik Supply A/S, a Danish company, re-distributes fuel bought from Polaroil to Greenlandic trawlers, ships etc. By using detailed data from Polaroil, Air BP and Malik Supply A/S it is possible to determine total import, total export, total international bunkers and total domestic fuel combustion.

Next, total domestic fuel combustion is divided into business sectors and private households by using data from a survey on energy consumption, company specific sales data from Polaroil and local fuel distributors, relevant tax accountings, and by estimation.

Since 2008 Statistics Greenland has conducted an annual survey among larger companies. By completing a questionnaire each company returns detailed information on annual consumption of specific types of fuel. The survey covered 42.6 % of total GHG emission from energy combustion in 2021, see Table 11.3.4.

By using detailed information on sales from Polaroil and local fuel distributors it is possible to determine fuel combustion in private businesses and public offices with an automatic deal on supply. Sales data covered 15.9 % of total GHG emission from energy combustion in 2021, see Table 11.3.4.

Tax accountings in DKK are used to determine annual consumption of fuel in private businesses, in municipalities, and within the Greenland Government. At the moment, tax accountings are primarily used for determining fuel combustion in municipalities and public offices in settlements. Accountings cover 6.0 % of total GHG emission from energy combustion in 2021, see Table 11.3.4.

The remaining amount of total inland fuel combustion 25.5 % - is divided into sectors and private households by estimation. This work is carried out by involving statistical material on population, housing, and fisheries and hunting. Danish Business Register (CVR) is used to divide remaining companies into sectors. Information on employees, operating units, vehicles etc. is used to determine the activity in each company.

Fuel combustion in private households is estimated using detailed information from a number of local fuel distributors. Fuel deliveries are registered by buildings. In Greenland each building has a unique number registered in the Greenlandic Area Register (NIN). By combining the NIN-register and the CVR-register (see above) with statistics on housing and population each building is labelled *private household* or located to a sector describing the main activity in the building. This new building-sector register, completed annually, is used extensively to determine the buyer of fuel delivered by Polaroil or local fuel distributors.

Fuel combustion in road traffic is based on a model designed by Statistics Greenland. The model contains data on the vehicle stock obtained from the Greenland Police Department's register on engine data. The vehicles are divided into broad categories of type e.g., personal car, lorry, taxi, truck, ambulance, motorbike etc. Each category is assigned with ratios on fuel type and mileage. Input data on mileage is derived from an annual survey among businesses and private road traffic in 2008-2021. Each vehicle is divided in business categories or labelled *private vehicle* according to the owner. For each group the emissions are estimated by combining vehicle and annual mileage numbers with standard emission factors according to the type of fuel. The model does not take cold start or hot engines into account.

For air traffic annual emissions are based on activity data from Air Greenland A/S and sales data from the Greenland Airport Authority. For navigation, ferries and freight, annual emissions are based on activity data from Royal Arctic Line A/S (freight), Royal Arctic Tankers A/S (freight) and Arctic Umiaq Line A/S (passengers).

Table 11.3.4 shows the part of total CO_2 emission divided into sources - survey, specific sales data, tax accountings, and estimation.

Table 11.3.4 Allocation of CO_2 emission from fuel combustion into sources to sectoral division (2007-2021).

	2007	2008	2009	2010	2011	2012	2013
				Pct.			
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Survey	49.6	50.3	52.8	63.0	61.3	53.2	52.2
Sales data from Polaroil	3.6	3.4	3.0	4.2	5.0	5.7	6.3
Sales data from local fuel distributors	5.1	6.6	6.5	5.0	5.6	6.1	5.2
Accountings	12.8	12.2	12.7	10.8	11.0	13.1	15.4
Estimation	29.0	27.5	25.0	17.0	17.0	21.8	21.0
continued	2014	2015	2016	2017	2018	2019	2020
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Survey	44.8	47.5	41.4	44.0	46.3	42.2	48.7
Sales data from Polaroil	6.8	7.0	6.9	6.4	6.8	5.9	15.5
Sales data from local fuel distributors	4.6	4.2	5.0	5.8	5.6	6.0	0.0
Accountings	15.6	16.9	20.5	13.9	14.6	14.6	7.0
Estimation	28.3	24.4	26.2	30.0	26.7	31.4	28.9
continued	2021						
Total	100.0						
Survey	52.6						
Sales data from Polaroil	11.4						
Sales data from local fuel distributors	4.5						
Accountings	6.0						
Estimation	25.5						

The procedure described above is used to determine fuel combustion in sectors and private households during the period 2004-2021. Formerly, the period 1990-2003, activity data on sectors and private households were estimated using aggregated statistics on population, housing, companies, data on sales from Polaroil, and data on energy consumption in larger companies.

An increasing part of municipal waste incineration is utilised for heat and power production. Thus, incineration with energy-recovery is included in the Energy sector. Table 11.3.5 shows the activity data on fuel combustion for the period 1990-2021.

Table 11.3.5 Activity data on fuel combustion (SINK categories).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
					TJ					
Total	8 572	8 370	8 179	7 496	6 812	7 342	8 201	8 486	8 201	8 178
Energy industries	2 519	2 447	2 393	2 169	1 944	1 685	1 698	1 794	1 766	1 805
Manufacturing industries and construction	363	353	344	311	278	601	610	633	549	628
Domestic aviation	541	556	547	524	500	581	636	660	775	748
Road transport	501	488	476	437	397	370	369	387	361	401
Domestic navigation	288	280	273	248	224	285	285	299	275	308
Commercial/Institutional	683	663	647	584	521	726	734	759	669	754
Residential	2 127	2 068	2 020	1 838	1 657	1 716	1 737	1 792	1 581	1 780
AFF	1 437	1 406	1 372	1 289	1 206	1 288	2 040	2 071	2 134	1 664
Other	113	110	107	97	86	91	91	91	91	91
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Total	9 199	8 521	8 002	8 970	8 840	8 898	9 153	9 031	9 371	8 207
Energy industries	1 868	1 885	1 900	1 915	1 976	1 959	2 032	1 934	2 057	1 813
Manufacturing industries and construction	660	626	592	682	696	755	763	787	814	592
Domestic aviation	738	632	603	646	608	633	691	701	753	635
Road transport	417	399	388	433	508	504	575	504	535	493
Domestic navigation	321	308	297	334	464	420	421	334	347	350
Commercial/Institutional	784	726	700	797	1 014	979	1 107	939	969	784
Residential	1 854	1 751	1 674	1 899	2 155	2 032	2 271	1 804	1 888	1 628
AFF	2 466	2 101	1 756	2 174	1 317	1 516	1 161	1 921	1 871	1 691
Other	91	91	91	91	103	100	132	105	138	219
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total	9 387	10 026	8 014	7 773	7 199	7 244	7 266	7 501	7 524	7 665
Energy industries	3 193	3 542	1 609	1 388	1 408	1 606	1 346	1 390	1 445	1 353
Manufacturing and construction	531	649	501	539	346	322	363	356	415	400
Domestic aviation	654	723	660	593	555	560	593	673	665	696
Road transport	478	479	469	462	434	427	470	460	481	542
National navigation	378	405	413	471	463	457	491	514	425	523
Commercial/Institutional	641	694	742	800	737	647	689	685	713	692
Residential	1 577	1 615	1 554	1 570	1 408	1 394	1 358	1 382	1 394	1 355
AFF	1 600	1 628	1 851	1 883	1 814	1 698	1 873	1 974	1 916	2 043
Other	335	292	215	67	33	134	82	65	70	59
continued	2020	2021								
Total	7 426	7 855								
Energy industries	1 433	1 460								
Manufacturing and construction	402	544								
Domestic aviation	378	468								
Road transport	545	570								
National navigation	361	397								
Commercial/Institutional	705	777								
Residential	1 486	1 407								
AFF	2 058	2 164								
Other	57	68								

Emission factors

The CO_2 emission factors applied are presented in Table 11.3.6. For liquid fossil fuels and the biomass part of municipal waste the same emission factor is applied for 1990-2021. Default emission factors are used for all liquid fossil fuels except for gasoil.

In 2013, a technical analysis was conducted on the arctic gasoil that is by far the most dominant type of fuel in Greenland. The analysis was conducted by the Danish Technological Institute in order to gain a country specific emission factor on the Greenlandic gasoil, see Table 11.3.6 and Section 11.3.7 for further details.

In reporting to the Climate Convention, the CO_2 emission is aggregated to three fuel types: Liquid fuel, Biomass and Other fuel.

The CO_2 emission from incineration of municipal waste with energy-recovery is divided into two parts: The emission from combustion of the fossil content of waste, which is included in the Greenlandic total, and the emission from combustion of the rest of the waste – the biomass part, which is reported as a memo item.

In the IPCC reporting, the fossil part of the waste and the associated emissions from fuel combustion of the plastic content of the waste is reported in the fuel category, *Other fuels*. Greenland uses the Danish emission factors on municipal waste, which have been revised recently due to new information. The time series for the fossil CO_2 emission factor for municipal waste is shown in Table 11.3.6, see chapter 3 for description.

Table 11.3.6 CO_2 emission factors 1990-2021.

Fuel	Year	Emission factor	Unit	Reference type	IPCC fuel category
Gasoil	-	72.967	kg pr GJ	Country specific	Liquid
Kerosene	-	71.900	kg pr GJ	IPCC 2006	Liquid
Jet-Kerosene	-	71.500	kg pr GJ	IPCC 2006	Liquid
Gasoline	-	69.300	kg pr GJ	IPCC 2006	Liquid
Fueloil	-	77.400	kg pr GJ	IPCC 2006	Liquid
LPG	-	63.100	kg pr GJ	IPCC 2006	Liquid
Wasteoil	-	77.400	kg pr GJ	IPCC 2006	Liquid
Municipal waste – biomass	-	75.100	kg pr GJ	Country specific	Biomass
Municipal waste – fossil fuel	1990-2010	37.000	kg pr GJ	Country specific	Other fuels
Municipal waste – fossil fuel	2011	37.500	kg pr GJ	Country specific	Other fuels
Municipal waste – fossil fuel	2012	40.000	kg pr GJ	Country specific	Other fuels
Municipal waste – fossil fuel	2013-2021	42.500	kg pr GJ	Country specific	Other fuels

The CO_2 emission from gasoil has been calculated by using the same methodology as described in the IPCC Guidelines (IPCC, 2006). This methodology implies use of C content per fuel type (default) and fraction of carbon oxidised (default); see the equation below.

$$E_{CO_2} = \sum Act_a \times EF_{C,a} \times Ox \times 44/12$$

where:

Act_a = activity; consumption of fuel a

$EF_{C,a}$ = C emission factor for fuel a

Ox = oxidation factor (by default equal to 1)

The emissions of CH_4, N_2O, NO_X, CO and NMVOC have been calculated at sector/fuel level by using IPCC default emission factors combined with measured/Danish EF waste incineration (with energy recovery), see Table 11.3.7 – Table 11.3.9 below.

The equation applied for each pollutant is:

$$E = \sum (EF_{ab} \times Act_{ab})$$

where:

EF = emission factor
Act = activity; fuel input
a = fuel type
b = sector activity

CH_4

The CH_4 emission factors applied for 1990-2021 are presented in Table 11.3.7. Emission factors for municipal waste refer to emission measurements carried out in Danish plants (Nielsen et al., 2010). Other emission factors refer to the IPCC Guidelines (IPCC, 2006).

Table 11.3.7 CH_4 emission factors 1990-2021.

		Liquid fuel						Bio-mass	Other fuel
CRF sector		Gasoil	Kerosene	Gasoline	Fueloil	LPG	Wasteoil	Municipal waste	
		g CH_4 per GJ							
1A1	Energy Industries	3	3	3	3	1	3	30	30
1A2	Manufacturing Industries and Construction	2	2	2	2	5	-	-	-
1A3a	Transport - Domestic aviation	0.5	0.5	0.5	0.5	-	-	-	-
1A3b	Transport - Road transportation	3.9	20	25	5	50	-	-	-
1A3d	Transport - Domestic navigation	5	5	5	5	-	-	-	-
1A4a	Other sectors - Commercial, Institutional	10	10	10	10	5	-	-	-
1A4b	Other sectors - Residential	10	10	10	10	5	-	-	-
1A4c	Other sectors - AFF stationary	10	10	10	10	5	-	-	-
1A4c	Other sectors - AFF mobile	5	5	5	5	5	-	-	-
1A5b	Other - Military mobile	5	5	5	5	-	-	-	-

Source:
- IPCC Guidelines 2006: Gasoil, kerosene, gasoline, fueloil, LPG and waste oil.
- Nielsen et al. (2010): Biomass and other fuel, both municipal waste.

N_2O

The N_2O emission factors applied for 1990-2021 are presented in Table 11.3.8. Emission factors for municipal waste refer to emission measurements carried out in Danish plants (Nielsen et al., 2010). Other emission factors refer to the IPCC Guidelines (IPCC, 2006).

Table 11.3.8 N_2O emission factors 1990-2021.

		Liquid fuel						Bio-mass	Other fuel
CRF sector		Gasoil	Kerosene	Gasoline	Fueloil	LPG	Wasteoil	Municipal waste	
		g N_2O per GJ							
1A1	Energy Industries	0.6	0.6	0.6	0.6	0.1	0.6	4	4
1A2	Manufacturing Industries and Construction	0.6	0.6	0.6	0.6	0.1	-	-	-
1A3a	Transport - Domestic aviation	2	2	2	2	-	-	-	-
1A3b	Transport - Road transportation	3.9	0.6	8	0.6	0.1	-	-	-
1A3d	Transport - Domestic navigation	0.6	0.6	0.6	0.6	-	-	-	-
1A4a	Other sectors	0.6	0.6	0.6	0.6	0.1	-	-	-
1A5b	Other - Military mobile	0.6	0.6	0.6	0.6	0.1	-	-	-

Source:
- IPCC Guidelines 2006: Gasoil, kerosene, gasoline, fueloil, LPG and waste oil.
- Nielsen et al. (2010): Biomass and other fuel, both municipal waste.

SO_2, NO_X, NMVOC and CO

Emission factors for SO_2, NO_X, NMVOC and CO are listed in Table 11.3.9. The same emission factors have been applied in the period 1990-2021.

Table 11.3.9 SO_2, NO_X, NMVOC and CO emission factors 1990-2021 (g pr GJ).

Fuel group	Fuel	CRF sector		NO_X	CO	NMVOC	SO_2	Ref
Liquid	Gasoil	1A1	Energy Industries	200	15	5	141	1
		1A2	Manufacturing Industries and Construction	200	10	5	141	1
		1A3a	Transport – Domestic aviation	300	100	50	141	1
		1A3b	Transport – Road transportation	800	1 000	200	141	1
		1A3d	Transport – Domestic navigation	1 500	1 000	200	141	1
		1A4a,b	Other sectors	100	20	5	141	1
		1A4c	Other sectors – AFF stationary	100	20	5	141	1
		1A4c	Other sectors – AFF mobile	1 200	1 000	200	141	1
		1A5b	Other – Military mobile	1 500	1 000	200	141	1
	Kerosene	1A1	Energy Industries	200	15	5	23	1
		1A2	Manufacturing Industries and Construction	200	10	5	23	1
		1A3a	Transport – Domestic aviation	300	100	50	23	1
		1A3b	Transport – Road transportation	600	8 000	1 500	23	1
		1A3d	Transport – Domestic navigation	1 500	1 000	200	23	1
		1A4a,b	Other sectors	100	20	5	23	1
		1A4c	Other sectors – AFF stationary	100	20	5	23	1
		1A4c	Other sectors – AFF mobile	1 200	1 000	200	23	1
		1A5b	Other – Military mobile	1 500	1 000	200	23	1
	Gasoline	1A1	Energy Industries	200	15	5	46	1
		1A2	Manufacturing Industries and Construction	200	10	5	46	1
		1A3a	Transport – Domestic aviation	300	100	50	46	1
		1A3b	Transport – Road transportation	600	8 000	1 500	46	1
		1A3d	Transport – Domestic navigation	1 500	1 000	200	46	1
		1A4a,b	Other sectors	100	20	5	46	1
		1A4c	Other sectors – AFF stationary	100	20	5	46	1
		1A4c	Other sectors – AFF mobile	1 200	1 000	200	46	1
		1A5b	Other – Military mobile	1 500	1 000	200	46	1
	Fueloil	1A1	Energy Industries	200	15	5	492	1
		1A2	Manufacturing Industries and Construction	200	10	5	492	1
		1A3a	Transport – Domestic aviation	300	100	50	492	1
		1A3b	Transport – Road transportation	600	8 000	1 500	492	1
		1A3d	Transport – Domestic navigation	1 500	1 000	200	492	1
		1A4a,b	Other sectors	100	20	5	492	1
		1A4c	Other sectors – AFF stationary	100	20	5	492	1
		1A4c	Other sectors – AFF mobile	1 200	1 000	200	492	1
		1A5b	Other – Military mobile	1 500	1 000	200	492	1
	LPG	1A1	Energy Industries	150	20	5	0.13	1
		1A2	Manufacturing Industries and Construction	150	30	5	0.13	1
		1A3a	Transport – Domestic aviation	-	-	-	-	1
		1A3b	Transport – Road transportation	600	400	5	0.13	1
		1A3d	Transport – Domestic navigation	-	-	-	-	1
		1A4a,b	Other sectors	50	50	5	0.13	1
		1A4c	Other sectors – AFF stationary	50	50	5	0.13	1
		1A4c	Other sectors – AFF mobile	1 000	400	5	0.13	1
		1A5b	Other – Military mobile	-	-	-	-	1
	Wasteoil	1A1	Energy Industries	200	15	5	477	1
Biomass	Municipal waste	1A1	Energy Industries	134	7.4	0.98	138	2
Other fuel	Municipal waste	1A1	Energy Industries	134	7.4	0.98	138	2

Sources: 1) IPCC Guidelines 2006. 2) Nielsen et al., 2010.

11.3.4 Emissions

The greenhouse gas (GHG) emissions are listed in Table 11.3.10. The total emission of greenhouse gases from the energy sector accounts for 93.4 % of total Greenlandic GHG emission in 2021.

CO_2 emission from energy accounts for 99.3 % of the Greenlandic CO_2 emission (excluding net CO_2 emission from Land Use, Land Use Change and Forestry (LULUCF). The CH_4 emission from fuel combustion (Sectoral Approach) accounts for 9.2 % of the Greenlandic emission and the N_2O emission from fuel combustion accounts for 24.1 % of the Greenlandic N_2O emission, see Table 11.3.10.

Table 11.3.10 Greenhouse gas emission 2021.

		CO_2	CH_4	N_2O
		Gg CO_2 equivalent		
1A1	Fuel consumption, Energy Industries	99.8	0.3	0.5
1A2	Fuel consumption, Manufacturing Industries and Construction	39.7	0.0	0.1
1A3	Fuel consumption, Transport	102.8	0.2	1.3
1A4	Fuel consumption, Other sectors	320.3	0.8	0.8
1B	Fugitive emissions from fuel, Oil and natural gas	NO	NO	NO
Total emission from energy		532.9	562.5	1.3
Greenlandic emission (excluding net emission from LULUCF)		537.2	566.7	14.5
			%	
Emission share for energy		99.3	9.2	24.1

CO_2 is the most important GHG pollutant and accounts for 99.3 % of the GHG emission in CO_2 equivalents from energy in 2021, see Figure 11.3.4.

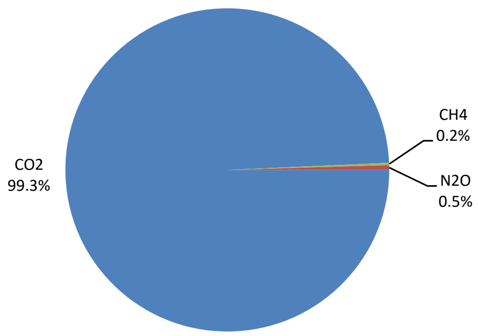


Figure 11.3.4 GHG emissions (CO_2 equivalent) from stationary combustion plants 2021.

Figure 11.3.5 depicts the time series of GHG emission in CO_2 equivalents from the energy sector. As shown by the blue curve the development in total GHG emission follows the CO_2 emission development very closely. Emission of CO_2 and total GHG emission are respectively 9.5 % and 9.4 % lower in 2021 compared to 1990.

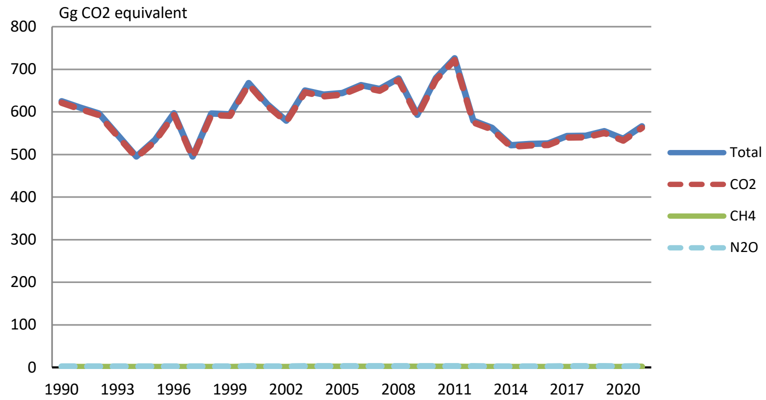


Figure 11.3.5 GHG emission time series for the Energy Sector.

Since 2014 emissions of GHG have more and less stayed level with only minor annual variations. In 2021 GHG emission increased due to higher activity in the transport sector after COVID19.

CO_2

CO_2 emission from fuel combustion accounts for 99.3 % of the total Greenlandic CO_2 emission. Table 11.3.11 lists the CO_2 emission inventory for the energy sector in 2021 as well as the relative percentage for each category under the sectoral approach.

The table reveals that Agriculture, Forestry and Fisheries (AFF) accounts for 27.7 % of the CO_2 emission. Other large CO_2 emission sources are Residental with a share of 18.2 % and Energy Industries with 17.7 % as well as Transports with 18.3 %. These are sectors, which also account for a considerable share of fuel consumption.

Table 11.3.11 Emission of CO_2 from fuel combustion 2021.

		Gg	%
1A1	Energy Industries	99.8	17.7
1A2	Manufacturing Industries	39.7	7.0
1A3	Transport	102.8	18.3
1A4a	Commercial / Institutional	56.7	10.1
1A4b	Residential	102.6	18.2
1A4c	Agriculture / Forestry / Fisheries	156.0	27.7
1A5	Other	5.0	0.9
1B	Fugitive emissions from fuel	NO	NO
1C	CO_2 Transport and Storage	NO	NO
Total		562.5	100.0

CO_2 emission from combustion of biomass fuels is not included in the total CO_2 emission data, since biomass fuels are considered CO_2 neutral. The CO_2 emission from biomass combustion is reported as a memo item in the Climate Convention reporting. In 2021, the CO_2 emission from biomass combustion was 16.5 Gg.

Time series for CO_2 emissions are provided in Figure 11.3.6. Since 1990 emission of CO_2 has decreased by 9.5 %. Fluctuations in CO_2 emission from AFF primarily regard fluctuations in fishing activities from year to year. Fluctuations in CO_2 emission from residential plants are largely a result of outdoor temperature variations from year to year. This also causes fluctuations in CO_2 emission from Energy Industries which cover electricity and heat production. However, the significant increase in emission from Energy Industries in 2010 continuing in 2011 is caused by the initiation of oil exploration in 2010, which is reported in the subsector "1.AA.1.c.ii Manufacture of Solid Fuels and Other Energy Industries". Since 2011 there has been no drilling for oil in Greenland.

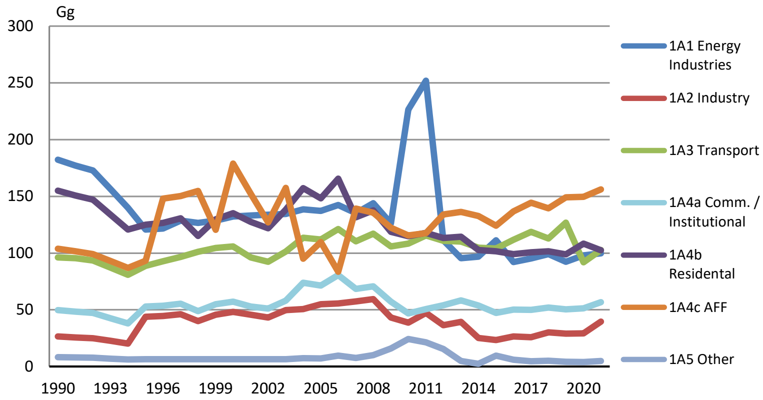


Figure 11.3.6 CO_2 Emission time series for Fuel Combustion (Sectoral Approach).

Detailed trend discussion on CRF category level is available in Section 11.2.

CH_4

CH_4 emission from fuel combustion accounts for 9.2 % of the Greenlandic CH_4 emission. Table 11.3.12 lists the CH_4 emission inventory for energy in 2021. The table reveals that Residentals accounted for 26.3 % of the CH_4 emission from energy in 2021. Agriculture, Forestry and Fisheries accounted for 20.2 %, and Energy Industries for 19.3 %.

Table 11.3.12 Emission of CH_4 from fuel combustion 2021.

		Mg	%
1A1	Energy Industries	10.3	19.3
1A2	Industry	1.1	2.0
1A3	Transport	9.1	17.0
1A4a	Commercial / Institutional	7.8	14.5
1A4b	Residential	14.1	26.3
1A4c	Agriculture / Forestry / Fisheries	10.8	20.2
1A5	Other	0.3	0.6
1B	Fugitive emissions from fuel	NO	NO
Total		53.5	100.0

Emission of CH_4 from fuel combustion has increased by 7.5 % since 1990. Time series for CH_4 emissions are provided in Figure 11.3.7. Fluctuations in CH_4 emission from AFF primarily regard fluctuations in fishing activities from year to year. Fluctuations in CH_4 emission from residential plants are largely a result of outdoor temperature variations from year to year. This also causes fluctuations in CH_4 emission from Energy Industries, which cover electricity and heat production and manufacture of solid fuels and other Energy Industries.

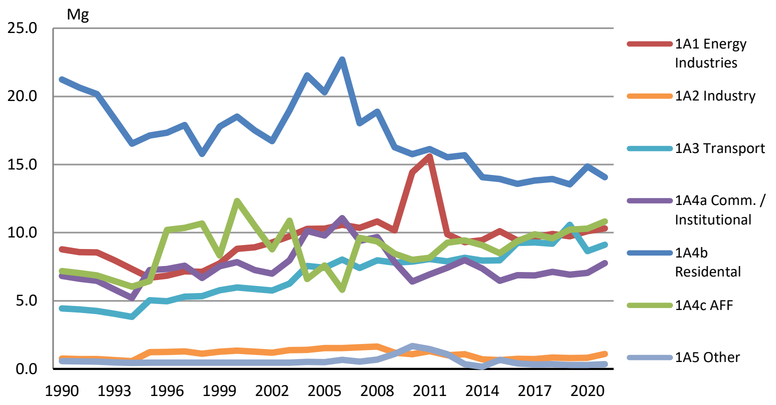


Figure 11.3.7 CH_4 emission time series for energy.

Detailed trend discussion on CRF category level is available in Section 11.2.

N_2O

Emission of N_2O from fuel combustion accounts for 24.1 % of the Greenlandic N_2O emission. Table 11.3.13 lists the N_2O emission inventory for energy in 2021. The table reveals that Transportation accounted for 48.3 % of the N_2O emission from the energy sector while Energy Industries accounted for 18.2 % of the emissions in 2021.

Table 11.3.13 Emission of N_2O from fuel combustion 2021.

		Mg	%
1A1	Energy Industries	1.6	18.2
1A2	Industry	0.3	3.7
1A3	Transport	4.3	48.3
1A4a	Commercial / Institutional	0.5	5.2
1A4b	Residential	0.8	9.5
1A4c	Agriculture / Forestry / Fisheries	1.3	14.6
1A5	Other	0.0	0.5
1B	Fugitive emissions from fuel	NO	NO
Total		8.9	100.0

Figure 11.3.8 shows the time series for the N_2O emission from energy. N_2O emission has increased by 13.4 % from 1990 to 2021.

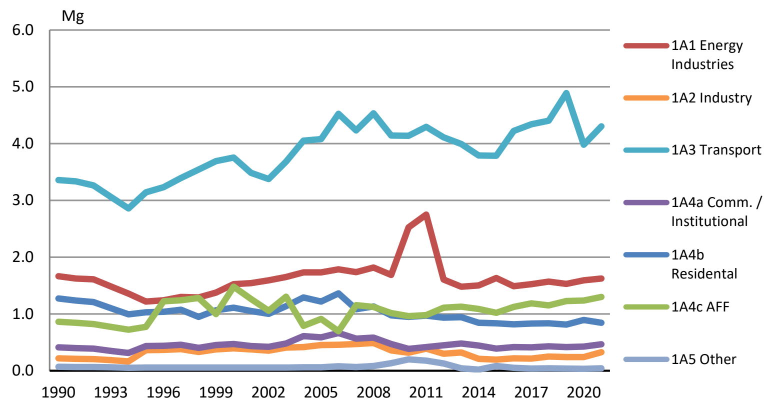


Figure 11.3.8 N_2O emission time series for energy.

Detailed trend discussion on CRF category level is available in Section 11.2.

SO_2, NO_X, NMVOC and CO

The emissions of SO_2, NO_X, NMVOC and CO from energy in 2021 are presented in Table 11.3.14. SO_2 from energy accounts for 99.3 % of the Greenlandic SO_2 emission. NO_X, CO and NMVOC account for 99.0 %, 88.0 % and 87.3 % respectively, of the Greenlandic emissions for these substances.

Table 11.3.14 Emission of SO_2, NO_X, NMVOC and CO from fuel combustion 2021.

	NO_X	CO	NMVOC	SO_2
	Gg	Gg	Gg	Gg
1A1 Fuel consumption, Energy Industries	0.3	0.0	0.0	0.2
1A2 Fuel consumption, Manuf. Industries and Constr.	0.1	0.0	0.0	0.1
1A3 Fuel consumption, Transport	1.1	2.6	0.5	0.1
1A4 Fuel consumption, Other sectors	2.9	2.3	0.5	0.6
1B Fugitive emissions from fuel	NO	NO	NO	NO
Total emission from fuel consumption and fugitive emissions from fuel	4.5	4.9	1.0	1.0
Greenlandic emission	4.5	5.5	1.1	1.0
		%		
Emission share for fuel consumption	99.0	88.0	87.3	99.3

11.3.5 Uncertainties

A tier 1 uncertainty assessment has been carried out in accordance with the IPCC Guidelines (IPCC, 2006). The uncertainty has been estimated for all sources included in the reporting for the energy sector. The uncertainties for the activity data and emission factors are shown in Table 11.3.15.

Table 11.3.15 Uncertainties for activity data and emission factors for the energy sector.

Subsector	Pollutant	Activity data uncertainty	Emission factor uncertainty
1A Liquid fuels	CO_2	3	2
1A Municipal waste	CO_2	3	25
1B2 Oil exploration	CO_2	3	1 000
1A Liquid fuels	CH_4	3	100
1A Municipal waste	CH_4	3	100
1A Biomass	CH_4	3	100
1B2 Oil exploration	CH_4	3	1 000
1A Liquid fuels	N_2O	3	500
1A Municipal waste	N_2O	3	500
1A Biomass	N_2O	3	200
1B2 Oil exploration	N_2O	3	1 000

With regard to uncertainty, the CO_2 emission factors are considered the most certain. Due to a technical analysis a country specific emission factor is available on the Greenlandic gasoil; the dominating liquid fuel. Consequently, the CO_2 emission factor uncertainty has been revised from 5 % to 2 % for liquid fuels. This revision was done in the 2014 submission.

To account for the more inhomogeneous nature of municipal waste the emission factor uncertainty has been set to 25 %. For CH_4 the emission factor uncertainty has been set to 100 % in accordance with the IPCC Guidelines (IPCC, 2006). For N_2O the emission factor uncertainties have been estimated between 200 % and 500 %. This is based on a first estimate and can be improved upon in the future.

Oil exploration has occurred in 2010 and 2011, but not since. However, fugitive emissions have been set to NA due to the fact that it has been impossible to obtain any information on the amount of oil and gas picked up during drillings in 2010 and 2011.

The resulting uncertainties for the individual greenhouse gases and the total uncertainty on the greenhouse gas emission are shown in Table 11.3.16.

Table 11.3.16 Uncertainties for the emission estimates.

	Uncertainty %	Trend 1990-2021 %	Trend uncertainty %
GHG	± 4.1	-9.4	± 3.8
CO_2	± 3.6	-9.5	± 3.8
CH_4	± 88	7.5	± 13.2
N_2O	± 451	13.4	± 47.9

11.3.6 Source specific QA/QC

The elaboration of a formal QA/QC plan is to be completed.

However, the official Greenland energy statistics is continuously going through a great deal of quality work with regard to accuracy, comparability and completeness. Statistics Greenland is responsible for the official Greenlandic energy statistics, and as such responsible for the completeness of data. The uncertainties connected with estimating fuel consumption do not influence the coherence between the energy statistics and the datasets used in the emission inventory submission. For the remainder of the datasets, it is assumed that the level of uncertainty is relatively small. See chapter regarding uncertainties for further comments.

Statistics on fuel consumption is reported by Statistics Greenland in form of a spreadsheet. Annual consumption of gasoil, kerosene, gasoline and LPG are divided into business categories and private households. To ensure consistency data are compared with those from previous years and large discrepancies are checked.

All external data used for the emission inventory submission are archived in spreadsheets. Data are archived annually in order to ensure that the basic data for a given report are always available in their original form.

Safely stored and quality checked activity data are then processes by using a methodological approach consistent with international guidelines.

Calculated emission factors are compared with guideline emission factors to ensure that they are reasonable. The calculations follow the principle in international guidelines.

During data processing, it is checked that calculations are being carried out correctly. However, a documentation plan for this is to be elaborated.

Time-series for activity data, emission factors and calculated emissions are used to identify possible errors in the calculation procedure. In fact, during the calculation, numerous controls take place to ensure correctness. Sums are checked of the various stages in the calculation procedure. Implied emission factors are compared to emission factors.

Every single time-series imported to the CRF Reporter is checked for fuel rate, units for fuel rate, emission factor and plant-specific emissions. Additional checks are performed on the database. The database encloses every single activity data, emission factors, emission, notation key and comment imported to the CRF Reporter. In other words, no information is typed manually into the CRF Reporter. Instead, all information is imported to the CRF Reporter through an XML-file to ensure maximum accuracy and completeness.

Reference approach

In addition to the sector-specific CO_2 emission inventories (the Greenlandic approach), the CO_2 emission is also estimated using the reference approach described in the IPCC Reference manual (IPCC, 2006). The reference approach is based on data for fuel production, import, export and stock change. The CO_2 emission inventory based on the reference approach is reported to the Climate Convention and used for verification of the official data in the Greenlandic approach.

Data on import, export and stock change used in the reference approach originate from the annual "basic data" table prepared by Statistics Greenland. The fraction of carbon oxidised has been assumed to be 1.00. The carbon emission factors are default factors originating from the IPCC Reference Manual (IPCC, 2006). The country-specific emission factors are not used in the reference approach, the approach being for the purposes of verification.

The Climate Convention reporting tables include a comparison of the Greenlandic approach and the reference approach estimates. To make results comparable, the CO_2 emission from incineration of the plastic content of municipal waste is added in the reference approach while the fuel consumption is subtracted.

In 2021 fuel consumption rates in the two approaches differ by 0 % and the CO_2 emission differs by 0.3 %. In the period 1990-2021 the CO_2 emission differs by 0.3 % or less at all times. The differences in energy consumption are 0 % for all years. According to IPCC Good Practice Guidance (IPCC, 2000) the difference should be within 2 %. A comparison of the Greenlandic approach and the reference approach is illustrated in Figure 11.3.9.

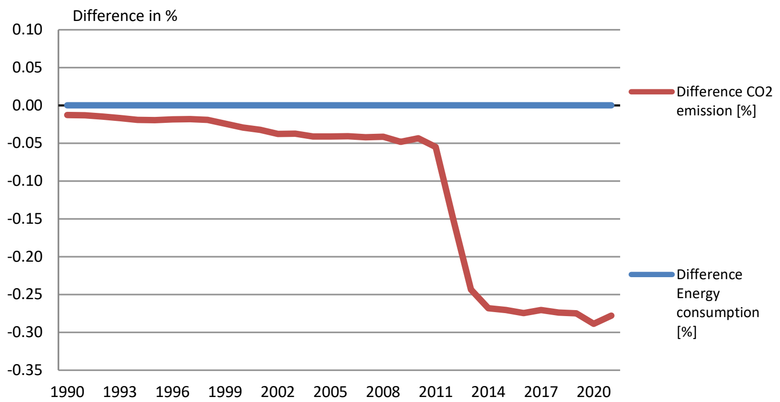


Figure 11.3.9 Comparison of the reference approach and the national approach.

11.3.7 Source specific recalculations and improvements

In this 2023 submission, there has been a few minor revisions in the energy sector, regarding the years 2019 and 2020. The revsision is caused by minor adjustments in fuel combustions for the two years.

Table 11.3.17 shows recalculations in the energy sector compared to the 2022 submission. Three minor changes occur.

Table 11.3.17 Changes in GHG emission in the energy sector compared to the 2022 submission.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Previous inventory, Gg CO_2 eqv.	625.2	610.4	596.2	546.0	495.7	534.3	597.1	617.8	596.5	594.3
Recalculated, Gg CO_2 eqv.	625.2	610.4	596.2	546.0	495.7	534.3	597.1	617.8	596.5	594.3
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-
Change in pct.	-	-	-	-	-	-	-	-	-	-
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Previous inventory, Gg CO_2 eqv.	668.0	618.2	579.8	650.2	640.5	644.7	663.1	653.9	678.7	593.3
Recalculated, Gg CO_2 eqv.	668.0	618.2	579.8	650.2	640.5	644.7	663.1	653.9	678.7	593.3
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-
Change in pct.	-	-	-	-	-	-	-	-	-	-
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Previous inventory, Gg CO_2 eqv.	679.6	726.4	579.4	562.7	522.0	525.1	526.3	543.5	544.1	555.0
Recalculated, Gg CO_2 eqv.	679.6	726.4	579.4	562.7	522.0	525.1	526.3	543.5	544.1	555.0
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	0.0
Change in pct.	-	-	-	-	-	-	-	-	-	0.0
continued	2020	2021								
Previous inventory, Gg CO_2 eqv.	536.7	-								
Recalculated, Gg CO_2 eqv.	536.7	566.5								
Change in Gg CO_2 eqv.	0.0	-								
Change in pct.	0.0	-								

11.3.8 Source specific planned improvements

Some planned improvements to the emission inventories are discussed below.

1) Memo Items, International Aviation Bunkers

Previously, emissions from international aviation bunkers have been considered to be of neglible importance in terms of Greenland. For that matter the annual amount of jet fuel loaded into foreign aircrafts has been included as part of the IPCC category 1A3a Domestic Aviation. However, some misunderstanding has taken place and this assumption seems to be incorrect! New data has emerged regarding the distinction between domestic and international flights, and it now seems possible that combustion of jet fuel in international bound aircrafts taking off from Greenland can be determined and reported as international aviation bunkers as from the 2019 submission. However, in this 2023 submission jet fuel loaded into foreign aircrafts is still included as part of the IPCC category 1A3a Domestic Aviation.

2) Improved documentation for emission factors

The reporting of, and references for, the applied emission factors have been improved in the current year and will be further developed in future inventories. This will happen on the advice from the Danish National Environmental Research Institute.

3) Improvements in plant specific fuel combustion

Plant specific fuel combustion will be further improved according to the developments made by Statistics Greenland in the energy statistics.

4) Uncertainty estimates

Uncertainty estimates are largely based on the default uncertainty levels for activity rates and emission factors. More country-specific uncertainty estimates will be incorporated in future inventories.

5) Country specific emission factors

Statistics Greenland has acquired a technical analysis on the gasoil that is imported to and used in Greenland. The technical analysis conducted by the Danish Techinal Institute has provided a country specific emission factor on the Greenlandic gasoil. Due to this technical analysis a new country specific emission factor on gas oil was implemented as from the 2014 submission. The arctic grade gas oil stands for 79.9 % of all liquid fuels in 2021.

The plan is to obtain additional country specific emission factors on other liquid fuels, but only if the UNFCCC recommend it as in the case of the Greenlandic gasoil.

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11.4 Industrial Processes and Product Use (CRF sector 2)

11.4.1 Overview of sector

In this chapter the emissions of greenhouse gases from industrial processes and product use, not related to generation of energy, are presented.

The emission of greenhouse gases from industrial processes and product use includes CO_2, HFCs and SF_6. The emissions are reported in CRF Tables 2(I), 2(I).A, 2(II) and 2(II).B. Furthermore, the emission of non-methane volatile organic compounds (NMVOC) and CO from industrial processes related to asphalt roofing, road paving with asphalt and production of food and drink are given in CRF Table 2(I). This section also includes the emissions of CO_2 and NMVOC from use of solvents in industrial processes and households that are related to the former source categories Paint application, degreasing and dry cleaning, chemical products, manufacture and processing and others. Emission of CO_2 and NMVOC from solvent use are reported in CRF Tables 2(I) and 2(I).A.

Solvents are chemical compounds that are used on a global scale in industrial processes and as constituents in final products to dissolve for example paint, cosmetics, adhesives, ink, rubber, plastic, pesticides, aerosols or are used for cleaning purposes e.g., degreasing. NMVOCs are main components in solvents - and solvent use in industries and households is typically the dominant source of anthropogenic NMVOC emissions. In industrial processes where solvents are produced or used NMVOC emissions to air and as liquid can be recaptured and either used or destroyed. Solvent containing products are used indoor and outdoor and the majority of solvent sooner or later evaporate. A small fraction of the solvents ends up in waste or as emissions to water and may finally also contribute to air pollution by evaporation from these compartments.

In this section the methodology for the Greenland NMVOC emission inventory for solvent use is presented and the results for the period 1990-2021 are summarised. The method is based on the detailed approach described in EMEP/CORINAIR (2019) and emissions are calculated for the CRF sectors mentioned above.

An overview of sources identified is presented in Table 11.4.1 with an indication of the contribution to the industrial part of the emission of greenhouse gases in 2021. Emissions are extracted from the CRF tables.

Table 11.4.1 Overview of greenhouse gas sources 2021.

Process	IPCC Code	Substance	Emission tonnes CO_2 eqv.	%
Mineral Industry				
Limestone and Dolomite Use	2A4	CO_2	54.37	0.4
Non-Energy Products of Fuels and Solvent use				
Paraffin Wax Use	2D2	CO_2	406.91	3.0
Paraffin Wax Use	2D2	CH_4	0.42	0.0
Paraffin Wax Use	2D2	N_2O	1.00	0.0
Solvent Use	2D3	CO_2	253.77	1.9
Road Paving with Asphalt	2D3	CO_2	0.19	0.0
Road Paving with Asphalt	2D3	CH_4	0.09	0.0
Asphalt Roofing	2D3	CO_2	0.14	0.0
Product uses as substitutes for ODS				
Refrigeration and Air Conditioning Equipment	2F1	HFCs	12 978.96	94.7
Other product manufacture and use				
Electrical Equipment	2G	SF_6	2.53	0.0
Total emission			13 698.38	100.0

The subsector *Product uses as substitutes for ODS* (2F) constitutes 94.7 % of the industrial emission of greenhouse gases in 2021. This reflects the emission of HFCs from refrigeration and air conditioning equipment. The subsector *Non-Energy Products of Fuels and Solvent use* (2D) constitutes 4.8 % of the industrial emission of greenhouse gases. In this subsector we find emissions from paraffin wax use and solvents as well as road paving with asphalt and asphalt roofing.

Limestone is used in cement and the production of concrete. Concrete is one of the common building materials in Greenland. The total emission of greenhouse gases (excl. LULUCF) in Greenland is estimated to 605.17 Gg CO_2 equivalents in 2021, of which industrial processes contribute with 13,698 Gg CO_2 equivalents (2.3 %). The emission of greenhouse gases from industrial processes from 1990-2021 are presented in Figure 11.4.1.

Greenland has no chemical industry, metal production or production of halocarbons or SF_6. Greenland has no consumption of PFCs.

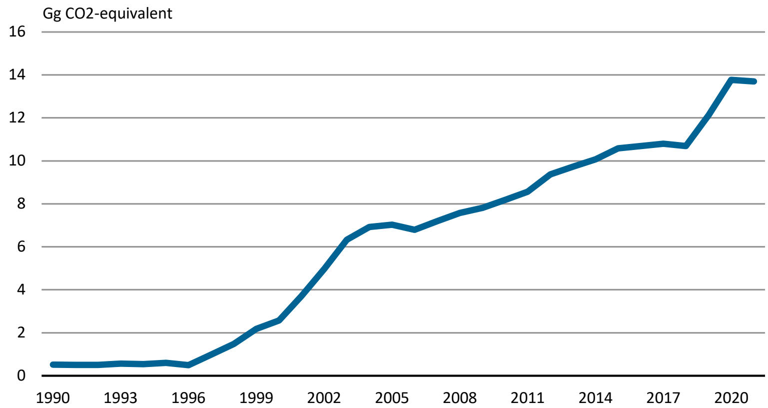

Figure 11.4.1 Emission of greenhouse gases from industrial processes 1990-2021.

The key category in the industrial sector *Consumption of Halocarbons* constitutes 2.1 % of the total emission of greenhouse gases in 2021. The trends in greenhouse gases from the industrial sector andsubsectors are presented in Table 11.4.2. The emissions are extracted from the CRF tables.

Table 11.4.2 Emission of GHG from industrial processes and product use in different subsectors from 1990-2021.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CO_2 (tonnes CO_2)										
A. Mineral Industry	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
D. Non-energy products from fuels and solvent use	514	500	507	542	507	531	399	558	697	789
CH_4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HFCs (tonnes CO_2 eqv.)										
F. Product uses as ODS substitutes	NE	NE	NE	0	27	33	87	421	781	1 384
PFCs (tonnes CO_2 eqv.)										
F. Product uses as ODS substitutes	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
SF_6 (tonnes CO_2 eqv.)										
G. Other product manufacture and use	NE	NE	NE	NE	NE	0	3.2	3.2	3.2	3.2
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
CO_2 (tonnes CO_2)										
A. Mineral Industry	4.0	2.8	1.3	2.6	1.8	0.1	0.0	1.5	3.0	0.0
D. Non-energy products from fuels and solvent use	561	569	740	1 257	1 122	1 280	945	986	1 015	1 004
CH_4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HFCs (tonnes CO_2 eqv.)										
F. Product uses as ODS substitutes	2 000	3 141	4 222	5 057	5 792	5 740	5 842	6 206	6 557	6 809
PFCs (tonnes CO_2 eqv.)										
F. Product uses as ODS substitutes	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
SF_6 (tonnes CO_2 eqv.)										
G. Other product manufacture and use	3.1	3.1	3.1	3.0	3.0	3.0	2.9	2.9	2.9	2.9
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
CO_2 (tonnes CO_2)										
A. Mineral Industry	4.9	0.0	19.6	0.0	6.6	0.0	0.1	3.2	39.9	130.3
D. Non-energy products from fuels and solvent use	895	876	940	763	805	812	696	718	909	884
CH_4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HFCs (tonnes CO_2 eqv.)										
F. Product uses as ODS substitutes	7 282	7 681	8 406	8 962	9 261	9 772	9 994	10 078	9 733	11 108
PFCs (tonnes CO_2 eqv.)										
F. Product uses as ODS substitutes	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
SF_6 (tonnes CO_2 eqv.)										
G. Other product manufacture and use	2.8	2.8	2.8	2.7	2.7	2.7	2.7	2.6	2.6	2.6
continued	2020	2021								
CO_2 (tonnes CO_2)										
A. Mineral Industry	109.5	54.4								
D. Non-energy products from fuels and solvent use	744	661								
CH_4	0.0	0.0								
N_2O	0.0	0.0								
HFCs (tonnes CO_2 eqv.)										
F. Product uses as ODS substitutes	12 910	12 979								
PFCs (tonnes CO_2 eqv.)										
F. Product uses as ODS substitutes	NO	NO								
SF_6 (tonnes CO_2 eqv.)										
G. Other product manufacture and use	2.6	2.5								

Greenland has no production of halocarbons or SF_6. Data on consumption of F-gases (HFCs and SF_6) are obtained from the Statistics Greenland (imports) and by an annual survey on consumption halocarbons and SF_6. Information on consumption of F-gases is available from 1995 onwards. Greenland has no consumption of PFCs.

One single plant in Greenland had a stock of SF_6 ultimo 1995. The emission of SF_6 from this stock was 3.2 tonnes CO_2 equivalents in 1996. Since 1996 there has been an annually emission from this stock. However, there has been no consumption of SF_6 in Greenland.

In December 2015 Statistics Greenland aqquired the following information from Nukissiorfiit; the main supplier of electricity and heat in Greenland: Acording to Nukissiorfiit the switchgears in all netstations were changed from regular switches without gas to gaseous switches containing SF_6 in 2002-2004. The new gaseous switchgears from Spanish Ormazabal are closed and sealed switches that do not need any filling of gas. For that reason the switchgears are considered to be completely tight with no leaks of gas. When Nukissiorfiit replace the gaseous Ormazabal switches the switchgears are returned directly to Ormazabal in Spain where the SF_6 within the switch are recycled.

Due to this information the Greenlandic switchgears in plants and netstations containing SF_6 are considered to be completely free from leaks from 2005 an onwards. This consideration is supported by the fact that Nukissiorfiit has not been buying any SF_6 for stockpiling or filling for many years and today has no record of any SF_6 in stock at all.

However, for the sake of good practice it has been decided to keep the SF_6-plant from 1995 within this material for at least 25 full years, which in 1995 was considered to be the lifetime of that specific switchgear. Due to that decision the plant and the estimated emission of SF_6 from that plant will be left in the material until (at least) 2030, which is the last year in the current model.

Energy consumption associated with industrial processes and emissions thereof are included in the Energy sector of the inventory.

11.4.2 Source category description

Mineral Industry

The subsector *Mineral Industry* (2A) covers the following processes:

- 2A4d Limestone and dolomite use.

Emission from limestone and dolomite use are presented in the CRF sector 2A.4d under 2A.4 Other Process Uses of Carbonates. The time series for the emission of CO_2 from Mineral industry (2A) is presented in Table 11.4.3. The emissions are extracted from the CRF tables and the values are rounded.

Table 11.4.3 Emission of CO_2 (tonnes) from Mineral Industry (2A).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
4d Limestone and dolomite use	-	-	-	-	-	-	-	-	-	-
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
4d Limestone and dolomite use	4.0	2.8	1.3	2.6	1.8	0.1	0.0	1.5	3.0	0.0
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
4d Limestone and dolomite use	4.9	0.0	19.6	0.0	6.6	0.0	0.1	3.2	39.9	130.3
continued	2020	2021								
4d Limestone and dolomite use	109.5	54.4								

The use of limestone and dolomite started in 2000. Hence there is no emission from limestone and dolomite use before 2000. The use of limestone and dolomite has been estimated from the annual import of these products to Greenland. Imports seem to vary a great deal from year to year, which causes the estimated use to vary as well. Import of dolomite has increased greatly from 2018 due to large-scale construction activities, primarily new airports, harbours etc.

The CO_2 emission from subsectors under Mineral Industry fluctuates a great deal from year to year, as seen in Figure 11.4.2. This is caused by fluctuations in activities from year to year. However fluctuations in CO_2 are primarily caused by the fact that activity data for Mineral Industry are based on import data, which do not allow distinction of imported amount into consumption and stockpiling.

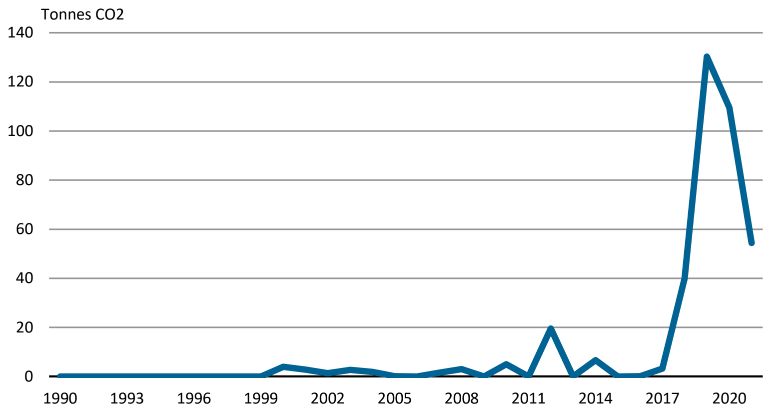

Figure 11.4.2 Emission of CO_2 from Mineral Industry 1990-2021.

Non-energy Products from Fuels and Solvent Use

The subsector *Non-energy Products from Fuels and Solvent Use* (2D) covers the following processes:

- 2D2 Paraffin Wax Use.
- 2D3 Solvent Use.
- 2D3 Road paving with asphalt.
- 2D3 Asphalt roofing.

Emissions from paraffin wax use are presented in the CRF 2D.2 subsector Paraffin Wax Use, while emissions from solvent use, road paving with asphalt and roof covering with asphalt materials are specified separately in the CRF 2D.3 subsector Other. The time series for the emission of CO_2 from Non-energy Products from Fuels and Solvent Use (2D) are presented in Table 11.4.4. The emissions are extracted from the CRF tables and the values are rounded.

Table 11.4.4 Emission of greenhouse gases from Non-energy Products from Fuels and Solvent Use (2D), tonnes CO_2 eqv.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
2. Paraffin Wax Use	251.6	241.3	250.3	279.8	232.0	254.6	189.7	295.6	426.9	480.0
3a. Solvent Use	263.4	259.7	257.4	262.5	275.6	276.7	209.3	263.4	271.0	310.1
3b. Asphalt roofing	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3
3c. Road paving	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	515.2	501.3	508.0	542.6	507.8	531.6	399.3	559.4	698.2	790.5
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
2. Paraffin Wax Use	313.7	346.8	508.4	945.6	846.8	957.0	715.2	764.4	797.8	666.1
3a. Solvent Use	247.9	223.6	233.5	314.0	277.5	326.1	232.5	224.0	219.9	339.9
3b. Asphalt roofing	0.2	0.3	0.2	0.8	0.4	0.8	0.2	0.3	0.4	0.2
3c. Road paving	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1
Total	561.9	570.8	742.2	1 260.5	1 124.7	1 284.0	948.1	988.8	1 018.3	1 006.3
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
2. Paraffin Wax Use	684.1	654.8	710.6	539.2	573.9	598.9	446.2	506.8	517.1	455.0
3a. Solvent Use	213.4	223.3	231.2	224.9	232.6	214.3	251.0	212.7	393.6	430.5
3b. Asphalt roofing	0.2	0.5	0.2	0.4	0.3	0.8	0.8	0.6	0.2	0.3
3c. Road paving	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	897.8	878.7	942.1	764.6	806.8	814.1	698.1	720.1	910.9	885.8
continued	2020	2021								
2. Paraffin Wax Use	420.3	408.3								
3a. Solvent Use	324.9	253.8								
3b. Asphalt roofing	0.4	0.3								
3c. Road paving	0.1	0.1								
Total	745.8	662.5								

In 2021 the most significant emission of greenhouse gases came from the use of paraffin wax use which constituted 61.6 % of total emission from *Non-energy Products from Fuels and Solvent Use* that year. Emission of greenhouse gases from solvent use accounted for 38.3 % of total emission from this subsector in 2021, while emission from asphalt roofing and road paving constituted less than 0.0 in 2021.

Emission from subsectors under Non-energy Products from Fuels and Solvent Use fluctuates a great deal from year to year, as seen in Figure 11.4.3. This is among others caused by fluctuations in building activities and road paving. However fluctuations in emission are also caused by the fact that activity data for Non-energy Products and Solvent Use are based on import data, which do not allow distinction of imported amount into consumption and stockpiling.

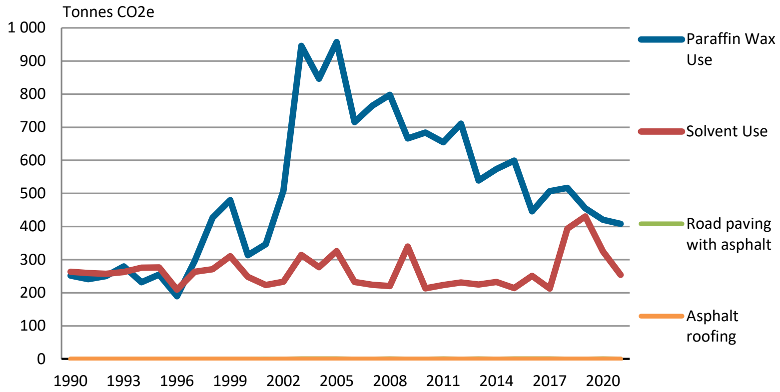

Figure 11.4.3 Emission of Greenhouse gases from Non-energy Products from Fuels and Solvent Use.

Product Uses as Substitutes for ODS – Consumption of Halocarbons

The subsector *Product Uses as Substitutes for ODS* (2F) includes the following source categories and the following halocarbons of relevance for Greenlandic emissions:

- 2F1 Refrigeration: HFC32, 125, 134a, 143a, unspecified HFCs.

A quantitative overview is given below for each of these source categories and each halocarbon, showing their emissions in tonnes through time. The data is extracted from the CRF tables that form part of this submission and the data presented is rounded values. It must be noticed that the inventories for the years 1990-1994 might not cover emissions of these gases in full. The chosen base-year for these gases is 1995 for Greenland.

Table 11.4.5 Emission of HFCs from refrigeration (t).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
HFC32	NE	NE	NE	NE	NE	NA	0.00	0.00	0.00	0.00
HFC125	NE	NE	NE	NE	NE	NA	0.00	0.04	0.07	0.13
HFC134a	NE	NE	NE	0.01	0.02	0.02	0.03	0.07	0.12	0.18
HFC143a	NE	NE	NE	NE	NE	NA	0.00	0.04	0.08	0.15
Unspecified HFCs	NE	NE	NE	NE	NE	NA	0.00	0.00	0.00	0.00
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
HFC32	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
HFC125	0.19	0.31	0.42	0.50	0.57	0.57	0.58	0.62	0.67	0.70
HFC134a	0.24	0.35	0.48	0.56	0.65	0.63	0.63	0.63	0.59	0.55
HFC143a	0.22	0.35	0.47	0.56	0.64	0.64	0.65	0.70	0.76	0.80
Unspecified HFCs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
HFC32	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00
HFC125	0.75	0.79	0.88	0.95	0.99	1.06	1.09	1.11	1.08	1.25
HFC134a	0.55	0.55	0.56	0.51	0.49	0.42	0.36	0.30	0.22	0.21
HFC143a	0.87	0.92	1.01	1.10	1.14	1.22	1.26	1.28	1.26	1.44
Unspecified HFCs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

continued	2020	2021
HFC32	0.01	0.00
HFC125	1.44	1.45
HFC134a	0.30	0.26
HFC143a	1.66	1.68
Unspecified HFCs	0.00	0.00

HFCs are used in various types of refrigeration in industry, retail, buildings and onboard ships. In 1993, 1994 and 1995 consumption of HFC134a was the only reported HFC used for refrigeration. Since 1996 consumption of HFC32, 125, 134A, 143A has been reported continuously. The emission of HFCs has increased a great deal since 1995. Emission of HFCs from refrigeration is shown in Figur 11.4.4.

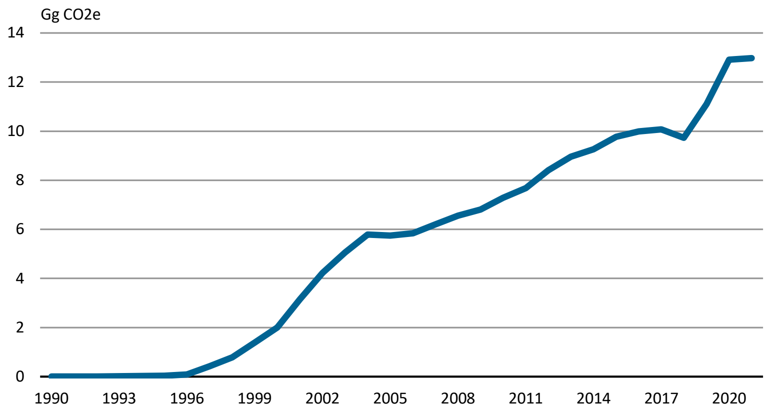

Figure 11.4.4 Emission of HFCs (from refrigeration).

Other Product Manufacture and Use – Consumption of SF_6

The subsector *Other Product Manufacture and Use* (2G) includes the following source categories and the following F-gases of relevance for Greenlandic emissions:

- 2G1 Electrical Equipment: SF_6.

Emissions of SF_6 are shown in Table 11.4.6 below. The data is extracted from the CRF tables that form part of this submission and the data presented is rounded values. It must be noticed that the inventories for the years 1990-1995 might not cover emissions of these gases in full. The chosen base-year for these gases is 1995 for Greenland.

Table 11.4.6 Emission of SF_6 from Electrical Equipment (kg).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
SF_6	NE	NE	NE	NE	NE	1.50	0.14	0.14	0.14	0.14
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
SF_6	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
SF_6	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11
continued	2020	2021								
SF_6	0.11	0.11								

The emission of SF_6 was highest in 1995, when one single plant in Greenland reported use of SF_6. The emission of SF_6 was 1.5 kg in 1995. Since 1995 the annual emission is assumed to be 0.5 % of the amount filled into the plant in 1995. This causes a relative high emission of SF_6 in 1995 and a much lower emission in the following years. In 2021 the emission of SF_6 was 0.11 kg. Emission of SF_6 from electrical equipment is shown in Figur 11.4.5.

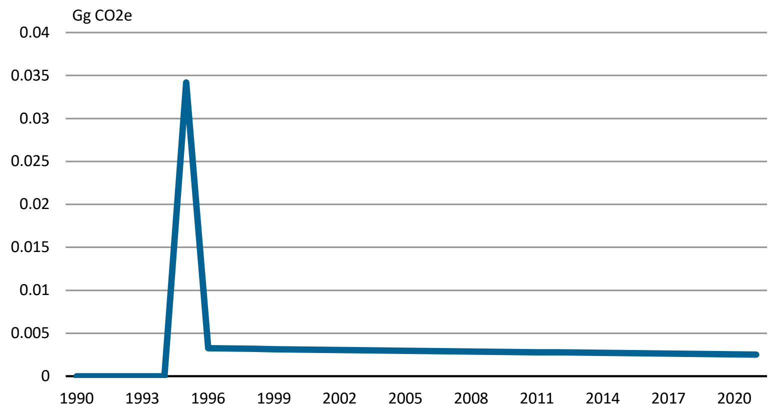

Figure 11.4.5 Emission of SF_6 (from electrical equipment).

Table 11.4.7 quantifies an overview of the emissions of the all F-gases in CO_2 eqv. from the two subsectors Product Uses as Substitutes for ODS (2F) and Other Product Manufacture and Use (2G). The emissions are extracted from the CRF tables and the values are rounded.

Table 11.4.7 Time series for emission of HFCs and SF_6 (tonnes CO_2 eqv.).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
HFCs	NE	NE	NE	18	27	33	87	421	781	1 384
SF_6	NE	NE	NE	NE	NE	34.2	3.2	3.2	3.2	3.2
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
HFCs	2 000	3 141	4 222	5 057	5 792	5 740	5 842	6 206	6 557	6 809
SF_6	3.1	3.1	3.1	3.0	3.0	3.0	2.9	2.9	2.9	2.9
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
HFCs	7 282	7 681	8 406	8 962	9 261	9 772	9 994	10 078	9 733	11 108
SF_6	2.8	2.8	2.8	2.7	2.7	2.7	2.7	2.6	2.6	2.6
continued	2020	2021								
HFCs	12 910	12 979								
SF_6	2.6	2.5								

HFCs is by far the most dominant group among the F-gases. HFCs constitute a key category both with regard to the key category level and the trend analysis.

Other

The subsector *Other* (2H) covers the following processes:

- 2H2 Food and Beverages Industry.

Emission of NMVOC from food and beverages industry is presented in the CRF sector 2H.2 Other. There is no emission of CO_2 from this source.

11.4.3 Methodological issues

General

The CO_2 emission from the use of limestone and dolomite, paraffin wax, asphalt materials used for roof covering and road paving has been estimated from the annual import of these products to Greenland.

The emissions of HFCs and SF_6 have been estimated from data on consumption of F-gases. Activity data includes annual imports and data on consumption of halocarbons and SF_6 obtained from an annual survey among importers and consumers of F-gases.

The emission modelling of solvents is done by estimating the amount of (pure) solvents consumed (EMEP/CORINAIR, 2019). All relevant solvents are estimated, or at least those representing more than 90 % of the total NMVOC emission. The estimation and modelling is based on a detailed set of data on imports of chemicals and products to Greenland. Each chemical (NMVOC) and chemical containing product (group) is estimated separately. The sum of emissions of all estimated NMVOCs used as solvents equals the NMVOC emission from solvent use.

The following sections contain a description of activity data and emission factors used for the subsectors under industrial processes. The section is concluded by a description of the emissions of greenhouse gases from industrial processes and product use.

Activity data

Activity data for subsectors *Mineral Industry* (2A), *Non-Energy Products of Fuel and Solvent Use* (2D) and *Other* (2H) are presented in Table 11.4.8. Activity data under subsector *Other* (2H) are used for calculation of emission of non-methane volatile organic compounds (NMVOC). Emission of non-methane volatile organic compounds (NMVOC) is also calculated from the use of solvents under subsector 2D.

The activity data are rounded. Notice that production of beer is given in hectolitre (hl). All other activity data are given in tonnes (t).

Statistics on imports are used to estimate annual consumption in mineral industry and the use of non-energy products of fuel and solvents.

The definitions of solvents and VOC that are used are as defined in the solvent directive (Directive 1999/13/EC) of the EU legislation: “Organic solvent shall mean any VOC which is used alone or in combination with other agents, and without undergoing a chemical change, to dissolve raw materials, products or waste materials, or is used as a cleaning agent to dissolve contaminants, or as a dissolver, or as a dispersion medium, or as a viscosity adjuster, or as a surface tension adjuster, or a plasticiser, or as a preservative”. VOCs are defined as follows: “Volatile organic compound shall mean any organic compound having at 293.15 K a vapour pressure of 0.01 kPa or more, or having a corresponding volatility under the particular condition of use”.

All the import data are collected by Statistics Greenland, the emission calculation based on the import data are performed by the Ministry of Industry and Labour.

Import figures of chemicals and chemical containing products are obtained from Statistics Greenland. There is no production or export of chemicals and chemical containing products, therefore the import amount is assumed to be equivalent to the used amount.

Statistics on imports of whole coffee beans and yeast for baking are used to estimate annual production of coffee and bread. Statistics on landings of fish and seafood to domestic plants are used to determine domestic processing of fish and seafood. Statistics on imports are produced by Statistics Greenland.

Production of beer including a fermentation process has taken place at the brewery “Godthåb Bryghus” since 2005 (Godthåb Bryghus, 2022). The brewery has reported annual production in rounded hectolitre. The much larger company "Nuuk Imeq" has no production of beer including a fermentation process. As a bottling company the activity at "Nuuk Imeq" only includes diluting of the concentrated quantities imported to Greenland and afterwards bottling of the beer.

Table 11.4.8 Activity data for Mineral Industry, Non-energy Products of Fuel and Solvent Use, and Other.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Mineral Industry										
2A4d Limestone and dolomite use (t)	-	-	-	-	-	-	-	-	-	-
Non-energy Products from Fuels and Solvent Use										
2D2 Paraffin wax use (t)	86	83	86	96	79	87	65	101	146	164
2D3a Solvent use (t)	190	187	188	195	198	174	141	198	206	254
2D3b Road paving with asphalt (t)	591	581	595	604	597	577	532	664	649	752
2D3c Asphalt roofing (t)	136	210	236	280	234	238	292	249	258	246
Other Production, Food and Beverage Industry										
2H2 Beans roasted to produce coffee (t)	0	0	0	0	-	0	-	-	0	0
2H2 Production of bread (t)	356	346	339	358	501	244	415	500	847	689
2H2 Landings of fish and seafood (t)	81 768	72 396	65 554	59 423	64 428	67 751	60 666	62 249	67 250	63 753
2H2 Production of beer (hl)	-	-	-	-	-	-	-	-	-	-
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Mineral Industry										
2A4d Limestone and dolomite use (t)	9	6	3	6	4	0	0	3	7	0
Non-energy Products from Fuels and Solvent Use										
2D2 Paraffin wax use (t)	107	119	174	324	290	328	245	262	273	228
2D3a Solvent use (t)	159	155	196	264	271	351	291	258	209	329
2D3b Road paving with asphalt (t)	694	988	705	2 218	1 127	2 258	698	912	1 206	629
2D3c Asphalt roofing (t)	136	124	148	187	282	172	242	258	387	322
Other Production, Food and Beverage Industry										
2H2 Beans roasted to produce coffee (t)	0	1	-	0	0	0	0	1	0	0
2H2 Production of bread (t)	687	566	1 020	1 048	1 338	1 014	1 134	859	931	587
2H2 Landings of fish and seafood (t)	74 105	66 929	85 970	80 667	102 570	103 642	111 351	118 260	109 420	102 393
2H2 Production of beer (hl)	-	-	-	-	-	1 000	2 000	2 000	1 850	1 650
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Mineral Industry										
2A4d Limestone and dolomite use (t)	11	0	45	0	15	0	0	7	91	296
Non-energy Products from Fuels and Solvent Use										
2D2 Paraffin wax use (t)	234	224	243	185	197	205	153	174	177	156
2D3a Solvent use (t)	225	234	299	275	292	244	242	246	315	358
2D3b Road paving with asphalt (t)	443	1 529	583	1 200	824	2 445	2 444	1 736	617	988
2D3c Asphalt roofing (t)	292	220	151	169	194	168	238	216	212	150
Other Production, Food and Beverage Industry										
2H2 Beans roasted to produce coffee (t)	0	0	1	3	1	1	0	2	4	11
2H2 Production of bread (t)	790	584	563	567	606	985	433	683	424	553
2H2 Landings of fish and seafood (t)	97 955	104 020	112 767	110 116	108 430	109 448	129 968	120 977	118 324	123 245
2H2 Production of beer (hl)	2 010	2 115	2 080	1 985	1 628	1 800	3 810	2 450	3 430	1 315

Continued on next page…

Continued	2020	2021	Source
Mineral Industry			
2A4d Limestone and dolomite use (t)	249	124	1
Non-energy Products from Fuels and Solvent Use			
2D2 Paraffin wax use (t)	144	140	1
2D3a Solvent use (t)	306	284	1
2D3b Road paving with asphalt (t)	1 261	838	1
2D3c Asphalt roofing (t)	318	361	1
Other Production, Food and Beverage Industry			
2H2 Beans roasted to produce coffee (t)	2	2	2
2H2 Production of bread (t)	382	377	2
2H2 Landings of fish and seafood (t)	118 311	117 986	3
2H2 Production of beer (hl)	1 121	838	4

The activitydata on HFCs and SF_6 are obtained by annual registrations on import and export of HFCs and SF_6, and by annual surveys among importers, wholesalers and suppliers as well as consumers of HFCs and SF_6. This means that the obtaining of acitvitydata includes the quantification and determination of any import and export of HFCs and SF_6 contained products and substances in stock form. This is in accordance with IPCC guidelines (IPCC, 2006), as well as the relevant decision trees from the IPCC Good Practice Guidance (IPCC, 2006).

The following sources of information have been used (Statistics Greenland):

- Importers, wholesaler and suppliers.
- Statistics Greenland.
- Consuming enterprises.

Importers and suppliers provide consumption data of F-gases. Emission factors are defaults from the GPG. Import/export data for sub-source categories where import/export is relevant are quantified on estimates from import/export statistics of products + default values of the amount of gas in the product.

The determination of emissions of F-gases is based on a calculation of the actual emission. The actual emission is the emission in the evaluation year, accounting for the time lapse between consumption and emission. The actual emission includes Greenlandic emissions from production and from products during their lifetimes. Consumption and emissions of F-gases are, whenever possible for individual substances, even though the consumption of certain HFCs has been limited. This has been varied out to ensure transparency of evaluation in the determination of GWP values. However, the continued use for Other HFCs has been necessary since not all importers and suppliers have specified records of sales for individual substances.

Only the actual emission has been calculated. Thus, the potential emission is assumed to be the same as the actual emission in the CRF tables.

Table 11.4.9 Content (w/w%) of "pure" HFC in HFC-mixtures, used as trade names.

HFC mixtures	HFC32	HFC125	HFC134a	HFC143a	Unspecified HFCs
	%	%	%	%	%
HFC-134, total			100		
HFC-404, total		44	4	52	
HFC-407c, total	23	25	52		
HFC-507a, total		50		50	
Unspecified HFCs					100

The substances have been accounted for in the survey according to their trade names, which are mixtures of HFCs used in the CRF. In the transfer to the "pure" substances used in the CRF reporting schemes, the ratios shown in Table 11.4.9 have been used.

The activity data expressed as total amount of HFCs and PFCs filled into new products, present in operating systems and remaining in products at decommissioning are included in the CRF tables and are not repeated here.

Heat pumps are part of category 2.F.1.a Commercial Refrigeration. There is however no production of heat pumps in Greenland and the stock of HFC-125 and HFC-134a and other HFCs in heat pumps therefore increase without any emission from manufacture.

Emission factors

The CO_2 emission factors applied for products in 2021 are presented in Table 11.4.10. The same emission factor has been applied for 1990-2021.

Table 11.4.10 CO_2 emission factors 2021.

Product	Emission factor	Unit	Reference	IPCC Category
Limestone and dolomite use	439.71	kg/t	IPCC, 2006	2A4d
Paraffin wax use	2 910	kg/t	Shires et al. (2004)	2D2
Asphalt used for road paving	0.23	kg/t	1	2D3b
Asphalt materials used for roofing	0.40	kg/t	1	2D3c

The CH_4 emission factors applied for products in 2021 are presented in Table 11.4.11. The same emission factor has been applied for 1990-2021.

Table 11.4.11 CH_4 emission factors 2021.

Product	Emission factor	Unit	Reference	IPCC Category
Paraffin wax use	0.121	kg/t	Shires et al. (2009)	2D2
Asphalt used for road paving	0.0044	kg/t	US EPA (2004)	2D3b

The N_2O emission factors applied for products in 2021 are presented in Table 11.4.12. The same emission factor has been applied for 1990-2021.

Table 11.4.12 N_2O emission factors 2021.

Product	Emission factor	Unit	Reference	IPCC Category
Paraffin wax use	0.024	kg/t	Shires et al. (2009)	2D2

The CO emission factors applied for the consumption of asphalt products in 2021 are presented in Table 11.4.13. The same emission factor has been applied for 1990-2021.

Table 11.4.13 CO emission factors 2021.

Product	Emission factor	Unit	Reference	IPCC Category
Asphalt used for road paving	0.1202	kg/t	US EPA (2004)	2D3b
Asphalt materials used for roofing	0.0095	kg/t	EMEP/EEA (2019)	2D3c

The NMVOC emission factors applied for the consumption of asphalt products and products used in the production of food and beverages in 2021 are presented in Table 11.4.14. The same emission factor has been applied for 1990-2021.

Table 11.4.14 NMVOC emission factors 2021.

Product	Emission factor	Unit	Reference	IPCC Category
Asphalt used for road paving	0.0016	kg/t	EMEP/EEA (2019)	2D3b
Asphalt materials used for roofing	0.130	kg/t	EMEP/EEA (2019)	2D3c
Food and Beverages Industry - Beans roasted to produce coffee	0.55	kg/t	IPCC, 1997	2H2
Food and Beverages Industry - Production of bread	8	kg/t	IPCC, 1997	2H2
Food and Beverages Industry - Landings of fish and seafood	0.3	kg/t	IPCC, 1997	2H2
Food and Beverages Industry - Production of beer	0.035	kg pr hl	IPCC, 1997	2H2

NMVOC-emissions from solvent use are estimated using emission modelling of solvents by estimating the amount of (pure) solvents consumed, thus representing a chemicals approach, where each pollutant is estimated separately. All relevant solvents must be estimated, or at least those together representing more than 90 % of the total pollutant emission. These emissions are summed up to one Greenlandic total CO_2 (NMVOC) emissions from solvent use.

Emission factors are calculated for a complete conversion to CO_2 of each NMVOC molecule in unit g CO_2 per g NMVOC from:

$$n \times 12\ \frac{g}{mol} / (molecular\ weight\ NMVOC) \times 3.667 \frac{g\ CO_2}{g\ C}$$

where n is the number of carbon atoms in the NMVOC molecule. The default NMVOC-CO_2 conversion factor of 0.85 * 3.667 = 3.11 is used for solvents.

The emission factors used in the Greenlandic inventory are the same as developed for the Danish inventory (please refer to Chapter 5).

11.4.4 Emissions

The greenhouse gas (GHG) emissions are listed in Table 11.4.15. The emission from industrial processes and product use accounts for 2.3 % of the Greenlandic GHG emission in 2021.

The CO_2 emission from industrial processes and product use accounts for just 0.13 % of the Greenlandic CO_2 emission (excluding net CO_2 emission from Land Use, Land Use Change and Forestry (LULUCF). The HFC emission from industrial processes and product use accounts for 100 % of the Greenlandic emission and the SF_6 emission accounts for 100 % of the Greenlandic SF_6 emission.

Table 11.4.15 Greenhouse gas emission for the year 2021.

		CO_2	HFC	SF_6
		Tonne CO_2 equivalent		
2A4	Limestone and Dolomite Use	54.37	NA	NA
2D2	Paraffin Wax Use	406.91	NA	NA
2D3	Solvent use	253.77	NA	NA
2D3	Road paving with asphalt	0.19	NA	NA
2D3	Asphalt roofing	0.14	NA	NA
2F1	Refrigeration and air conditioning	NA	12 979	NA
2G1	Electrical Equipment	NA	NA	2.5
Total emission from industrial processes and product use		715.38	12 979	2.5
Greenlandic emission (excluding net emission from LULUCF)		566 721	12 979	2.5
			%	
Emission share for industrial processes and product use		0.13	100.00	100.00

Note: Emission of CH_4 and N_2O has been omitted from Table 11.4.15 due to very low values of emission.

HFC is the most important GHG pollutant and accounts for 94.7 % of the GHG emission in CO_2 equivalents from industrial processes and product use. Illustration of the percentage of share in a figure is omitted due to the large share of HFC, which completely dominates as the most significant GHG pollutant from industrial processes.

CO_2

Figure 11.4.6 depicts the time series of CO_2 emission from industrial processes. As shown by the red curve total CO_2 emission follows the CO_2 emission from solvent use closely. The reason is that solvent use is such a dominat source to CO_2 emission within the sector *Industrial processes and product use*.

Data on imports are used to estimate annual use of paraffin wax use, solvent use, limestone and dolomite as well as asphalt for road paving and roofing. This causes a great deal of fluctuations from year to year. Hence, in years with none or low import of solvents e.g., 2008, 2010 and onwards, CO_2 emission from solvent use are on a lower level.

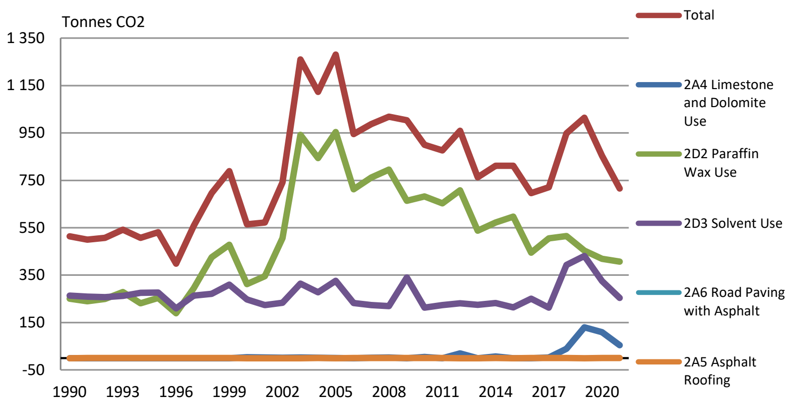

Figure 11.4.6 Emission of CO_2 from industrial processes and product use.

Emission of HFCs and SF_6 are illustrated in Figure 11.4.4 and Figure 11.4.5.

NMVOC and CO

The emissions of NMVOC and CO from industrial processes and product use in 2021 are presented in Table 11.4.16. NMVOC and CO account for 10.79 % and 0.002 % respectively, of the Greenlandic emissions for these substances.

Table 11.4.16 NMVOC and CO emission from industrial processes 2021.

		NMVOC	CO
		Tonnes	
2D3	Solvent Use	81.35	NA
2D3	Asphalt Roofing	0.05	0.00
2D3	Road Paving with Asphalt	0.01	0.10
2H2	Food and beverages industry	38.44	NA
Total emission from industrial processes and product use		119.85	0.10
Greenlandic emission		1 111.11	5 526.14
		%	
Emission share for industrial processes and product use		10.79	0.002

11.4.5 Uncertainties

A tier 1 uncertainty assessment has been carried out in accordance with the IPCC GPG (IPCC, 2006). The uncertainty has been estimated for all sources included in the reporting for industrial processes. The uncertainties for the activity data and emission factors are shown in Table 11.4.17.

Table 11.4.17 Uncertainties for activity data and emission factors for industrial processes.

Subsector	Pollutant	Activity data uncertainty	Emission factor uncertainty
2A4 Limestone and dolomite use	CO_2	5	5
2D2 Paraffin wax use	CO_2	5	25
2D3 Solvent use	CO_2	5	25
2D3 Road paving with asphalt	CO_2	5	25
2D3 Asphalt roofing	CO_2	5	25
2D2 Paraffin wax use	CH_4	5	25
2D3 Road paving with asphalt	CH_4	5	25
2D2 Paraffin wax use	N_2O	5	25
2F Consumption of HFC	HFC	10	50
2G Consumption of SF_6	SF_6	10	50

The activity data comes from the import statistics, which is of high quality. Thus, the uncertainty value of the activity data has been set to 5 % for limestone and dolomite use, paraffin wax use, solvent use and asphalt used for road paving and roofing. For consumption of HFCs and SF_6 the uncertainty value of the activity data has been set to 10 %.

With regards to uncertainty, the CO_2 emission factor for limestone and dolomite use is considered very certain. It is derived from stoichiometric calculations. Thus, an emission factor of 5 % has been assumed. The uncertainty levels for paraffin wax use, solvent use, asphalt roofing and road paving are expert judgements set to 25 % for the emission factor. The emission of F-gases is dominated by emissions from refrigeration equipment and, therefore, the uncertainties assumed for this sector will be used for all the F-gases. The IPCC propose an uncertainty of 30-40 % for regional estimates. However, Greenlandic statistics have been developed over several years and, therefore the uncertainty on activity data is assumed to be 10 %. The uncertainty on the emission factor is, on the other hand, assumed to be 50 %. The base year for F-gases for Greenland is 1995.

The resulting uncertainties for the individual greenhouse gases and the total uncertainty on the greenhouse gas emission are shown in Table 11.4.18.

Table 11.4.18 Uncertainties for the emission estimates.

	Uncertainty %	Trend 1990-2021[1] %	Trend uncertainty %
GHG	± 48	2 252	± 1 149
CO_2	± 17	39.1	± 9.0
HFC	± 51	39 173	± 5 554
SF_6	± 51	-93	± 1.0

[1] For f-gases the base year of 1995 is used.

11.4.6 Source specific QA/QC

The elaboration of a formal QA/QC plan is to be completed.

However, the official Greenlandic import statistics has gone through a great deal of quality work with regards to accuracy, comparability and completeness. Statistics Greenland is responsible for the official Greenlandic import statistics, and as such responsible for the completeness of data. The import statistics is obtained by Statistic Greenland, which are used for emission for Industrial Processes and Product use.

Statistics on imports is reported by Statistics Greenland in form of a spreadsheet. Annual import of limestone and dolomite, paraffin wax use, asphalt materials used for roof covering and road paving, chemicals and chemical containing products, whole coffee beans and yeast for baking are compared with imports in previous years and large discrepancies are checked. The same procedure is used to ensure accuracy in annual use of F-gases and statistics on landings of fish and seafood to domestic plants.

All external data used for the emission inventory submission are archived in spreadsheets. Data are archived annually in order to ensure that the basic data for a given report are always available in their original form.

Safely stored and quality checked activity data are then processes by using a methodological approach consistent with international guidelines.

Calculated emission factors are compared with guideline emission factors to ensure that they are reasonable. The calculations follow the principle in international guidelines.

During data processing, it is checked that calculations are being carried out correctly. However, a documentation plan for this needs to be elaborated.

Time series for activity data, emission factors and calculated emissions are used to identify possible errors in the calculation procedure. In fact, during the calculation, numerous controls take place to ensure correctness. Sums are checked in the various stages in the calculation procedure. Implied emission factors are compared to emission factors.

Every single time series imported to the CRF Reporter is checked for annual activity, units for activity, emission factor and emissions. Additional checks are performed on the database. The database encloses every single activity data, emission factors, emission, notation key and comment imported to the CRF Reporter.

11.4.7 Source specific recalculations and improvements

In this 2023 submission there has been no revisions in the industrial processes and product use sector.

Table 11.3.19 shows recalculations in the industrial processes and product use sector compared to the 2022 submission. No changes occur.

Table 11.4.19 Changes in GHG emission in Industrial Processes and Product Use compared to the 2022 submission.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Previous inventory, Gg CO_2 eqv.	0.5	0.5	0.5	0.6	0.5	0.6	0.5	1.0	1.5	2.2
Recalculated, Gg CO_2 eqv.	0.5	0.5	0.5	0.6	0.5	0.6	0.5	1.0	1.5	2.2
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-
Change in pct.	-	-	-	-	-	-	-	-	-	-
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Previous inventory, Gg CO_2 eqv.	2.6	3.7	5.0	6.3	6.9	7.0	6.8	7.2	7.6	7.8
Recalculated, Gg CO_2 eqv.	2.6	3.7	5.0	6.3	6.9	7.0	6.8	7.2	7.6	7.8
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-
Change in pct.	-	-	-	-	-	-	-	-	-	-
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Previous inventory, Gg CO_2 eqv.	8.2	8.6	9.4	9.7	10.1	10.6	10.7	10.8	10.7	12.1
Recalculated, Gg CO_2 eqv.	8.2	8.6	9.4	9.7	10.1	10.6	10.7	10.8	10.7	12.1
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-
Change in pct.	-	-	-	-	-	-	-	-	-	-
continued	2020	2021								
Previous inventory, Gg CO_2 eqv.	13.8	-								
Recalculated, Gg CO_2 eqv.	13.8	13.7								
Change in Gg CO_2 eqv.	-	-								
Change in pct.	-	-								

11.4.8 Source specific planned improvements

Some planned improvements to the emission inventories are discussed below.

1) Distribution of unspecified mix of HFCs into single HFCs

An unspecified mix of HFCs is used in commercials and industries. In future inventories attempts will be made in order to distribute the unspecified mix of HFCs into single substances.

It will be investigated whether use of N_2O from solvents is occurring in Greenland.

11.4.9 References

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11.5 Agriculture (CRF sector 3)

The emission of greenhouse gases from agricultural activities includes CH_4 emission from enteric fermentation, CH_4 and N_2O emission from manure management and N_2O emission from agricultural soils. The emissions are reported in CRF Tables 3.A, 3.B, 3.D and 3.G.

Emission from rice production, burning of agricultural crop residue and burning of savannas does not occur in Greenland and the CRF Tables 3.C, 3.E and 3.F have, consequently, not been completed.

Emission of non-methane volatile organic compounds (NMVOC) from agricultural activities has not been estimated.

11.5.1 Overview of sector

In CO_2 equivalents, the agricultural sector (without LULUCF) contributes with 1.5 % of the overall greenhouse gas emission (GHG) in 2021. From 1990 to 2021 emissions have decreased from 9.54 Gg CO_2 equivalents to 9.12 Gg CO_2 equivalents, which correspond to a decrease of 4.4 %, see Table 11.5.1. This emission decrease is primarily caused by a decrease in the number of reindeers.

Table 11.5.1 Emission of GHG in the agricultural sector 1990-2021 in Gg CO_2 equivalents.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
CH_4	7.81	7.88	7.08	6.21	6.78	7.29	7.50	8.20	7.81	7.08	6.88
N_2O	1.73	1.74	1.57	1.42	1.54	1.64	2.26	2.01	2.49	2.57	2.29
Total	9.54	9.62	8.65	7.63	8.32	8.92	9.76	10.21	10.30	9.65	9.17
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
CH_4	6.99	6.72	6.81	7.16	7.45	7.22	7.39	7.21	7.06	7.24	7.08
N_2O	2.36	2.22	2.26	2.40	2.52	2.53	2.23	3.28	2.43	2.40	2.61
Total	9.35	8.94	9.07	9.56	9.97	9.75	9.62	10.49	9.49	9.63	9.70
continued	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	
CH_4	7.05	7.01	6.62	6.24	6.45	6.33	6.46	6.33	6.43	6.45	
N_2O	2.48	2.44	2.56	2.34	2.31	1.83	1.61	2.35	2.48	2.67	
Total	9.52	9.45	9.18	8.58	8.76	8.16	8.07	8.68	8.91	9.12	

As showed in Figure 11.5.1, CH_4 emission contributed with 71% of the total GHG emission from the agricultural sector in 2021. N_2O contributed with 29 %. The major part of the emission is related to livestock production, which in Greenland particularly means the production of sheep. A smaller part is related to the reindeer production. Concerning the emission from agricultural soils, the main sources are use of inorganic fertiliser, nitrogen leaching from leaching and run-off and emission from grassing animals.

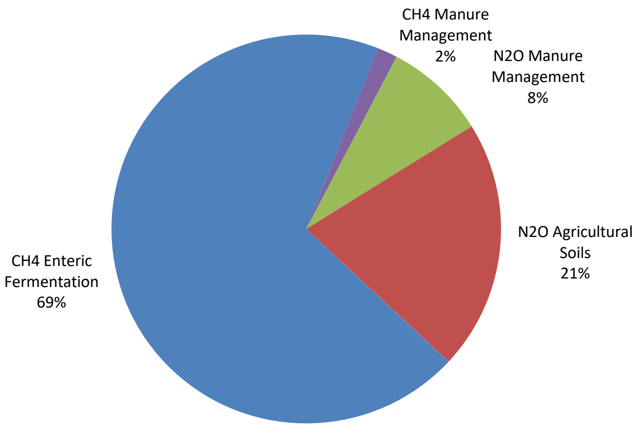

Figure 11.5.1 Emission of greenhouse gases from agriculture in 2021.

11.5.2 Source category description

The calculations of the emissions are based on methods described in the IPCC Reference Manual (IPCC, 2006) and the Good Practice Guidance (IPCC, 2000).

Statistics Greenland is responsible for collecting of data, preparation of emission inventory and reporting. Inputs of data are basically obtained from Statistics Greenland and the Greenland Agricultural Consulting Services (ACS). Data on climate are supplied by the Danish Meteorological Institute (DMI) and Greenland Survey (ASIAQ) and published by Statistics Greenland.

Table 11.5.2 List of institutes involved in the emission inventory for the agricultural sector.

References	Link	Abbreviation	Data/information
Statistics Greenland	*www.stat.gl*	GS	- reporting - data collecting - no. of animal - feed import - use of inorganic fertiliser - spring temperature
The Agricultural Consulting Services	*http://nunalerineq.org*	ACS	- N-excretion - milk yield - feed consumption and composition - stable- and grassing situation - animal growth and weight - land use - crop production
The Danish Plant Directorate	*www.pdir.dk*	PD	- N content in different fertiliser types
The Danish Agricultural Advisory Centre, Aarhus University	*www.lr.dk*	DAAC	- N content in crop residue - CO_2 from liming

11.5.3 CH_4 emission from Enteric Fermentation (CRF sector 3A)

Description

The majority part of the agricultural CH_4 emission originates from digestive processes. In 2021 this source accounts for 69.0 % of the total GHG emission from agricultural activities. The emission is primarily related to ruminants, which in Greenland is sheep. In 2021 sheep contributed with 87.3 % and the remaining 12.7 % from reindeer.

Methodological issues

The implied emission factors for all animal categories are based on the Tier 2/Country Specific (CS) approach. Feed consumption and composition for sheep and reindeer is based on data from Statistics Greenland and the Agricultural Consulting Services (ACS), which has information concerning the agricultural conditions in practice. Default values for the methane conversion rate (Y_m) for sheep given by the IPCC are used, as an average of mature sheep and lambs, which mean an Y_m value of 6.5 % for sheep and 6.0 % for reindeer.

Gross energy intake (GE)

The gross energy intake for sheep and reindeer is based on feeding plans for sheep from the Greenland Agricultural Consulting Services supplemented by data on imported feed. For reindeer information on gross energy intake is based on an article on reindeer management in Greenland.

Table 11.5.3 Parameters for calculation of emission from enteric fermentation.

Animal Category	Gross Energy (GE)	Methane conversion factor (Y_m)	Emission factor
	MJ pr head pr day		Kg CH_4 pr head pr yr
Sheep	28.4	0.065	12.1
Reindeer	27.2	0.060	10.7

The default CH_4 emission factor for sheep Tier 1 methodology is estimated to 8 kg CH_4 per animal per year for developed countries. The default GE is given as 20 MJ/head/yr, which is lower than the calculated GE for Greenland, and can explain the lower emission factor. Another reason could be the fact that the national value for feed intake includes lambs. After lambing, ewes and lambs are put out to pasture. Thus, lambs only feed through their mother and grass. Lambs are not fed separately before slaughter.

There is no default GE for reindeer. However, Norway, Sweden and Finland have estimated gross energy intake for reindeer to 29.6 – 31.6 MJ/head/day. Based on an article on reindeer management in southern Greenland by H.E. Rasmussen in 1992, the Greenlandic gross energy intake for reindeer has been estimated to 27.2 MJ pr head pr day, which is lower than Norway, Sweden and Finland. However, holding in mind that food conditions for reindeer is more scarcely in Greenland compared to conditions in Norway, Sweden and Finland, which have more forest, and that reindeer in Greenland are not fed separately, the estimated of gross energy intake for reindeer in Greenland seems acceptable.

Activity data

Table 11.5.4 shows the development in livestock. The number of sheep is varying slightly. The number of reindeer has decreased considerably since 1990. The reindeer livestock decreased significantly in 1999, when one of two reindeer stations closed. Since 1999 there has been only one reindeer station in Greenland.

Table 11.5.4 Number of animals from 1990-2020, CRF Table 3.A., 3.B (a) and 3.B (b).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Sheep	19 929	20 134	17 900	16 256	17 818	19 464	20 163	23 134	19 929	21 007	20 444
Reindeer	6 000	6 000	5 600	4 300	4 600	4 600	4 600	3 800	6 000	2 106	2 000
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Sheep	20 394	18 967	19 259	20 383	21 317	21 289	21 704	21 080	20 139	20 729	20 232
Reindeer	2 480	3 100	3 100	3 100	3 100	2 318	2 441	2 500	3 000	3 000	3 000
continued	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	
Sheep	20 107	19 994	18 738	17 501	18 190	17 785	18 212	17 785	18 105	18 184	
Reindeer	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	

Implied emission factor

The implied emission factor (IEF) could vary across years for sheep and reindeer due to changes in feed consumption. However, no existing data can document a change in feed intake. Thus, the same IEF is used for all years.

Time series consistency

The emission from enteric fermentation is given in Table 11.5.5. From 1990 to 2021, the emission has decreased by 17.4 % specifically due to a fall in number of both reindeer and sheep.

Table 11.5.5 Emission of CH_4 from Enteric Fermentation 1990-2021, tonnes CH_4.

CRF 3.A	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Sheep	241	243	216	197	215	235	244	280	241	254	247
Reindeer	64	64	60	46	49	49	49	41	64	23	21
Total, tonnes CH_4	305	308	276	243	265	284	293	320	305	276	269
Total, tonnes CO_2 eqv.	7 627	7 689	6 907	6 063	6 615	7 112	7 324	8 008	7 627	6 912	6 714
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Sheep	247	229	233	246	258	257	262	255	243	251	245
Reindeer	27	33	33	33	33	25	26	27	32	32	32
Total, tonnes CH_4	273	262	266	280	291	282	288	282	276	283	277
Total, tonnes CO_2 eqv.	6 827	6 561	6 650	6 989	7 272	7 054	7 212	7 040	6 889	7 067	6 917
continued	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	
Sheep	243	242	227	212	220	215	220	215	219	220	
Reindeer	32	32	32	32	32	32	32	32	32	32	
Total, tonnes CH_4	275	274	259	244	252	247	252	247	251	252	
Total, tonnes CO_2 eqv.	6 879	6 845	6 465	6 091	6 300	6 177	6 306	6 177	6 274	6 298	

11.5.4 CH_4 and N_2O emission from Manure Management (CRF sector 3B)

Description

The emissions of CH_4 and N_2O from manure management are given in CRF Table 3.B (a) and 3.B (b). This source contributes with 10.1 % of the total emission from the agricultural sector in 2020. The majority part of the emission originates from the production of sheep.

Methodological issues

CH_4 emission

The IPCC 2006 Tier 2/CS methodology has been used for the estimation of the CH_4 emission from manure management. Calculation of volatile solid excretion rates, VS is based on national value of gross energy intake (GE). The VS excretion rate is estimated as:

$$VS = \left[GE \times \left(1 - \frac{DE\%}{100}\right) + (UE \times GE)\right] \times \left[\left(\frac{1 - ASH}{18.45}\right)\right]$$

Where default values are used for digestibility (DE), the fraction of urinary energy excretion (UE) and the ash content (ASH), see Table 11.5.6.

In the calculation of the CH4 emission factor from manure management default values are used for maximum methane producing capacity (B_0) and the methane conversion factor (MCF), see Table 11.5.6.

For reindeer no default values exist. Thus DE, ASH and B_o estimates for sheep are used. Sheep and reindeer are similar creatures, both ruminants. Greenlandic reindeer weigh an average of 70 kg. Greenlandic sheep weight approximately 50 kg. However, while sheep are fed relative more intensively, reindeer only feed on what they find in nature all year around. On these arguments the best estimate is to use DE, ASH and B_0 estimates for sheep on reindeer as well.

Table 11.5.6 CH_4 – Manure management – use of national parameters and IPCC default values.

Parameter	Unit	Sheep	Reindeer	Default or national value
Gross energy intake (GE)	MJ pr head pr day	28.4	27.2	National
Digestibility (DE)	Percent	60	60	IPCC default
Urinary energy excretion (UE)	Percent	4	4	IPCC default
Ash content (ASH)	Percent	8	8	IPCC default
Volatile solids (VS)	Kg VS pr head pr day	0.62	0.60	National
Max. methane producing capacity (B_0)	M^3 pr kg VS	0.19	0.19	IPCC default
CH_4 conversion factor (MCF), dry lot	Percent	1	1	IPCC default
CH_4 conversion factor (MCF), pasture, range and paddock	Percent	1	1	IPCC default
Emission factor	Kg CH_4 pr head pr yr	0.29	0.28	Tier 2

There are no changes in stable conditions or feed intake during the years 1990 to 2021. The implied emission factor is therefore the same for all years.

The default emission factor for sheep in cool areas is 0.19 kg CH_4 per head per year. The higher national value is due to a higher estimate for gross energy intake that accounts for both sheep and lamb.

Table 11.5.7 shows a decrease in the CH_4 emission from manure management from 1990 to 2021 by 18.0 % related to the fall in the number of both reindeer and sheep.

Table 11.5.7 Emission of CH_4 from Manure Management 1990-2021, tonnes CH_4.

CRF 3.A	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Sheep	5.8	5.8	5.2	4.7	5.2	5.6	5.8	6.7	5.8	6.1	5.9
Reindeer	1.7	1.7	1.6	1.2	1.3	1.3	1.3	1.1	1.7	0.6	0.6
Total, tonnes CH_4	7.5	7.5	6.8	5.9	6.5	6.9	7.1	7.8	7.5	6.7	6.5
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Sheep	5.9	5.5	5.6	5.9	6.2	6.2	6.3	6.1	5.8	6.0	5.9
Reindeer	0.7	0.9	0.9	0.9	0.9	0.6	0.7	0.7	0.8	0.8	0.8
Total, tonnes CH_4	6.6	6.4	6.5	6.8	7.0	6.8	7.0	6.8	6.7	6.9	6.7
continued	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	
Sheep	5.8	5.8	5.4	5.1	5.3	5.2	5.3	5.2	5.3	5.3	
Reindeer	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	
Total, tonnes CH_4	6.7	6.6	6.3	5.9	6.1	6.0	6.1	6.0	6.1	6.1	

N_2O emission

Based on information from the Greenland Agricultural Consulting Services it is estimated that for sheep 55 % of the N-excretion is taken place in stable (dry lot) and all manure is handled as solid manure. The IPCC default emission value is applied, which means 2.0 % of the N-excretion for solid manure. Sheep is grassing 45 % of the year. The emission from manure deposits on grass is included in "Pasture, Range and Paddock".

Reindeer is grassing all year. The emission from manure deposits on grass is included in "Pasture, Range and Paddock".

The total nitrogen excretion for sheep has decreased by 18.0 % from 1990 to 2021 due to a drop in the number of livestock, see Table 11.5.8.

Table 11.5.8 Total nitrogen excretion for sheep, 1990-2021, tonnes N.

CRF table 3.B(b)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
N-excreted, tonnes in total	154	155	140	122	133	143	147	161	154	138	134
N-excretion, tonnes in stable	66	66	59	54	59	64	67	76	66	69	67
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
N-excreted, tonnes in total	137	132	133	140	146	141	144	141	138	142	139
N-excretion, tonnes in stable	67	63	64	67	70	70	72	70	66	68	67
continued	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	
N-excreted, tonnes in total	138	137	130	122	126	124	127	124	126	126	
N-excretion, tonnes in stable	66	66	62	58	60	59	60	59	60	60	

Time series consistency

As shown in Table 11.5.9 total emission from manure management has decreased by 12.3 % from 1990 to 2021 due to a decrease in the number of sheep and reindeer.

Table 11.5.9 Emissions of N_2O and CH_4 from Manure Management 1990-2021.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
N_2O emission, tonnes CO_2 eqv.	869	877	782	704	771	839	867	983	869	882	858
CH_4 emission, tonnes CO_2 eqv.	186	188	169	148	161	173	178	194	186	167	162
Total, tonnes CO_2 eqv.	1 055	1 065	951	852	932	1 012	1 046	1 178	1 055	1 049	1 020
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
N_2O emission, tonnes CO_2 eqv.	860	806	818	864	903	896	914	888	854	878	857
CH_4 emission, tonnes CO_2 eqv.	165	159	161	169	176	171	174	170	167	171	168
Total, tonnes CO_2 eqv.	1 025	965	980	1 034	1 079	1 066	1 088	1 059	1 021	1 049	1 025
continued	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	
N_2O emission, tonnes CO_2 eqv.	852	848	796	745	773	757	774	757	770	773	
CH_4 emission, tonnes CO_2 eqv.	167	166	157	148	153	150	153	150	152	153	
Total, tonnes CO_2 eqv.	1 019	1 014	953	893	926	907	927	907	922	926	

11.5.5 N_2O emission from Agricultural Soils (CRF sector 3D)

Description

N_2O emissions from agricultural soils contributed with 21.6 % of total emissions from the agricultural sector in 2021. Figure 11.5.2 shows the overall development from 1990 to 2021 and the distribution on different sources.

Emission from inorganic fertiliser and nitrogen leaching is an essential part of the total emission from agricultural soils and contributes totally with 60.0 % of total in 2021. Of the remaining sources the greatest part of the emission, by 15.2 %, origins from urine and dung deposited by grazing animals. Emissions from all sources have increased or remained the same from 1990 to 2020 except from animal manure applied to soils and urine and dung deposited by grazing animals both due to a fall in number of reindeer and sheep.

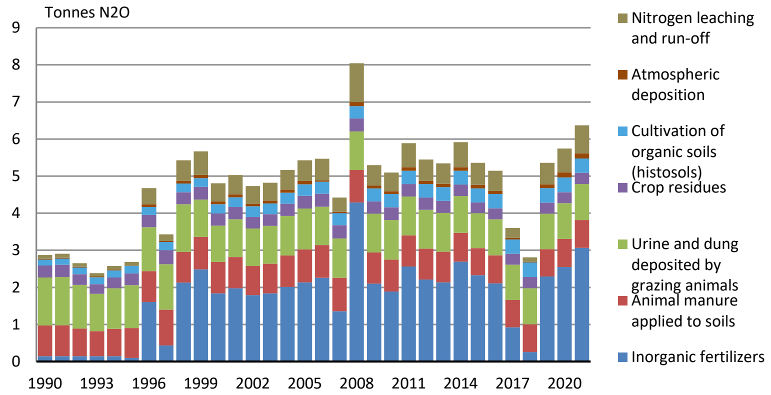

Figure 11.5.2 N_2O emissions from agricultural soils 1990-2021.

Methodological issues

To calculate the N_2O emission a combination of IPCC Tier 1a and Tier 1b is used. Tier 1b is used in calculation of emission from crop residues. Emissions of N_2O are closely related to the nitrogen balance. Data concerning the N-excretion, evaporation of ammonia from inorganic fertiliser and grassing animal are based on national values.

The NH_3 and N_2O emission factor survey is presented in Table 11.5.10 and shows that except from histosols all N_2O emission factor is based on IPCC default values. The estimated emissions from the different sub-sources are described in the text which follows.

Table 11.5.10 Emissions factor - N_2O emission from Agricultural Soils 1990-2021.

Agricultural soils – emission sources CRF Table 3.D	Ammonia emission factor	N_2O emission factor (country specific value)	N_2O emission factor (IPCC default value)
	Kg NH_3-N pr kg N	kg N_2O-N pr ha	kg N_2O -N pr kg N
a. Direct N_2O emissions from managed soils			
1. Inorganic N fertilisers	0.04 (CS)		0.01
2. Organic N fertilisers			
Animal manure applied to soils	0.20 (IPCC default)		0.01
3. Urine and dung deposited by grazin animals			0.01
4. Crop residues			0.01
Cultivation of organic soils (i.e., histosols)		0.84*	
b. Indirect N_2O emissions from managed soils			
Atmospheric deposition			0.01
Nitrogen leaching and run-off			0.0075

CS = country specific value. FracGASF, depending upon the annual mix of inorganic fertilisers.

* Include both emission from cropland and improved grassland. For further details see Section 11.6.

Direct emissions

Inorganic fertiliser

The calculation of nitrogen (N) applied to soils from use of inorganic fertiliser is based on data on imports from Statistics Greenland. No data is available before 1994. The consumption for 1990 to 1993 is assumed to be on the same level as 1994. The nitrogen content for each fertiliser type is estimated based on expert judgement from the Danish Plant Directorate (Troels Knudsen, pers. comm.).

Table 11.5.11 shows the consumption of each type of fertiliser in 2021. Furthermore, the ammonia emission factor for each fertiliser is given, based on the values given in EMEP/EEA emission inventory guidebook 2019 (Table 3-2). The emission factors are depending on a normal pH of 7.0 or below, and a cool climate with mean spring temperature estimated to seven degrees in Greenland. The spring temperature must reflect the time where the fertilisers are applied, which in Greenland normally is June.

Table 11.5.11 Consumption of inorganic fertiliser 2021 and the NH_3 emission factors.

Inorganic fertiliser	NH_3 Emission factor[1] kg NH_3 per kg N applied	Consumption[2] t N
Type of fertiliser		
Ammonium sulphate	0.090	NO
Ammonium nitrate	0.015	40.9
Calcium ammonium nitrate	0.008	NO
Anhydrous ammonia	0.019	NO
Urea	0.155	20.5
Nitrogen solutions	0.098	NO
Ammonium phosphates	0.050	NO
Other NK and NPK	0.050	133.4
Total consumption of N in inorganic fertiliser		194.9
National emission of NH_3, tonnes	10.467	
National emission of NH_3-N, tonnes	8.620	
Average NH_3-N emission ($Frac_{GASF}$)[3]	0.044	

[1]) EMEP/EEA (2019), cool cimate and pH-value of 7.0 or below.

[2]) Statistics Greenland and the Danish Plant Directorate.

[3]) $Frac_{GASF}$ fraction of synthetic fertiliser N that volatises as NH_3.

The Greenlandic value for the FracGASF is estimated to 0.044 in 2021, which is considerably lower than the recommended default value 0.10 (IPCC 2006, Table 11.3). The majority part of the fertiliser types used in Greenland is related to NPK fertiliser where the emission factor is relatively low e.g., 5.0 kg NH_3-N pr kg N. Before 1995, urea accounted for a higher fraction. The value of FracGASF for these years is estimated to 0.127.

Table 11.5.12 FracGASF, 1990-2021.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
FracGASF	0.127	0.127	0.127	0.127	0.127	0.106	0.047	0.055	0.036	0.034	0.041
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
FracGASF	0.041	0.041	0.041	0.041	0.040	0.016	0.026	0.025	0.039	0.041	0.036
continued	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	
FracGASF	0.040	0.041	0.034	0.043	0.040	0.040	0.049	0.044	0.055	0.044	

Table 11.5.13 shows a general increase in use of fertiliser and a particularl jump upwards in 1996 and 2008. Due to a relatively small number of farms the individual handling of one farmer has a high effect on the total consumptions. With consumption of fertilisers being based on imports of fertilisers it is not possible to account for fertilisers bought for stockpiling. Thus, it is possible that the relative high increase in use of fertilisers in 2008 is due to stockpiling. Another explanation could be that both 2007 and 2008 were relative dry years leading to a considerable decrease in amount of hey harvested.

Table 11.5.13 Nitrogen applied as fertiliser to agricultural soils 1990-2021.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
N content in inorganic fertiliser, tonnes N	9	9	9	9	9	6	102	28	135	158
NH_3-N emission, tonnes	1	1	1	1	1	1	5	2	5	5
N in fertiliser applied on soil, tonnes N	8	8	8	8	8	5	97	26	130	153
N_2O emission, tonnes	0.15	0.15	0.15	0.15	0.15	0.10	1.60	0.43	2.13	2.49
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
N content in inorganic fertiliser, tonnes N	117	126	114	117	128	136	144	86	273	134
NH_3-N emission, tonnes	5	5	5	5	5	5	2	2	7	5
N in fertiliser applied on soil, tonnes N	112	120	109	112	123	131	141	84	266	129
N_2O emission, tonnes	1.84	1.97	1.79	1.84	2.01	2.14	2.26	1.36	4.29	2.10
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
N content in inorganic fertiliser, tonnes N	120	163	141	136	172	148	134	59	16	146
NH_3-N emission, tonnes	5	6	6	6	6	6	5	2	1	6
N in fertiliser applied on soil, tonnes N	115	157	135	130	166	142	129	56	15	140
N_2O emission, tonnes	1.89	2.56	2.21	2.13	2.70	2.33	2.11	0.92	0.25	2.30
continued	2020	2021								
N content in inorganic fertiliser, tonnes N	162	195								
NH_3-N emission, tonnes	9	9								
N in fertiliser applied on soil, tonnes N	153	186								
N_2O emission, tonnes	2.55	3.06								

Manure applied to soil

The amount of nitrogen applied to soils from sheep in stables is estimated as the N-excretion in stables minus the ammonia emission, which occur in stables, under storage and in relation to the application of manure. There are no measurements of ammonia emission from stables in Greenland. Thus, the IPCC default for FracGASM at 0.20 is used (IPCC 2006, Table 11-3).

Table 11.5.14 shows the development in nitrogen excretion in stables, the estimated amount of N applied on soil and the N_2O emission.

Table 11.5.14 Nitrogen applied as manure to agricultural soils 1990-2021.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
N-excretion in stable, tonnes N	66	66	59	54	59	64	67	76	66	69
NH_3-N emission, tonnes N	13	13	12	11	12	13	13	15	13	14
N in manure applied on soil, tonnes N	53	53	47	43	47	51	53	61	53	55
N_2O emission, tonnes N_2O	0.83	0.84	0.74	0.67	0.74	0.81	0.84	0.96	0.83	0.87
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
N-excretion in stable, tonnes N	67	67	63	64	67	70	70	72	70	66
NH_3-N emission, tonnes N	13	13	13	13	13	14	14	14	14	13
N in manure applied on soil, tonnes N	54	54	50	51	54	56	56	57	56	53
N_2O emission, tonnes N_2O	0.85	0.85	0.79	0.80	0.85	0.88	0.88	0.90	0.87	0.84
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
N-excretion in stable, tonnes N	68	67	66	66	62	58	60	59	60	59
NH_3-N emission, tonnes N	14	13	13	13	12	12	12	12	12	12
N in manure applied on soil, tonnes N	55	53	53	53	49	46	48	47	48	47
N_2O emission, tonnes N_2O	0.86	0.84	0.83	0.83	0.78	0.73	0.75	0.74	0.76	0.74
continued	2020	2021								
N-excretion in stable, tonnes N	60	60								
NH_3-N emission, tonnes N	12	12								
N in manure applied on soil, tonnes N	48	48								
N_2O emission, tonnes N_2O	0.75	0.75								

Crop residue

The cultivated area is approximately 1,178 ha with the main part as grass fields. Only 10.5 ha are used for potato production. The cultivated area has increased slightly over the years.

The emission from crop residues is estimated based on the tier 1 methodology in the 2006 IPCC Guidelines. Default values for all parameters given in IPCC 2006 Table 11.2 are used.

N_2O emissions from crop residues are calculated based on the total above- and belowground Nintrogen content (N-content) in crop residue returned to soil, which in Greenland includes residue of leafs and roots from grass fields and the top and root from potatoes. Harvest of potatoes and grass-clover are calculated based on relatively few observations related to Danish conditions but are at present the best available data.

In the 2022-submission the calculation of belowground N-content was revised. In prior submissions calculation of belowground N-content was based only on the dry matter fraction (DRY) of the harvested crop. However, Danish studies have shown that the above-ground residue dry matter (AGDM) should be included in the calculation of belowground N-content. The revised calculation of belowground N-content in crop residue has let to a higher amount of dry matter and therefore to a higher estimate of N-content in the belowground crop residue.

Table 11.5.15 N-content in crop residues 2021.

	Husks	Stubble	Top	Leafs	Frequency of ploughing	Nitrogen content in crop residue	
Crop type		kg N pr ha			No. of years between ploughing	kg N pr ha	kg N
Potatoes	7.8	-	4.8	-	1	12.7	133
Grass-Clover mixtures in rotation	-	11.1	-	5.0	5	16.2	18 963
Total N from crop residue, kg							19 096

Reference: National data and IPCC 2006 (Table 11.2).

To calculate the N_2O emission the IPCC standard emission factor 1.0 % is used. The national emission from crop residues has been relatively stable from 1990 to 2021 (Table 11.5.16).

Table 11.5.16 Emission from crop residues 1990-2021.

Crop residue	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Potatoes, kg N	-	-	-	-	-	-	-	-	-	-
Grass-Clover, kg N	20 783	20 997	18 667	16 953	18 581	20 298	21 027	24 125	20 783	21 907
Crop residue total, kg N	20 783	20 997	18 667	16 953	18 581	20 298	21 027	24 125	20 783	21 907
N_2O emission, kg	327	330	293	266	292	319	330	379	327	344
continued	2000	2001	2004	2005	2006	2007	2008	2009	2010	2011
Potatoes, kg N	-	63	63	63	63	63	63	63	63	82
Grass-Clover, kg N	21 320	21 268	19 780	20 084	21 256	22 230	22 201	22 634	21 983	21 002
Crop residue total, kg N	21 320	21 331	19 843	20 148	21 320	22 294	22 265	22 697	22 047	21 084
N_2O emission, kg	335	335	312	317	335	350	350	357	346	331
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Potatoes, kg N	82	133	133	133	133	133	133	133	133	133
Grass-Clover, kg N	21 617	21 099	20 969	20 851	19 541	18 251	18 969	18 547	18 992	18 547
Crop residue total, kg N	21 700	21 232	21 102	20 984	19 674	18 384	19 102	18 680	19 125	18 680
N_2O emission, kg	341	334	332	330	309	289	300	294	301	294
continued	2020	2021								
Potatoes, kg N	133	133								
Grass-Clover, kg N	18 881	18 963								
Crop residue total, kg N	19 014	19 096								
N_2O emission, kg	299	300								

Cultivation of histosols

N_2O emissions from histosols are based on the area with organic soils multiplied by the emission factor of 0.86 kg N_2O-N pr. hectare in 2021. See Section 11.6 on LULUCF for further description on cultivation of histosols.

Table 11.5.17 shows an increase in the N_2O emission from 1990 to 2021 due an increase in the agricultural area.

Table 11.5.17 Activity data and emission from cultivation of histosols 1990-2021.

CRF – Table 3.D	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Cultivated histosols, ha	123	129	136	142	149	155	161	168	174	181
N_2O emission, kg	160	169	177	186	194	203	211	220	228	237
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Cultivated histosols, ha	187	195	214	220	223	232	242	247	252	262
N_2O emission, kg	245	260	285	293	297	308	321	328	335	350
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Cultivated histosols, ha	268	270	273	275	277	282	285	287	291	293
N_2O emission, kg	357	364	367	370	373	379	383	386	391	394
continued	2020	2021								
Cultivated histosols, ha	294	293								
N_2O emission, kg	396	389								

Pasture, Range and Paddock

The amount of nitrogen deposited on grass includes grassing from reindeer 365 days a year and from sheep 164 days a year. An ammonia emission factor of 7 % is used for all animal categories based on investigations from the Netherlands and the United Kingdom (Jarvis et al., 1989a, Jarvis et al., 1989b and Bussink, 1994). EMEP/EEA Emission Inventory Guidebook 2019 use a similar emission factor at 9 % for sheep (Table 3.9).

Table 11.5.18 shows the estimated values of N-excretion from grassing animals, ammonia emission and N_2O emission. Due to an overall drop in number of reindeer and recently also sheeps N_2O emission has decreased from 1990 to 2021.

Table 11.5.18 Emission from grassing animals 1990-2021.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
N-excretion on grass, tonnes N	88	89	81	69	75	79	81	84	88	69
NH_3-N emission, tonnes	6	6	6	5	5	6	6	6	6	5
N deposited on grass, tonnes N	82	83	75	64	69	73	75	78	82	64
N_2O emission, tonnes	1.29	1.30	1.18	1.00	1.09	1.15	1.18	1.23	1.29	1.01
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
N-excretion on grass, tonnes N	67	69	69	70	73	75	71	73	71	72
NH_3-N emission, tonnes	5	5	5	5	5	5	5	5	5	5
N deposited on grass, tonnes N	62	64	64	65	68	70	66	68	66	67
N_2O emission, tonnes	0.97	1.01	1.01	1.02	1.06	1.10	1.03	1.06	1.04	1.05
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
N-excretion on grass, tonnes N	73	72	72	71	68	65	66	65	66	65
NH_3-N emission, tonnes	5	5	5	5	5	5	5	5	5	5
N deposited on grass, tonnes N	68	67	67	66	63	60	62	61	62	61
N_2O emission, tonnes	1.07	1.05	1.05	1.04	0.99	0.94	0.97	0.95	0.97	0.95
continued	2020	2021								
N-excretion on grass, tonnes N	66	66								
NH_3-N emission, tonnes	5	5								
N deposited on grass, tonnes N	62	62								
N_2O emission, tonnes	0.97	0.97								

Indirect emissions

Atmospheric deposition

Atmospheric deposition includes ammonia emission from manure management, use of inorganic fertiliser and from grassing animals.

N_2O emission from atmospheric deposition has more than doubled from since 1990. Even though the number of reindeer and sheep has decreased, the increasing use of inorganic fertiliser has increased total N_2O emission from atmospheric deposition by 632.7 % from 1990 to 2021.

Table 11.5.19 Emission from atmospheric deposition 1990-2021.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
NH_3-N manure management, tonnes	13	13	12	11	12	13	13	15	13	14
NH_3-N inorganic fertlizer, tonnes	1	1	1	1	1	1	5	2	5	5
NH_3-N pasture, tonnes	6	6	6	5	5	6	6	6	6	5
NH_3-N total, tonnes	21	21	19	17	18	19	24	23	24	24
N_2O emission, tonnes	0.02	0.02	0.02	0.02	0.02	0.01	0.08	0.02	0.08	0.09
Continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
NH_3-N manure management, tonnes	13	13	13	13	13	14	14	14	14	13
NH_3-N inorganic fertlizer, tonnes	5	5	5	5	5	5	2	2	7	5
NH_3-N pasture, tonnes	5	5	5	5	5	5	5	5	5	5
NH_3-N total, tonnes	23	23	22	22	24	25	21	22	26	24
N_2O emission, tonnes	0.08	0.08	0.07	0.08	0.08	0.09	0.04	0.04	0.11	0.08
Continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
NH_3-N manure management, tonnes	14	13	13	13	12	12	12	12	12	12
NH_3-N inorganic fertlizer, tonnes	5	6	6	6	6	6	5	2	1	6
NH_3-N pasture, tonnes	5	5	5	5	5	5	5	5	5	5
NH_3-N total, tonnes	24	24	24	24	23	22	22	19	17	23
N_2O emission, tonnes	0.08	0.09	0.09	0.09	0.09	0.10	0.08	0.04	0.01	0.10
Continued	2020	2021								
NH_3-N manure management, tonnes	12	12								
NH_3-N inorganic fertlizer, tonnes	9	9								
NH_3-N pasture, tonnes	5	5								
NH_3-N total, tonnes	26	25								
N_2O emission, tonnes	0.14	0.14								

Nitrogen leaching and Run-off

The amount of nitrogen lost by leaching and run-off is calculated by using the IPCC default FracLEACH-(H) at 0.3 (IPCC 2006, Table 11.3).

N_2O emission from N-leaching and runoff has increased more than seven times from 1990 to 2021.

From 1990 to 2021 total nitrogen content in manure has decreased due to a fall in the number of reindeer and sheep. However, in the same period the use of inorganic fertilisers has increased significantly causing the overall N_2O emission from N-leaching and runoff to increase. The annual use of inorganic fertiliser seems to fluctuate from year to year, causing overall N_2O emission from N-leaching and runoff to vary from year to year as well.

Table 11.5.20 Emission from N-leaching and runoff 1990-2021.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
N-excretion total, tonnes N	154	155	140	122	133	143	147	161	154	138
N in inorganic fertiliser, tonnes	9	9	9	9	9	6	102	28	135	158
N_2O emission, tonnes	0.11	0.11	0.10	0.09	0.10	0.09	0.44	0.18	0.55	0.64
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
N-excretion total, tonnes N	134	137	132	133	140	146	141	144	141	138
N in inorganic fertiliser, tonnes	117	126	114	117	128	136	144	86	273	134
N_2O emission, tonnes	0.49	0.52	0.47	0.48	0.53	0.56	0.59	0.39	1.04	0.55
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
N-excretion total, tonnes N	142	139	138	137	130	122	126	124	127	124
N in inorganic fertiliser, tonnes	120	163	141	136	172	148	134	59	16	146
N_2O emission, tonnes	0.50	0.65	0.57	0.55	0.68	0.59	0.54	0.27	0.12	0.58
continued	2020	2021								
N-excretion total, tonnes N	126	126								
N in inorganic fertiliser, tonnes	162	195								
N_2O emission, tonnes	0.64	0.76								

Activity data

Table 11.5.21 provides an overview on activity data from 1990 to 2021 used for the estimation of N_2O emission from agricultural soils. For all emission sources the unit tonnes of nitrogen are used except from cultivation of histosols, where the unit is given as hectare.

Table 11.5.21 Activity data - agricultural soils 1990-2021, tonnes N (cultivation of histosols = ha).

CRF – Table 3.D	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
A. Direct N_2O emissions from managed soils										
Inorganic fertiliser	9	9	9	9	9	6	102	28	135	158
Animal manure applied to soils	53	53	47	43	47	51	53	61	53	55
Urine and dung deposited by grazing animals	82	83	75	64	69	73	75	78	82	64
Crop residue	21	21	19	17	19	20	21	24	21	22
Cultivation of histosols	123	129	136	142	149	155	161	168	174	181
B. Indirect N_2O emissions from managed soils										
Atmospheric deposition	1	1	1	1	1	1	5	2	5	5
Nitrogen leaching and run-off	9	9	8	8	8	8	37	16	47	54
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
A. Direct N_2O emissions from managed soils										
Inorganic fertiliser	117	126	114	117	128	136	144	86	273	134
Animal manure applied to soils	54	54	50	51	54	56	56	57	56	53
Urine and dung deposited by grazing animals	62	64	64	65	68	70	66	68	66	67
Crop residue	21	21	20	20	21	22	22	23	22	21
Cultivation of histosols	187	195	214	220	223	232	242	247	252	262
B. Indirect N_2O emissions from managed soils										
Atmospheric deposition	5	5	5	5	5	5	2	2	7	5
Nitrogen leaching and run-off	41	44	40	41	45	47	50	33	89	46
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
A. Direct N_2O emissions from managed soils										
Inorganic fertiliser	120	163	141	136	172	148	134	59	16	146
Animal manure applied to soils	55	53	53	53	49	46	48	47	48	47
Urine and dung deposited by grazing animals	68	67	67	66	63	60	62	61	62	61
Crop residue	22	21	21	21	20	18	19	19	19	19
Cultivation of histosols	268	270	273	275	277	282	285	287	291	293
B. Indirect N_2O emissions from managed soils										
Atmospheric deposition	5	6	6	6	6	6	5	2	1	6
Nitrogen leaching and run-off	43	55	49	47	57	50	46	23	11	49
continued	2020	2021								
A. Direct N_2O emissions from managed soils										
Inorganic fertiliser	162	195								
Animal manure applied to soils	48	48								
Urine and dung deposited by grazing animals	62	62								
Crop residue	19	19								
Cultivation of histosols	294	296								
B. Indirect N_2O emissions from managed soils										
Atmospheric deposition	9	9								
Nitrogen leaching and run-off	54	64								

Time series consistency

N_2O emissions from agricultural soils have increased from 2.9 tonnes N_2O in 1990 to 6.4 tonnes N_2O in 2021, see Table 11.5.22.

Table 11.5.22 Emissions of N_2O from Agricultural Soils 1990–2021, tonnes N_2O.

CRF – Table 3.D	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Total N_2O emission	2.9	2.9	2.7	2.4	2.6	2.7	4.7	3.4	5.4	5.7
A. Direct N_2O emissions from managed soils										
Inorganic fertiliser	0.1	0.1	0.1	0.1	0.1	0.1	1.6	0.4	2.1	2.5
Animal manure applied on soil	0.8	0.8	0.7	0.7	0.7	0.8	0.8	1.0	0.8	0.9
Urine and dung deposited by grazing animals	1.3	1.3	1.2	1.0	1.1	1.2	1.2	1.2	1.3	1.0
Crop residue	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.3
Cultivation of histosols	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
B. Indirect N2O emissions from managed soils										
Atmospheric deposition	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1
Nitrogen leaching and run-off	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.2	0.6	0.6
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Total N_2O emission	4.8	5.0	4.7	4.8	5.2	5.4	5.5	4.4	8.0	5.3
A. Direct N2O emissions from managed soils										
Inorganic fertiliser	1.8	2.0	1.8	1.8	2.0	2.1	2.3	1.4	4.3	2.1
Animal manure applied on soil	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.8
Urine and dung deposited by grazing animals	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.1	1.0	1.0
Crop residue	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.4	0.3	0.3
Cultivation of histosols	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
B. Indirect N2O emissions from managed soils										
Atmospheric deposition	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.1
Nitrogen leaching and run-off	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.4	1.0	0.5
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total N_2O emission	5.1	5.9	5.4	5.3	5.9	5.4	5.1	3.6	2.8	5.4
A. Direct N2O emissions from managed soils										
Inorganic fertiliser	1.9	2.6	2.2	2.1	2.7	2.3	2.1	0.9	0.3	2.3
Animal manure applied on soil	0.9	0.8	0.8	0.8	0.8	0.7	0.8	0.7	0.8	0.7
Urine and dung deposited by grazing animals	1.1	1.1	1.0	1.0	1.0	0.9	1.0	1.0	1.0	1.0
Crop residue	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Cultivation of histosols	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
B. Indirect N2O emissions from managed soils										
Atmospheric deposition	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.1
Nitrogen leaching and run-off	0.5	0.7	0.6	0.6	0.7	0.6	0.5	0.3	0.1	0.6

continued	2020	2021
Total N_2O emission	5.7	6.4
A. Direct N2O emissions from managed soils		
Inorganic fertiliser	2.6	3.1
Animal manure applied on soil	0.8	0.8
Urine and dung deposited by grazing animals	1.0	1.0
Crop residue	0.3	0.3
Cultivation of histosols	0.4	0.4
B. Indirect N2O emissions from managed soils		
Atmospheric deposition	0.1	0.1
Nitrogen leaching and run-off	0.6	0.8

11.5.6 Uncertainties

A tier 1 uncertainty assessment has been carried out in accordance with the IPCC Guidelines (IPCC, 2006). The uncertainty has been estimated for all sources included in the reporting for agricultural sector. The uncertainties for the activity data and emission factors are shown in Table 11.5.23.

Table 11.5.23 Uncertainties for activity data and emission factors for agriculture.

Subsector	Pollutant	Activity data uncertainty	Emission factor uncertainty
3A Enteric Fermentation	CH_4	10	100
3B Manure Management	CH_4	10	100
3B Manure Management	N_2O	10	100
3D Agricultural soils	N_2O	20	50
3G Liming	CO_2	5	50

The resulting uncertainties for the individual greenhouse gases and the total uncertainty on the greenhouse gas emission are shown in Table 11.5.24.

Table 11.5.24 Uncertainties for the emission estimates.

	Uncertainty %	Trend 1990-2021 %	Trend uncertainty %
GHG	± 71	-4.4	± 16.1
CO_2	± 50	-50.0	± 3.5
CH_4	± 98	-17.4	± 11.4
N_2O	± 48	54.8	± 48.6

11.5.7 Source specific QA/QC

The elaboration of a formal QA/QC plan is to be completed.

However, data on livestock, land-use categories, inorganic fertilisers and cultivation of histosols has gone through a great deal of quality work with regards to accuracy, comparability and completeness.

All external data used for the emission inventory submission are archived in spreadsheets. Data are archived annually in order to ensure that the basic data for a given report are always available in their original form.

Annual data on livestock, land-use categories, inorganic fertilisers and cultivation of histosols are compared with previous years and large discrepancies are checked.

Safely stored and quality checked activity data are then processes by using a methodological approach consistent with international guidelines.

Calculated emission factors are compared with guideline emission factors to ensure that they are reasonable. The calculations follow the principle in international guidelines.

During data processing, it is checked that calculations are being carried out correctly. However, a documentation plan for this needs to be elaborated.

Time series for activity data, emission factors and calculated emissions are used to identify possible errors in the calculation procedure. In fact, during the calculation, numerous controls take place to ensure correctness. Sums are checked of the various stages in the calculation procedure. Implied emission factors are compared to emission factors.

Every single time series imported to the CRF Reporter is checked for annual activity, units for activity, emission factor and emissions. Additional checks are performed on the database. The database encloses every single activity data, emission factors, emission, notation key and comment imported to the CRF Reporter.

11.5.8 Source specific recalculations and improvements

In this 2022 submission there has been no revisions in the agricultural sector.

Table 11.5.25 shows recalculations in the agricultural sector compared to the 2022 submission. No changes occur.

Table 11.5.25 Changes in GHG emission in the agricultural sector compared to the 2022 submission.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Previous inventory, Gg CO_2 eqv.	9.5	9.6	8.7	7.6	8.3	8.9	9.8	10.2	10.3	9.7
Recalculated, Gg CO_2 eqv.	9.5	9.6	8.7	7.6	8.3	8.9	9.8	10.2	10.3	9.7
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-
Change in pct.	-	-	-	-	-	-	-	-	-	-
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Previous inventory, Gg CO_2 eqv.	9.2	9.4	8.9	9.1	9.6	10.0	9.8	9.6	10.5	9.5
Recalculated, Gg CO_2 eqv.	9.2	9.4	8.9	9.1	9.6	10.0	9.8	9.6	10.5	9.5
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-
Change in pct.	-	-	-	-	-	-	-	-	-	-
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Previous inventory, Gg CO_2 eqv.	9.6	9.7	9.5	9.5	9.2	8.6	8.8	8.2	8.1	8.7
Recalculated, Gg CO_2 eqv.	9.6	9.7	9.5	9.5	9.2	8.6	8.8	8.2	8.1	8.7
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-
Change in pct.	-	-	-	-	-	-	-	-	-	-
continued	2020	2021								
Previous inventory, Gg CO_2 eqv.	8.9	-								
Recalculated, Gg CO_2 eqv.	8.9	9.1								
Change in Gg CO_2 eqv.	-	-								
Change in pct.	-	-								

11.5.9 Source specific planned improvements

The Greenlandic emission inventory for the agricultural sector largely meets the request as set down in the IPCC Good Practice Guidance. Thus, for the moment improvements especially concern the QA/QC practice.

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11.6 LULUCF (CRF sector 4)

11.6.1 Overview of LULUCF

This LULUCF chapter covers only the territory of Greenland. Greenland is part of the Danish Kingdom.

Figure 11.6.1 Municipalities and major cities in Greenland.

Greenland is the world's largest non-continental island located on the northern American continent between the Arctic Ocean and the North Atlantic Ocean, northeast of Canada. The northernmost point of Greenland, Cape Morris Jesup, is only 740 km from the North Pole. The southernmost point is Cape Farewell, which lies at about the same latitude as Oslo in Norway. Geographical coordinates are 72 00 N, 40 00 W.

Greenland is covering approximately 2,166,086 km^2. It has been estimated that 81 % is covered permanently with ice leaving only 410,449 km^2 ice free. The distance from the South to the North is 2,670 km, and from East to West 1,050 km.

The terrain is flat to gradually sloping ice cap, which covers all but a narrow, mountainous, barren, rocky coast. The ice cap is up to 3 km thick and contains 10 per cent of the world's resources of freshwater.

The climate is arctic to sub-arctic with cool winters and cold summers in which the mean temperature does not exceed 10° C.

The mean temperature in January is for Nuuk -4.0°, Kangerlussuaq -16.5° and Ilulissat -8.4° (2021) and for July: Nuuk 7.9°, Kangerlussuaq 11.1° and Ilulissat 8.9° (2021).

Greenland is normally defined as having three different climatic zones. For the purpose of reporting is used the definition "Polar and Moist" according to IPCC 2006 Guidelines although some areas may qualify as arctic deserts.

The sparse population is confined to small settlements along the coast, but close to one-quarter of the population lives in the capital, Nuuk. In January 2023 the total Greenlandic population was 56 609 inhabitants.

Due to the cold climate and the constant small population, there is almost no land use change occurring. The total area with Forests has been estimated to 218.5 hectares and 10.5 hectares with Cropland. Grassland is divided into improved Grassland covering 1 168 hectares and unimproved Grassland covering 240 817 hectares. Wetlands consist of man-made water reservoirs – in total 1 076 hectares. Settlements cover 6 661 hectares. Land classified as "Other Land" is then 99.9 % of the total area.

In the following text the abbreviations are used in accordance with definitions in the IPCC guidelines:

A:	Afforestation, areas which has been forested within the last 30 years
D:	Deforestation, areas where forests are permanently removed to allow for other land use
FF:	Forest remaining Forest, areas remaining for the last 30 years
FL:	Forest Land meeting the definition of forests.
CL:	Cropland.
GL:	Grassland.
SE:	Settlements.
OL:	Other land, unclassified land.
HWP:	Harvested Wood Products.

The LULUCF sector differs from the other sectors in that it contains both sources and sinks of carbon dioxide. LULUCF are reported in the CRF format. Removals are given as negative figures and emissions are reported as positive figures in accordance with the guidelines.

In total the LULUCF sector has been estimated as a net source of 1.371 kt CO_2 equivalents in 2021 equivalent to 0.2 % of the total Greenlandic emission.

The overall land use change from 1990 to 2021 is very small. Afforestation has been made on 14 hectares. No deforestation has occurred, and the Cropland area has increased from none to 10.5 hectares.

The emission data are reported in the CRF format under IPCC categories 4A (Forestry), 4B (Cropland), 4C (Grassland), 4D (Wetlands), 4E (Settlements) and 4F (Other Land).

Fertilisation of forests and other land is not occurring, and all fertiliser consumption is therefore reported in the agricultural sector. No drainage of forest soils is made. All liming is reported under Grassland because liming is not occurring in the forests and the very small area with Cropland. Field burning of wooden biomass is not occurring. Wildfires may occur sporadic in the mountains, and these are reported as "Other land". Hence, wildfires are reported as NO.

Table 11.6.1 gives an overview of the emission from the LULUCF sector in Greenland. The Forests are a net sink. Cropland is ranging from being zero in 1990 (no Cropland was occurring in 1990) to being a net source in 2021. Grassland has been estimated to be a net source too. The major emission from Cropland and Grassland in 2021 is due to cultivation of organic soils.

Table 11.6.1 Overall emission (kt CO_2 eq) from the LULUCF sector in Greenland, 1990-2021.

	1990	2000	2010	2015	2018	2019	2020	2021
4. Land use, land-use change and forestry	0.26	0.58	1.02	1.13	1.18	1.27	1.33	1.37
A. Forest land	0.05	0.01	0.01	0.00	-0.01	-0.01	-0.02	-0.02
B. Cropland	NO	NO	0.03	0.05	0.05	0.05	0.05	0.03
C. Grassland	0.21	0.56	0.98	1.08	1.15	1.24	1.30	1.37
D. Wetlands	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE
E. Settlements	NO	NO	NO	NO	NO	NO	NO	NO
F. Other land	NO	NO	NO	NO	NO	NO	NO	NO
G. Harvested wood products	NO	NO	NO	NO	NO	NO	NO	NO

11.6.2 Forest remaining forest (4A1)

Forests and forest management

Greenland has virtually no forests and therefore there exist no official forest statistics. All forests are situated in the most southern part of Greenland. To introduce trees to Greenland research were carried out to find species adaptable to the Greenlandic climate. This resulted in establishment of the Greenlandic Arboretum, which covers 150 hectares out of the total area of 218.5 hectares, Figure 11.6.2 and Table 11.6.2. Information about the Greenlandic Arboret can be found at
http://ign.ku.dk/om/arboreter/arboret-groenland/skovplantninger

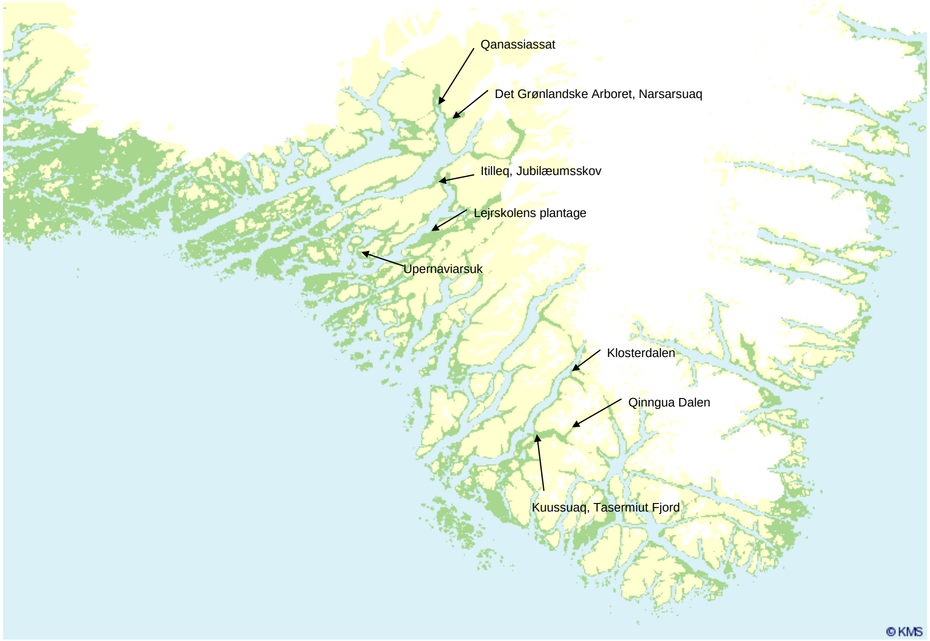

Figure 11.6.2 The position of the Greenlandic forests (Courtesy to Rasmus Enoksen Christensen).

Table 11.6.2 Forests in Greenland 1990 and 2021.

Location	Establis-hed	Dominant	Area,ha	1990 Average tree height, m	2021 Average tree height, m	Density 1990 (trees pr ha)	Density 2009 (trees pr ha)
Qinngua Valley	Natural	Birch and mountain ash	45	n.a	6.0	100	100
Qanassiassat Forest	1953-63	Conifer	1	5.0	14.1	1500	1000
Kuussuaq Forest	1962-64 -1982	Conifer	5	3.0	13.9	1300	900
Kuussuaq Forest	2008	Conifer	3	***	< 1	***	3500
Greenland Arboretum	(1976-1980)	Conifer	3	4.0	7.0	300	300
Greenland Arboretum	1980 -	Conifer	150	2.0	3.0	1500	1700
Itilleq	2004-2005	Conifer	6	***	< 1	***	3500
Upernaviarsuk	1954	Conifer	0.5	1.5	3.0	200	200
Lejrskolen	1999-2005	Conifer	4	***	1.0	***	2500
Klosterdalen	2000	Conifer	1	***	1.0	***	2000
Total			218.5				

Forest definition

The forest definition adopted in Greenland is almost identical to the FAO definition (TBFRA, 2000). It includes "wooded areas larger than 0.5 ha, that form a forest with a height of at least 5 m and crown cover of at least 10 %. The minimum width is 20 m." Temporarily non wooded areas, fire breaks, and other small open areas, that are an integrated part of the forest, are also included. However, due to extreme slow growing rates many of the forests are currently below 5 meters height.

Figure 11.6.3 shows a picture of the best developed forest in Greenland.

Figure 11.6.3 The forest in Kuusuaq. Photo: Rasmus E. Christensen, 2005.

Of special interest is the forest in Qinngua Valley. The Qinngua Valley is situated in a remote area. It consists of natural birch (*Betula pubescens spp. czerepanovii* and *B. glandulosa.)* which develops to forest like trees probably due to an introgressiv hybridisation (Rasmus Enoksen Christensen). This forest will probably not follow the FAO forest definition but are included in the inventory as a sub-division under forests. The Qinngua-valley is not included in the FAO forest statistics.

Figure 11.6.4 Kuussuaq, Tasermiut fjor. Photo: Rasmus E. Christensen, Juni 2004.

Methodological issues for forests

Estimation of volume, biomass and carbon pools

Due to lack of precise data and slow growth rates, simple functions are used that only include the height of the trees and the number per hectare.

The height of the trees has been estimated by Rasmus Enoksen Christensen based on data from the Aboretum. It is assumed that the trees are conical and the stem diameter at ground level is based on the general formula for even-aged forests (Vanclay, 2009).

$$D = \beta(H - 1.3) / \ln(N) \qquad \text{(eq.1)}$$

Where:
D = diameter at breast height, cm
ß = slope, species dependent
H = Height of the trees (meters)
N = Number of trees per hectare

Eq. 1 has been simplified by omitting the breast height (1.3 meters) to

$$D = \beta(H) / \ln(N) \qquad \text{(eq.2)}$$

so that D is representing the diameter at ground level. The ß-value used is given in Table 11.6.3.

Table 11.6.3 ß-values for estimating the diameter of trees (from Vanclay, 2009).

	Betula, spp	Conifers
ß-values	6.54	7.51

In order to estimate the C stock and C stock change is used the average default values from the IPCC 2006 guidelines for BCEF, density, C-content and Root-Shoot ratio for Boreal stands with a growing stock level of 21-50 m^3, IPCC table 4.5, pp 4.50. The values are given in Table 11.6.4.

Table 11.6.4 Biomass expansion factors used for Greenland.

		Qinngua Walley (Betula, spp.) Birch	Conifers	Orpiuteqarfia (Larix sibirica) Sibirian Larch)
BCEF	Dimensionless	0.7	0.66	0.78
Density	kg dry matter per litre	0.51	0.4	0.46
C-content	kg C per kg dry matter	0.48	0.51	0.51
Root-shoot-ratio	Dimensionless	0.39	0.39	0.39
Dead Organic Matter	kg per kg aboveground biomass	0.1	0.2	0.1

Source: IPCC 2006 guidelines.

Dead wood volume, biomass and carbon

The volume of dead organic matter (DOM) is estimated as a fraction of the aboveground biomass (Table 11.6.4). It is assumed that litter is included in DOM.

Forest soils: forest floors and mineral soil

Following the cold climate and the slow growing rate it is assumed that no changes take place in C-stock in the soil and hereby following the IPCC 2006 guidelines at Tier 1 level.

Uncertainties and time series consistency

The uncertainty in estimation of the C stock changes in the Greenlandic forests is very high. As there are very limited resources to visit and monitor in the remote areas there are very few data available. The current inventory is therefore based on the best knowledge available. It should also be taken into consideration that the importance of the forest sector in Greenland is marginal as only very little thinning is taking place as well as no deforestation and that the effect on the inventory is almost not measurable.

In the overall uncertainty section for the LULUCF is made a Tier 1 uncertainty analysis.

QA/QC and verification

Focus on the measurements of carbon pools in forest in Greenland will contribute to QA/QC and verification, but presently there are no plans to a further monitoring of the Greenlandic forests.

Recalculations and changes made in response to the review process

No recalculations have been made.

Planned improvements

No improvements are planned.

11.6.3 Land converted to forests (4A2)

Forest area

See Section 11.2.1 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation.

Forest definition

See Section 11.2.1 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories (e.g., land use and land-use change matrix).

Methodological issues for land converted to forest

See also Section 11.2.1.

Since 1990, there has been a slight increase in the forest area of 14 hectares. This has taken place on land converted from “OL”.

Uncertainties and time series consistency

For time series consistency, see Section 11.2.1. For uncertainties, please see Chapter 11.6.15.

QA/QC and verification

No QA/QC plan has been made yet. The afforestated area is known.

Recalculations, including changes made in response to the review process

None

Planned improvements

No improvements are planned.

11.6.4 Cropland (4B)

Cropland and cropland management (4B1)

In 1990 there were no cropland occurring in Greenland. Due to global warming, it is now possible to have a few crops, which may mature. In 2001, the first five hectares with annual crops were established. These are reported under 5.B.2. A more intensive description of the agriculture in Greenland can be found at

http://nunalerineq.gl/english/landbrug/jord/index-jord.htm

Land converted to cropland (4B2)

In 2001, the first annual crops were grown in Greenland. Approximately five hectares with garden crops were grown. Of this is it assumed that 25 % of the area is on organic soils (pers. comm. with Kenneth Høeg, former chief agricultural advisor in Greenland). The area converted to cropland was improved grassland.

Figure 11.6.5 Cropland and Grassland in Greenland.
(Photos from: http://nunalerineq.gl/english/landbrug/landbrug/index-landbrug.htm).

The region is generally characterized by a slightly podsol type of soil with a low pH value and small amounts of accessible plant nutrients. Larger concentrations of clay rarely occur, but considerable quantities of silt are often observable on the surface. Also, a certain amount of brown earth occurs in inland areas.

Methodological issues

Change in carbon stock in living biomass

For land converted to cropland is used a standard default value of 5,000 kg DM (dry matter) per hectare in above- and below-ground (IPCC 2006).

Change in carbon stock in dead organic matter

No organic matter is reported under Cropland.

Change in carbon stock in soils

No C stock changes in mineral soils are assumed. The emission in the 25 % organic soils is estimated by using the IPCC 2006 default value for cropland, Table 5.6 pp 5.19 of 5,000 kg C per ha per year. The emission factors for organic soils in the 2013 Wetland Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC 2014a) are based on expert judgement assumed to be too high for the cold conditions in Greenland.

Uncertainties and time series consistency

The time series are complete. For uncertainties, please see Chapter 11.6.15.

Category-specific QA/QC and verification

The number of hectares is provided by the Greenlandic Agricultural Consulting Services. As agricultural activities are economically subsidised in Greenland the figures are very accurate.

Category-specific recalculation

No recalculations have been made.

Category-specific planned improvements

No improvements are planned.

11.6.5 Grassland (4C)

Grassland remaining grassland (4C1)

Grassland in Greenland is dominated by unimproved grassland where the sheep is grazing. The total area with Grassland has been estimated to 241,990 hectares. Of these, only approximately 1,668 hectare is improved where stones have been removed combined with sowing of more high yielding species, see Figure 11.6.5.

Since 1990, the area with improved grassland has been extended from 490 hectares to 1,668 hectares.

Methodological issues for grassland

Grassland is divided into improved and unmanaged Grassland.

Change in carbon stock in living biomass

As more Grassland becomes improved the amount of living biomass at peak is increased. To estimate the amount of living biomass in improved Grassland is using the same default value as for Cropland e.g., 5,000 kg DM per hectare, IPCC 2006 default value for cropland, Table 5.9 pp 5.28. For unmanaged Grassland is used a default value of 1700 kg DM per hectare according to IPCC 2006 default, Table 6.4 pp 6.27. No estimates for below-ground biomass are given. For conversion from DM to C is used a default value of 0.5 kg C per kg DM.

Change in carbon stock in dead organic matter

No changes in dead organic matter are estimated as this is not occurring for this category.

Change in carbon stock in soils

No changes in the carbon stock in mineral soils are assumed. For organic soils on improved grassland is used a default EF of 1,250 kg C per ha per year (IPCC, 2006) default value for grassland, Table 6.3 pp 6.17. For unmanaged grassland no carbon stock change is expected. The emission factors for organic soils in the 2013 Wetland Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC 2014a) are based on expert judgement assumed to be too high for the cold conditions in Greenland.

Uncertainties and time series consistency

The time series is complete. For uncertainties, please se Chapter 11.6.15.

Category-specific QA/QC and verification

The number of hectares is provided by the Greenlandic Agricultural Consulting Services. As the agriculture is subsidised in Greenland the figures are very accurate.

Recalculations
No recalculation has been made.

Planned improvements
No improvements are planned.

11.6.6 Wetlands (4D)

Wetland in Greenland includes only human made water reservoirs and not naturally occurring wetlands. In total 1,076 hectares with ponds and water reservoirs distributed on 48 locations are reported.

No emission estimates from these reservoirs have yet been made.

Uncertainties and time series consistency
Not estimated.

QA/QC and verification
QA and QC have been made by DCE and Statistics Greenland.

Recalculations
No recalculations have been made.

Category-specific planned improvements
No improvements are planned.

11.6.7 Settlements (4E)

In total there are approximately 56,000 inhabitants in Greenland with about one quarter of the population in the capital, Nuuk.

Table 11.6.5 Inhabitants and the area occupied with houses, hectares.

	1990	2000	2015	2021
Inhabitants	55 589	56 176	55 916	56 609
Settlements, total, ha	4 801	4 891	5 761	6 062

The cities are built on the rocky coastline where almost no vegetation occurs. Consequently, estimates for C stock in living biomass and in soil have been made.

The small increase in the area with Settlements since 1990 has taken place on "Other land".

Currently, no official data or measurements of the area of villages and settlements are available. Alternatively, land utilized for villages and settlements have been measured using NunaGIS, which is a digital internet atlas displaying maps over villages and settlements in Greenland. NunaGIS is available at www.nunagis.gl.

11.6.8 Other land (4F)

The major part of Greenland is covered with snow or rocks. Thus, Other Land consists of 99.9 % of the total area.

No emission estimates have been made for this area.

The global warming can be seen in Greenland with longer and warmer summers, which again increase the amount of living biomass. Especially since the early 1990's there has been changes observed in the environment e.g. as the area with Cropland and Grassland has increased. However, no methodology exists currently to estimate a proper estimate of the amount of living biomass in the large area classified as "Other land".

11.6.9 Harwested Wood Products (4G)

Due to the very low area with slowgrowing forests and the constant Grenlandic population is it assumed that no national changes in the carbon stock in Harwested Wood Products (HWP) are taking place.

11.6.10 Direct nitrous oxide (N_2O) emissions from nitrogen (N) inputs to managed soils– 4(I)

Reported under 3.D.

11.6.11 Emissions and removals from drainage and rewetting and other management of organic and mineral soils – 4(II)

Not occurring.

11.6.12 Direct nitrous oxide (N_2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matter - 4(III)

Not occurring.

11.6.13 Indirect nitrous oxide (N_2O) emissions from managed soils– 4(IV)

Reported under 3.D.

11.6.14 Biomass burning – 4(V)

No biomass burning takes place in Greenland, and wildfires rarely occur due to the moist climate.

11.6.15 Uncertainties

A tier 1 uncertainty assessment has been carried out in accordance with the IPCC Guidelines (IPCC, 2006). The uncertainty has been estimated for all sources included in the reporting for LULUCF. The uncertainties for the activity data and emission factors are shown in Table 11.6.6.

Table 11.6.6 Uncertainties for activity data and emission factors for LULUCF.

Subsector	Pollutant	Activity data uncertainty	Emission factor uncertainty
4A Forest	CO_2	5	50
4B Cropland	CO_2	5	50
4C Grassland	CO_2	5	50
4A Forest	CH_4	5	50
4C Grassland	CH_4	5	50
4A Forest	N_2O	5	50

The assumed uncertainties represent expert judgement.

The resulting uncertainties for the individual greenhouse gases and the total uncertainty on the greenhouse gas emission are shown in Table 11.6.7.

Table 11.6.7 Uncertainties for the emission estimates.

	Uncertainty %	Trend 1990-2021 %	Trend uncertainty %
GHG	± 450	424.4	± 85.8
CO_2	± 52	537	± 51.2
CH_4	± 50	4.8	± 7.4

11.6.16 References

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11.7 Waste (CRF sector 5)

11.7.1 Overview of sector

The waste sector consists of the CRF source category 5.A. Solid Waste Disposal, 5.C. Incineration and Open Burning of Waste and 5.D. Wastewater Treatment and Discharge.

In CO_2 equivalents, the waste sector (without LULUCF) contributes with 2.6 % of the overall greenhouse gas emission in 2021. This corresponds to an emission of 15.8 Gg CO_2 equivalents.

The Greenlandic inventory includes CH_4 emissions from managed and unmanaged waste disposal sites on land, N_2O from wastewater and CO_2, CH_4, N_2O, NO_x, CO, NMVOC and SO_2 from open burning and waste incineration and open burning. Only emissions from waste incineration without energy recovery are included in the waste sector. Emissions from waste incineration with energy recovery are included in the energy sector.

There is no biological treatment of waste in Greenland. Greenland has an arctic climate and mostly consists of rocks with very little soil. Therefore, it is not a suitable place for composting waste because, in addition to the difficulties that sub-zero temperatures present for composting, there is no use for compost in such a climate.

Table 11.7.1 shows the greenhouse gas emissions from the waste sector. The emissions are taken from the CRF tables and are presented as rounded figures.

Table 11.7.1 Emissions from the waste sector, Gg CO_2 equivalents.

		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
5A Solid waste disposal	CH_4	4.6	4.6	4.7	4.8	4.9	4.9	5.0	5.1	5.1	5.2
5B Incineration and open burning	CO_2	2.6	2.6	2.6	2.6	2.7	2.7	2.9	3.1	3.5	3.4
5B Incineration and open burning	CH_4	2.7	2.7	2.7	2.8	2.8	2.8	2.8	2.8	2.6	2.5
5B Incineration and open burning	N_2O	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7
5C Wastewater treatment and discharge	N_2O	7.2	7.2	7.1	7.1	7.2	7.2	7.2	7.2	7.2	7.2
5. Waste total		17.7	17.8	17.9	18.0	18.2	18.4	18.6	18.9	19.2	18.9
continued		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
5A Solid waste disposal	CH_4	5.2	5.2	5.2	5.2	5.1	5.1	5.0	5.0	5.0	4.9
5B Incineration and open burning	CO_2	3.2	3.3	3.2	3.1	3.1	3.1	3.1	3.1	3.1	3.1
5B Incineration and open burning	CH_4	2.1	2.1	2.1	1.9	1.9	1.9	1.9	1.9	1.9	1.9
5B Incineration and open burning	N_2O	0.6	0.6	0.6	0.6	0.5	0.5	0.6	0.6	0.5	0.6
5C Wastewater treatment and discharge	N_2O	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.3	7.6	6.3
5. Waste total		18.3	18.4	18.2	18.0	17.8	17.8	17.8	17.8	18.1	16.7
continued		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
5A Solid waste disposal	CH_4	4.9	4.9	4.9	4.8	4.8	4.8	4.8	4.8	4.8	4.7
5B Incineration and open burning	CO_2	3.1	3.2	3.2	3.3	3.4	3.4	3.4	3.4	3.4	3.4
5B Incineration and open burning	CH_4	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
5B Incineration and open burning	N_2O	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
5C Wastewater treatment and discharge	N_2O	6.0	6.1	5.7	4.6	4.4	4.2	4.8	4.8	4.9	5.0
5. Waste total		16.5	16.6	16.2	15.2	15.0	14.8	15.4	15.4	15.6	15.7
continued		2020	2021								
5A Solid waste disposal	CH_4	4.7	4.7								
5B Incineration and open burning	CO_2	3.4	3.5								
5B Incineration and open burning	CH_4	1.9	2.0								
5B Incineration and open burning	N_2O	0.6	0.6								
5C Wastewater treatment and discharge	N_2O	5.3	5.1								
5. Waste total		16.0	15.8								

The largest sources of greenhouse gas emission from the waste sector in 2021 are N_2O emission from wastewater treatment and discharge (32.1 %) and CH_4 emission from solid waste disposal (29.9 %) followed by CO_2 from waste incineration and open burning (21.9 %).

Total greenhouse gas emission from the waste sector has decreased by 10.5 % since 1990. In 2021, emissions from all sources were more or less unchanged. However, emissions from wastewater treatment decreased by 3.2 %.

11.7.2 Solid waste management

Activity data for waste amounts for solid waste management are shown in Table 11.7.2.

Table 11.7.2 Waste amounts for solid waste management, tonnes.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
5A1 Managed waste disposal sites	6 057	6 126	6 170	6 233	6 335	6 430	6 412	6 418	6 150	5 704
5A2 Unmanaged waste disposal sites	1 361	1 358	1 356	1 359	1 340	1 288	1 215	1 159	1 060	986
5C1 Incineration, with energy recovery	5 520	5 579	5 619	5 734	5 919	6 073	6 179	6 276	6 403	8 208
5C1 Incineration, without energy rec.	0	0	0	0	56	225	795	1 240	2 666	2 899
5C2 Open burning of waste	16 567	16 714	16 808	16 956	17 140	17 236	17 033	16 922	16 101	14 941
5. Waste total	29 505	29 777	29 953	30 281	30 789	31 251	31 635	32 016	32 380	32 738
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
5A1 Managed waste disposal sites	4 880	4 945	4 750	4 455	4 216	4 248	4 267	4 296	4 321	4 355
5A2 Unmanaged waste disposal sites	906	865	839	830	825	824	815	788	756	738
5C1 Incineration, with energy recovery	11 283	11 526	12 658	14 084	15 312	15 576	15 791	16 060	16 371	16 691
5C1 Incineration, without energy rec.	3 148	3 306	3 390	3 415	3 437	3 461	3 485	3 468	3 444	3 466
5C2 Open burning of waste	12 924	12 976	12 481	11 803	11 259	11 329	11 351	11 355	11 338	11 374
5. Waste total	33 142	33 618	34 118	34 587	35 049	35 437	35 709	35 968	36 229	36 624
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
5A1 Managed waste disposal sites	4 418	4 481	4 507	4 520	4 549	4 569	4 589	4 633	4 693	4 751
5A2 Unmanaged waste disposal sites	718	687	654	629	600	576	569	549	527	509
5C1 Incineration, with energy recovery	17 082	17 505	17 860	18 137	18 401	18 685	18 996	19 322	19 660	20 028
5C1 Incineration, without energy rec.	3 486	3 488	3 501	3 523	3 550	3 548	3 557	3 592	3 616	3 628
5C2 Open burning of waste	11 470	11 541	11 526	11 498	11 499	11 491	11 519	11 573	11 658	11 748
5. Waste total	37 174	37 702	38 048	38 307	38 600	38 869	39 230	39 669	40 153	40 664
continued	2020	2021								
5A1 Managed waste disposal sites	4 793	4 829								
5A2 Unmanaged waste disposal sites	500	501								
5C1 Incineration, with energy recovery	20 487	20 945								
5C1 Incineration, without energy rec.	3 653	3 678								
5C2 Open burning of waste	11 820	11 903								
5. Waste total	41 252	41 856								

Waste amounts are based on municipal data on waste and waste incineration with energy recovery on local incinerator plants in 2004, and a survey by Consulting Company Carl Bro in 1996 and 2001, where waste amounts per person per year was identified as 650 kg and 455 kg for Greenlandic towns and settlements, respectively. For the time series these amounts were regulated by 1 % per year upwards for years after 2004 and by 1 % per year downwards for years before 2004. Further, to construct the time series statistical data from Statistics Greenland on population in towns and settlements were used. Other results of the survey used for the time series are that it was estimated that (1) 70 % of waste amounts is incinerated and 30 % deposited and (2) 80 % of combustible waste amounts deposited is burned in open burning.

Solid waste disposal

Source Category Description

The category consists of managed and unmanaged disposal sites of waste on land.

Methodological issues, activity data, emission factors and emissions

In Table 11.7.3 the composition of the waste according to the survey mentioned is shown.

Table 11.7.3 Composition of household and commercial waste before and after open burning.

Fraction	Household waste[2]	Commercial waste[2]	Household / Commercial Weighted	After open burning	Weighted (after open burning)
			%		
Paper/cardboard, dry	8.00[1]	20.00	11.84	2.37	7.66
Paper/cardboard, wet	10.00[1]	7.00	9.04	1.81	5.85
Plastics	7.00[1]	9.00	7.64	1.53	4.94
Organic waste	44.00[1]	34.00	40.80	8.16	26.38
Other combustible	17.50[1]	16.00	17.02	3.40	11.01
Glass	7.50[1]	3.00[1]	6.06	6.06	19.59
Metal	3.50[1]	3.00[1]	3.34	3.34	10.80
Other, non combustible	1.00[1]	5.00	2.28	2.28	7.37
Hazardous waste	1.50[1]	3.00[1]	1.98	1.98	6.40
Total	100.00	100.00	100.00	30.93	100.00
Pct (%)	68[3]	32[3]		80[4]	

Notes:
1 Measured values.
2 Source: Former Environmental and Nature Agency, Ministry of Infrastructure and Environment. Survey from 2004.
3 Distribution of household and commercial waste.
4 Share of combustible waste burned at waste disposal sites.

A Tier 2 approach with a first order decay model is used for estimation of emissions of CH_4 from the solid waste disposals. For this purpose the activity data in Table 11.7.2 are estimated back to 1960 (not shown) based on the methodology described in connection to Table 11.7.2. Combining these activity data and the composition data in Table 11.7.3 time series for 1960-2021 with amounts of waste in waste fractions is calculated.

For these time series the waste fractions are associated to (1) Dissolved Organic Carbon (DOC) values according to Section 11.7.2 of this NIR and (2) emission factors based on DOC values and values of methane correction factors, fraction of DOC dissimilated and fraction of CH_4 in gas emitted according to the IPCC 2006 Gudelines (Table 2.4) and GPG for managed disposals, Table 11.7.4 and unmanaged disposals, Table 11.7.5.

Table 11.7.4 DOC values and emission factors for CH_4 for managed disposals.

	Paper / cardboard, dry	Paper / cardboard, wet	Plastics	Organic waste	Other combustible	Glass	Metal	Other, non combustible	Hazardous waste
DOC weighted (after open burning) fraction	0.44	0.40	0.00	0.15	0.24	0.00	0.00	0.00	0.00
Emission factor kg CH_4/tonnes[1]	146.7	133.3	0.0	50.0	80.0	0.0	0.0	0.0	0.0
[1]) based on:									
Methane correction factor				1					
Fraction of DOC dissimilated and emitted				0.5					
Fraction of CH_4 in gas emitted				0.5					

Table 11.7.5 DOC values and emission factors for CH_4 for unmanaged disposals.

	Paper/ cardboard dry	Paper/ cardboard wet	Plastics	Organic waste	Other combustible	Glass	Metal	Other, non-combustible	Hazardous waste
DOC weighted (after open burning) fraction	0.44	0.40	0.00	0.15	0.24	0.00	0.00	0.00	0.00
Emission factor kg CH_4/tonnes[1]	58.7	53.3	0.0	20.0	32.0	0.0	0.0	0.0	0.0

[1]) based on:

Methane correction factor	0.4
Fraction of DOC dissimilated and emitted	0.5
Fraction of CH_4 in gas emitted	0.5

For managed and unmanaged disposals, the default half life time of 14 years and a time lag of 0.5 years are used. For the oxidation factor and according to the GPG for managed disposal 0.1 and for unmanaged 0.0 are used.

In Tables 11.7.6 and 11.7.7 selected data and results are shown for 1990-2021 for managed and unmanaged disposal, respectively. The data in the tables are as follows. The AD for the FOD model as amounts of waste in fractions, the potential emission of CH_4 calculated with emission factors on waste amounts in fractions, the annual generated emission of CH_4 calculated with the FOD model using the potential emissions, the oxidized CH_4 and the actual annual CH_4 emission calculated as the annual generated emission minus the CH_4 oxidized. Calculations are performed since 1960 and are not shown.

Table 11.7.6 Managed disposal. AD for the FOD model (amount of waste in fractions), potential emission of CH_4, oxidized CH_4 and annual CH_4 emission 1990-2021.

	Paper/ cardboard dry	Paper/ cardboard wet	Plastics	Organic waste	Other com- bustible	Glass	Metal	Other, non com- bustible	Hazardous waste	Waste total	Potential emission	Annual gen- erated emission	Annual oxidized emission	Annual emission
Unit	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes CH_4	Tonnes CH_4	Tonnes CH_4	Tonnes CH_4
1990	464	354	299	1 598	667	1 187	654	447	388	6 057	244.6	183.8	18.4	165.4
1991	469	358	303	1 616	674	1 200	662	452	392	6 126	248.5	186.9	18.7	168.2
1992	472	361	305	1 628	679	1 209	666	455	395	6 170	251.3	190.0	19.0	171.0
1993	477	364	308	1 645	686	1 221	673	460	399	6 233	253.1	193.1	19.3	173.8
1994	485	370	313	1 671	697	1 241	684	467	406	6 335	255.7	196.1	19.6	176.5
1995	492	376	318	1 696	708	1 260	694	474	412	6 430	259.9	199.2	19.9	179.3
1996	491	375	317	1 692	706	1 256	692	473	410	6 412	263.8	202.3	20.2	182.1
1997	491	375	317	1 693	706	1 258	693	473	411	6 418	263.0	205.2	20.5	184.7
1998	471	359	304	1 622	677	1 205	664	453	394	6 150	263.3	208.0	20.8	187.2
1999	437	333	282	1 505	628	1 118	616	420	365	5 704	252.3	210.2	21.0	189.2
2000	374	285	241	1 288	537	956	527	360	312	4 880	234.0	211.3	21.1	190.2
2001	379	289	244	1 305	544	969	534	365	317	4 945	200.2	210.8	21.1	189.7
2002	364	278	235	1 253	523	931	513	350	304	4 750	202.9	210.4	21.0	189.4
2003	341	260	220	1 175	490	873	481	328	285	4 455	194.8	209.7	21.0	188.7
2004	323	246	208	1 112	464	826	455	311	270	4 216	182.7	208.4	20.8	187.5
2005	325	248	210	1 121	468	832	459	313	272	4 248	172.9	206.6	20.7	186.0
2006	327	249	211	1 126	470	836	461	315	273	4 267	174.3	205.1	20.5	184.6
2007	329	251	212	1 133	473	842	464	317	275	4 296	175.0	203.6	20.4	183.3
2008	331	253	213	1 140	476	847	467	319	277	4 321	176.2	202.3	20.2	182.1
2009	333	255	215	1 149	479	853	470	321	279	4 355	177.2	201.1	20.1	181.0
2010	338	258	218	1 166	486	866	477	326	283	4 418	178.6	200.0	20.0	180.0
2011	343	262	221	1 182	493	878	484	330	287	4 481	181.2	199.1	19.9	179.2
2012	345	263	223	1 189	496	883	487	332	289	4 507	183.8	198.4	19.8	178.5
2013	346	264	223	1 193	497	886	488	333	289	4 520	184.9	197.7	19.8	177.9
2014	348	266	225	1 200	501	891	491	335	291	4 549	185.4	197.1	19.7	177.4
2015	350	267	226	1 206	503	895	493	337	293	4 569	186.6	196.6	19.7	177.0
2016	351	268	227	1 211	505	899	496	338	294	4 589	187.4	196.2	19.6	176.6
2017	355	271	229	1 222	510	908	500	342	297	4 633	188.2	195.8	19.6	176.2
2018	359	274	232	1 238	517	920	507	346	300	4 693	190.0	195.5	19.6	176.0

continued

Continued

Unit	Paper/ cardboard dry	Paper/ cardboard wet	Plastics	Organic waste	Other com-bustible	Glass	Metal	Other, non com-bustible	Hazardous waste	Waste total	Potential emission	Annual gen-erated emission	Annual oxidized emission	Annual emission
Unit	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes CH_4	Tonnes CH_4	Tonnes CH_4	Tonnes CH_4
2019	364	278	235	1 253	523	930	513	350	304	4 748	192.5	195.4	19.5	175.8
2020	366	280	236	1 263	527	938	517	353	306	4 786	194.8	195.3	19.5	175.8
2021	370	282	239	1 274	531	946	521	356	309	4 829	196.6	195.4	19.5	175.9

Table 11.7.7 Unmanaged disposal. AD for the FOD model (amount of waste in fractions), potential emission of CH_4, oxidized CH_4 and annual CH_4 emission 1990-2021.

Unit	Paper/ cardboard dry	Paper/ cardboard wet	Plastics	Organic waste	Other com-bustible	Glass	Metal	Other, non combustible	Hazardous waste	Waste total	Potential emission	Annual ge-nerated emission	Annual oxidized emission	Annual emission
Unit	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes CH_4	Tonnes CH_4	Tonnes CH_4	Tonnes CH_4
1990	104	80	67	359	150	267	147	100	87	1 361	22.3	16.6	0.0	16.6
1991	104	79	67	358	149	266	147	100	87	1 358	22.3	16.9	0.0	16.9
1992	104	79	67	358	149	266	146	100	87	1 356	22.3	17.1	0.0	17.1
1993	104	79	67	358	150	266	147	100	87	1 359	22.3	17.4	0.0	17.4
1994	103	78	66	354	147	263	145	99	86	1 340	22.3	17.6	0.0	17.6
1995	99	75	64	340	142	252	139	95	82	1 288	22.0	17.8	0.0	17.8
1996	93	71	60	321	134	238	131	90	78	1 215	21.1	18.0	0.0	18.0
1997	89	68	57	306	128	227	125	85	74	1 159	19.9	18.1	0.0	18.1
1998	81	62	52	280	117	208	114	78	68	1 060	19.0	18.1	0.0	18.1
1999	76	58	49	260	109	193	107	73	63	986	17.4	18.1	0.0	18.1
2000	69	53	45	239	100	178	98	67	58	906	16.2	18.0	0.0	18.0
2001	66	51	43	228	95	170	93	64	55	865	14.9	17.9	0.0	17.9
2002	64	49	41	221	92	164	91	62	54	839	14.2	17.7	0.0	17.7
2003	64	49	41	219	91	163	90	61	53	830	13.8	17.5	0.0	17.5
2004	63	48	41	218	91	162	89	61	53	825	13.6	17.3	0.0	17.3
2005	63	48	41	217	91	162	89	61	53	824	13.5	17.1	0.0	17.1
2006	62	48	40	215	90	160	88	60	52	815	13.5	16.9	0.0	16.9
2007	60	46	39	208	87	154	85	58	50	788	13.4	16.8	0.0	16.8
2008	58	44	37	200	83	148	82	56	48	756	12.9	16.6	0.0	16.6
2009	57	43	36	195	81	145	80	54	47	738	12.4	16.4	0.0	16.4

continued

Continued														
	Paper/ cardboard dry	Paper/ cardboard wet	Plastics	Organic waste	Other com-bustible	Glass	Metal	Other, non combustible	Hazardous waste	Waste total	Potential emission	Annual ge-nerated emission	Annual oxidized emission	Annual emission
Unit	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes CH_4	Tonnes CH_4	Tonnes CH_4	Tonnes CH_4
2010	55	42	35	189	79	141	78	53	46	718	12.1	16.2	0.0	16.2
2011	53	40	34	181	76	135	74	51	44	687	11.8	16.0	0.0	16.0
2012	50	38	32	173	72	128	71	48	42	654	11.3	15.7	0.0	15.7
2013	48	37	31	166	69	123	68	46	40	629	10.7	15.5	0.0	15.5
2014	46	35	30	158	66	117	65	44	38	600	10.3	15.2	0.0	15.2
2015	44	34	28	152	63	113	62	42	37	576	9.8	15.0	0.0	15.0
2016	44	33	28	150	63	112	61	42	36	569	9.5	14.7	0.0	14.7
2017	42	32	27	145	60	108	59	40	35	549	9.3	14.5	0.0	14.5
2018	40	31	26	139	58	103	57	39	34	527	9.0	14.2	0.0	14.2
2019	39	30	25	134	56	100	55	38	33	509	8.6	13.9	0.0	13.9
2020	38	29	25	132	55	98	54	37	32	500	8.3	13.7	0.0	13.7
2021	38	29	25	132	55	98	54	37	32	501	8.2	13.4	0.0	13.4

11.7.3 Incineration and open burning of waste

Source category description

In Greenland waste incineration is carried out both with and without energy recovery. According to IPCC Guidelines the emissions associated with waste incineration for energy production is included in the energy sector more specifically in the source category 1.A1a Public Electricity and Heat Production. The emissions from waste incineration without energy recovery is reported in source category 5.C. Waste Incineration. Additionally in Greenland open burning of waste occurs at landfill sites. Emissions associated with this are also reported under sector 5.C. Waste Incineration.

Methodological issues

The methodology used follows the IPCC Guidelines (IPCC, 2006). For waste incineration the Danish emission factors are used, as it is trusted that they are also a good representation of Greenlandic conditions.

The emission factors used for both waste incineration and open burning are included in Section 11.7.3.4.

Activity data

The amount of waste incinerated without energy recovery is presented in Table 11.7.8. The activity data is provided by the method described in Section 11.7.2.

Table 11.7.8 Activity data for waste incineration without energy recovery, Mg.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Incinerated waste without energy recovery, Mg	NO	NO	NO	NO	56	225	795	1 240	2 666	2 899
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Incinerated waste without energy recovery, Mg	3 148	3 306	3 390	3 415	3 437	3 461	3 485	3 468	3 444	3 466
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Incinerated waste without energy recovery, Mg	3 486	3 488	3 501	3 523	3 550	3 548	3 557	3 592	3 616	3 628
continued	2020	2021								
Incinerated waste without energy recovery, Mg	3 653	3 678								

The open burning of waste is assumed to be 80 % of the waste deposited to landfills (Survey on waste by Carl Bro, 1996 and 2001). The activity data for open burning is presented in Table 11.7.9. The activity data for open burning is provided by the method described in Section 11.7.2.

Table 11.7.9 Activity data for open burning of waste, Mg.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Open burning of waste, Mg	16 567	16 714	16 808	16 956	17 140	17 236	17 033	16 922	16 101	14 941
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Open burning of waste, Mg	12 924	12 976	12 481	11 803	11 259	11 329	11 351	11 355	11 338	11 374
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Open burning of waste, Mg	11 470	11 541	11 526	11 498	11 499	11 491	11 519	11 573	11 658	11 748
continued	2020	2021								
Open burning of waste, Mg	11 820	11 903								

Emission factors

Waste incineration

For waste incineration without energy recovery the same emission factors have been assumed as for waste incineration with energy recovery. The emission factors refer to the IPCC, 2006 and Danish emission factors (Nielsen et al., 2010). CO_2 emission factors have been revised recently, see chapter 3 for description. The greenhouse gas emission factors are shown in Table 11.7.10.

Table 11.7.10 Emission factors for greenhouse gases from waste incineration.

	Year	Emission factor	Unit
CO_2	1990-2010	37.0	Kg pr GJ
CO_2	2011	37.5	Kg pr GJ
CO_2	2012	40.0	Kg pr GJ
CO_2	2013-2021	42.5	Kg pr GJ
CH_4	1990-2021	30	g pr GJ
N_2O	1990-2021	4	g pr GJ

The emission factors used for the indirect greenhouse gases are shown in table 11.7.11.

Table 11.7.11 Emission factors for indirect greenhouse gases from waste incineration.

	NO_x	SO_2	NMVOC	CO	Unit
Waste incineration	134	138	0.98	7.4	g pr GJ

Open burning

For open burning emissions are calculated using the methodology, standard parameters and emission factors provided by the IPCC 2006 Guidelines.

The CH_4 emission factor used is the recommended and default is 6,500 g per tonne MSW wet weight (IPCC, 2006).

For N_2O a default emission factor of 150 g/t MSW dry weight is recommended (IPCC, 2006) this is corrected for the dry matter content to acquire an N_2O emission factor of 214 g per tonne MSW wet weight.

For calculating the CO_2 emission, the dry matter content, carbon content and the fossil carbon content of the waste fractions are used. The parameters are included in Table 11.7.12.

Table 11.7.12 Parameter used in calculating CO_2 emissions from open burning.

	Dry matter content	Total carbon content, %	Fossil carbon content as percent of total carbon
Paper	0.90	46	1
Cardboard	0.90	46	1
Plastics	1.00	75	100
Organic waste	0.40	38	0
Other	0.85	3	100

Source: IPCC Guidelines 2006, Volume 5, Chapter 2, Table 2.4

An oxidation factor of 58 % is assumed for open burning (IPCC, 2006).

The emission factors for NO_x, SO_2, NMVOC and CO are presented in Table 11.7.13. The source of these emission factors is EMEP/EEA 2019 (Table 3.1).

Table 11.7.13 Emission factors for indirect greenhouse gases from open burning of waste.

	NO_x	SO_2	NMVOC	CO	Unit
Open burning of municipal waste	3.18	0.11	1.23	55.83	Kg pr Mg

Emissions

Total emission of greenhouse gases from sector 5.C. Incineration and open burning of waste is shown in Table 11.7.14. Figure 11.7.1 shows total emission of greenhouse gases from sector 5.C. Incineration and open burning.

Table 11.7.14 Greenhouse gas emissions from incineration and open burning.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CO_2, Gg	2.6	2.6	2.6	2.6	2.7	2.7	2.9	3.1	3.5	3.4
CH_4, Mg	107.7	108.6	109.3	110.2	111.4	112.1	111.0	110.4	105.5	98.0
N_2O, Mg	2.5	2.5	2.5	2.5	2.6	2.6	2.6	2.6	2.5	2.4
CO_2 eqv., Gg	6.0	6.0	6.1	6.1	6.2	6.3	6.5	6.6	6.9	6.6
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
CO_2, Gg	3.2	3.3	3.2	3.1	3.1	3.1	3.1	3.1	3.1	3.1
CH_4, Mg	85.0	85.4	82.2	77.8	74.3	74.7	74.9	74.9	74.8	75.0
N_2O, Mg	2.1	2.1	2.0	1.9	1.8	1.8	1.8	1.8	1.8	1.9
CO_2 eqv., Gg	6.0	6.0	5.9	5.7	5.5	5.5	5.5	5.5	5.5	5.5
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
CO_2, Gg	3.1	3.2	3.2	3.3	3.4	3.4	3.4	3.4	3.4	3.4
CH_4, Mg	75.7	76.1	76.0	75.8	75.9	75.8	76.0	76.4	76.9	77.5
N_2O, Mg	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
CO_2 eqv., Gg	5.6	5.6	5.7	5.8	5.8	5.8	5.8	5.9	5.9	5.9
continued	2020	2021								
CO_2, Gg	3.4	3.5								
CH_4, Mg	78.0	78.5								
N_2O, Mg	1.9	1.9								
CO_2 eqv., Gg	6.0	6.0								

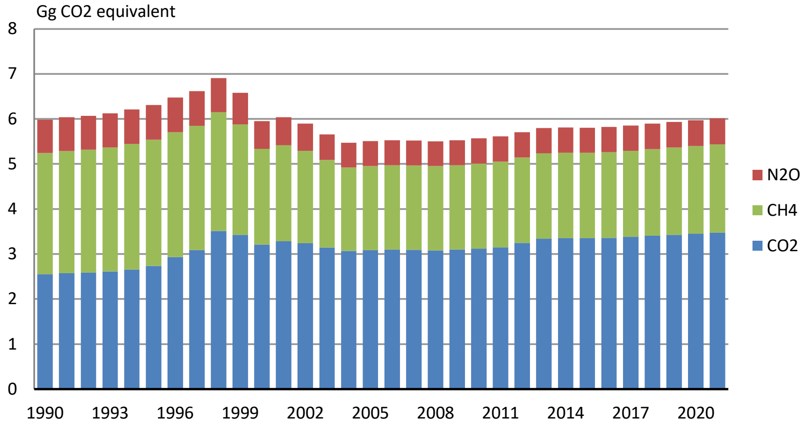

Figure 11.7.1 Emission of greenhouse gases from incineration and open burning.

The emissions of indirect greenhouse gases from incineration and open burning are shown in Table 11.7.15.

Table 11.7.15 Emission of indirect greenhouse gases from incineration and open burning, Mg.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
NO_x	52.7	53.1	53.5	53.9	54.6	55.1	55.3	55.6	55.0	51.6
SO_2	1.8	1.8	1.8	1.9	2.0	2.2	3.0	3.7	5.6	5.8
NMVOC	20.4	20.6	20.7	20.9	21.1	21.2	21.0	20.8	19.8	18.4
CO	924.9	933.1	938.4	946.6	956.9	962.3	951.0	944.9	899.1	834.4
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
NO_x	45.5	45.9	44.5	42.3	40.6	40.9	41.0	41.0	40.9	41.0
SO_2	6.0	6.2	6.3	6.2	6.2	6.3	6.3	6.3	6.2	6.3
NMVOC	15.9	16.0	15.4	14.6	13.9	14.0	14.0	14.0	14.0	14.0
CO	721.8	724.7	697.1	659.2	628.9	632.7	634.0	634.2	633.3	635.3
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
NO_x	41.4	41.6	41.6	41.5	41.6	41.5	41.6	41.9	42.2	42.5
SO_2	6.3	6.3	6.3	6.4	6.4	6.4	6.4	6.5	6.5	6.5
NMVOC	14.1	14.2	14.2	14.2	14.2	14.2	14.2	14.3	14.4	14.5
CO	640.7	644.6	643.8	642.2	642.3	641.8	643.4	646.4	651.1	656.1
continued	2020	2021								
NO_x	42.7	43.0								
SO_2	6.6	6.6								
NMVOC	14.6	14.7								
CO	660.2	664.8								

11.7.4 Wastewater treatment and discharge

Source category description

In Greenland no wastewater treatment occurs; although it should be mentioned some filtering of solid residues from industry may occur and likewise there are ongoing projects focussing on septic tanks at household levels. N_2O emission from human sewage is estimated. It is assumed that no methane emission occurs.

Methodological issues

According to the IPCC Guidelines (IPCC, 2006) the important factors for CH_4 production from handling of wastewater are: wastewater characteristics; especially the quantity of degradable organic material in the wastewater, handling systems, temperature and BOD vs. COD.

The Guidelines state that production of CH_4 generally requires temperatures above 15˚C, and at temperatures below this the lagoon is principally a sedimentation tank (IPCC2006). Temperatures in Greenland rarely exceed 15˚C, and the monthly average temperature has not exceeded 12˚C during the period 1993-2021. Therefore, CH_4 is reported as Not Applicable in the CRF.

N_2O emission from wastewater handling

The IPCC default methodology only includes N_2O emissions from human sewage based on annual per capita protein intake. The methodology account for nitrogen intake ("outcome") i.e., faeces and urine, only and neither the industrial nitrogen input nor non-consumption protein from kitchen, bath and laundry discharges are included.

Total nitrogen in the effluent discharges is calculated by the following formula from IPCC, 2006 (Equation 6.8):

$$N_{EFFLUENT} = (P \times Protein \times F_{NPR} \times F_{NON-CON} \times F_{IND-CON}) - N_{SLUDGE}$$

where *P* is the Greenlandic population (source: Statistics Greenland).

Protein is the annual per capita protein consumption (kg/person/yr) set contant to 171.5 g/day (see text below).

F_{NPR} is the fraction of nitrogen in protein, default 0.16 kg N/kg protein (IPCC, 2006).

$F_{NON-CON}$ is the factor for non-consumed protein added to wastewater, default 1.1 (IPCC, 2006).

$F_{IND-CON}$ is the factor for industrial and commercial co-discharged protein into the sewer system, default 1.25 (IPCC, 2006).

N_{SLUDGE} is nitrogen removed with sludge, default zero kg N/yr.

Thus, total N_2O emission from effluent discharges is calculated by the formula:

$$N_2O_{EFFLUENT} = N_{EFFLUENT} \times EF_{N_2O-N} \times \frac{44}{28}$$

The default IPCC emission factor for N_2O emissions from domestic wastewater nitrogen effluent is 0.005 kg N_2O-N/kg N. This emission factor is based on limited field data and on specific assumptions regarding the occurrence of nitrification and denitrification in rivers and in estuaries. To convert total N in effluents to emissions in N_2O the mass ratio 44/28 is used.

For households

A large part of the diet originates from seafood, fish or sea mammals, but imported fabricated foods are expected to continue to take over an increasing part of human energy consumption. Due to weather conditions most of fresh food comes from wild animals or fish. Greenland has a production of lamb and a limited supply of vegetables; still most of the produced foods are imported from outside (Mulvad et al., 2007).

In Greenland, the traditional diet based on meat and fish has undergone diversification towards more carbohydrates with the development of a monetary economy; in 1855 the protein content of a mean diet was 377 g protein, whereas 80 years later, in 1935 – 43, the protein content of a mean diet was 257 g protein (Périssé and François, 1981). Today, the majority of young urbanised Greenlandic Inuit have Western dietary habits and consume less meat from marine mammals, terrestrial mammals and birds than Inuit from the hunting districts; Dietary profiles of Canadian Baffin Island Inuit with a high consumption of traditional foods have shown a mean daily protein intake of 144-199 g/day in 41- to 61-year-old (Laursen et al, 2001).

As no data on the protein intake are available a protein intake of 171.5 g/day i.e., the average of the Canadian Inuit were adopted, as it is assumed that the protein intake has declined even more since 1935 due to increased number of urbanised Greenlandic Inuit. For comparison the Danish yearly protein consumption according to FAOSTAT has increased from 98 g/day in 1990 to 112 g/day in 2005. Using this number, the yearly protein intakes may be derived by multiplying with the population number and days in a year. Based on the above it was decided to set the protein intake to the average value of the Canadian Inuit data, 171.5 g/day. The N-content in effluent wastewater in Greenland was calculated the equation shown above.

From industries

The production of residue products from the fish industry in Greenland amounts to around 14,000 tonnes per year (Nielsen et al., 2005). Overall, the waste amount from the Greenland halibut production is around 40 %, while the waste amount from codfish production is 50 %; this governs only the fish production including pre-processing.

According to IPCC, the fraction of nitrogen in protein is 0.16 (IPCC, 2006). The IPCC reports a range of 0.3 to 3.1 kg total N/tonne fish referring to effluent loads from cod filleting i.e., 0.0031. The report also presents values of the total N content of untreated wastewater from the fish industry in the range of 400-1000 mg/l corresponding to a fraction of corresponding. However, as it was not possible to find data for all fish groups, and as it was not possible to determine that fraction of fish, which was pre-processed and how big a fraction that was sold without pre-processing, the below approach was adopted.

From the EC BAT note (EC, 2003) the total N-content of untreated wastewater from the fishing industry was reported to be between 400 and 1000 mg/L with an average value of 700 mg/L. The number was multiplied by the water used within the fishing industry reported for 2004 to 2020 by Statistics Greenland. The effluent N-content for 1990 to 2002 was set equal to the estimated value for 2003.

Emissions

Emission of N_2O from wastewater discharges is shown in Table 11.7.16.

Table 11.7.16 N_2O emissions in wastewater from households and industries 1990-2021.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
N_2O emission, effluents households, Gg	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
N_2O emission, effluents industries, Gg	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
N_2O emission, effluents sum, Gg	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
N_2O emission, effluents households, Gg	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
N_2O emission, effluents industries, Gg	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.020	0.021	0.016
N_2O emission, effluents sum, Gg	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.025	0.021
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
N_2O emission, effluents households, Gg	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
N_2O emission, effluents industries, Gg	0.015	0.016	0.014	0.010	0.010	0.009	0.011	0.011	0.012	0.012
N_2O emission, effluents sum, Gg	0.020	0.020	0.019	0.015	0.015	0.014	0.016	0.016	0.017	0.017
continued	2020	2021								
N_2O emission, effluents households, Gg	0.005	0.005								
N_2O emission, effluents industries, Gg	0.013	0.012								
N_2O emission, effluents sum, Gg	0.018	0.017								

Total emission of N_2O increased slightly until 2008 due to an increase in the emission from industrial effluents. However, since 2009 total emission of N_2O has decreased to a total level of 0.015-0.020 Gg (which is lower than 1990) due to a temporarily decrease in industrial effluents primaryly caused by a decrease in the catches of shrimps.

11.7.5 Uncertainties

A tier 1 uncertainty assessment has been carried out in accordance with the IPCC Guidelines (IPCC, 2006). The uncertainty has been estimated for all sources included in the reporting for the waste sector. The uncertainties for the activity data and emission factors are shown in Table 11.7.17.

Table 11.7.17 Uncertainties for activity data and emission factors for the waste sector.

Subsector	Pollutant	Activity data uncertainty	Emission factor uncertainty
5C Waste incineration	CO_2	10	25
5A Solid Waste Disposals sites	CH_4	10	100
5C Waste incineration	CH_4	10	50
5D Wastewater Handling	N_2O	30	100
5C Waste incineration	N_2O	10	100

The amount of waste incinerated and open burned is relatively well known and the uncertainty is set to 10 %. The same is the case for the waste deposited to landfills. For wastewater handling an uncertainty of 30 % on the activity data has been assumed.

Regarding the emission factor uncertainty, a value of 100 % has been used for CH_4 from solid waste disposal, N_2O from wastewater treatment and N_2O from waste incineration. This is in the same range as recommended by the IPCC Guidelines (IPCC, 2000). For CO_2 and CH_4 from waste incineration emission factor uncertainties of 25 % and 50 % respectively have been chosen.

The resulting uncertainties for the individual greenhouse gases and the total uncertainty on the greenhouse gas emission are shown in Table 11.7.18.

Table 11.7.18 Uncertainties for the emission estimates.

	Uncertainty %	Trend 1990-2021 %	Trend uncertainty %
GHG	± 46	-10.5	± 15.7
CO_2	± 27	36.2	± 19.3
CH_4	± 73	-7.6	± 12.8
N_2O	± 94	-28.3	± 27.4

11.7.6 Source specific QA/QC

The elaboration of a formal QA/QC plan is to be completed.

However, data on solid waste disposal, wastewater handling and waste incineration has gone through a great deal of quality work with regard to accuracy, comparability and completeness.

All external data used for the emission inventory submission are archived in spreadsheets. Data are archived annually in order to ensure that the basic data for a given report are always available in their original form.

Annual data on solid waste disposal, wastewater handling and waste incineration are compared with previous years and large discrepancies are checked.

Safely stored and quality checked activity data are then processed by using a methodological approach consistent with international guidelines.

Calculated emission factors are compared with guideline emission factors to ensure that they are reasonable. The calculations follow the principle in international guidelines.

During data processing, it is checked that calculations are being carried out correctly.

Time series for activity data, emission factors and calculated emissions are used to identify possible errors in the calculation procedure. In fact, during the calculation, numerous controls take place to ensure correctness. Sums are checked in the various stages in the calculation procedure. Implied emission factors are compared to emission factors.

Every single time series imported to the CRF Reporter is checked for annual activity, units for activity, emission factor and emissions. Additional checks are performed on the database. The database encloses every single activity data, emission factors, emission, notation key and comment imported to the CRF Reporter.

11.7.7 Source specific recalculations and improvements

In this 2023 submission there has been minor revisions in the waste sector. These revisions are caused by upwards adjustments of waste amounts in 2019 and 2020.

Table 11.8.19 shows recalculations in the waste sector compared to the 2022 submission. Minor changes occur.

Table 11.8.19 Changes in GHG emission in the waste sector compared to the 2022 submission.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Previous inventory, Gg CO_2 eqv.	17.7	17.8	17.9	18.0	18.2	18.4	18.6	18.9	19.2	18.9
Recalculated, Gg CO_2 eqv.	17.7	17.8	17.9	18.0	18.2	18.4	18.6	18.9	19.2	18.9
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-
Change in pct.	-	-	-	-	-	-	-	-	-	-
continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Previous inventory, Gg CO_2 eqv.	18.3	18.4	18.2	18.0	17.8	17.8	17.8	17.8	18.1	16.7
Recalculated, Gg CO_2 eqv.	18.3	18.4	18.2	18.0	17.8	17.8	17.8	17.8	18.1	16.7
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-
Change in pct.	-	-	-	-	-	-	-	-	-	-
continued	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Previous inventory, Gg CO_2 eqv.	16.5	16.6	16.2	15.2	15.0	14.8	15.4	15.4	15.6	15.7
Recalculated, Gg CO_2 eqv.	16.5	16.6	16.2	15.2	15.0	14.8	15.4	15.4	15.6	15.7
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	0.0
Change in pct.	-	-	-	-	-	-	-	-	-	0.0
continued	2020	2021								
Previous inventory, Gg CO_2 eqv.	16.0	-								
Recalculated, Gg CO_2 eqv.	16.0	15.8								
Change in Gg CO_2 eqv.	0.0	-								
Change in pct.	0.0	-								

11.7.8 Source specific planned improvements

Some planned improvements to the emission inventories are discussed below.

1) Improved data on solid waste disposals

In future inventories attempts will be made in order to improve data on solid waste disposals in general. Statistics Greenland has encouraged the municipal technical departments with responsibility for waste handling to start gathering data on the yearly amounts of waste handled.

2) Improved data on wastewater handling

In future inventories attempts will be made in order to improve data on wastewater handling in general. However, at the moment the municipal technical departments seem to have no data on wastewater handling at all.

11.7.9 References

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11.8 Other

In CRF Sector 7, there are no activities and emissions or removals for the inventory of Greenland.

11.9 Recalculations and improvements

The 2023 submission is the thirdteen year where Greenland on the request of the ERT submits a full CRF.

For recalculations and improvements please refer to Sections 11.3 - 11.7.

11.10 Annex 1 Key categories

A Key Category Analysis (KCA) for year 1990 and 2021 for Greenland has been carried out in accordance with the IPCC Good Practice Guidance. For 1990 a level KCA has been carried out.

The base year in the analysis is the year 1990 for the greenhouse gases CO_2, CH_4, N_2O and 1995 for the greenhouse F-gases HFC, PFC and SF_6. The KCA approach is a Tier 1 quantitative analysis.

The level assessment of the Tier 1 KCA is a ranking of the source categories in accordance to their relative contribution to the national total of greenhouse gases calculated in CO_2 equivalents. The level key categories are found from the list of source categories ranked according to their contribution in descending order. Level key categories are those from the top of the list and of which the sum constitutes 95 % of the national total.

The trend assessment of the Tier 1 KCA is a ranking of the source categories according to their contribution to the trend of the national total of greenhouse gases, calculated in CO_2 equivalents, from the base year to the year under consideration. The trend of the source category is calculated relative to that of the national totals and the trend is then weighted with the contribution, according to the level assessment. The ranking is in descending order. As for the level assessment, the cut-off point for the sum of contribution to the trend is 95 % and the source categories from the top of the list to the cut-off line are trend key categories.

Result of the Key Category Analysis for Greenland for the year 1990 and 2021

The entries in the results of KCA in Tables 11.10.1 to 11.10.3 for the years 1990 and 2021 are composed from CRFs for those years in this report. Note that base-year estimates are not used in the level assessment analysis for year 2021, but only included in Table 11.10.2 to make it more uniform with Tables 11.10.1 and 11.10.3.

The result of the Tier 1 KCA level assessment for Greenland for 1990 is shown in Table 11.10.1. For the assessment, five categories were identified as key categories and marked as shaded, see Table 11.10.1.

The result of the Tier 1 KCA level assessment for Greenland for 2021 is shown in Table 11.10.2. For the assessment, seven categories were identified as key categories, see Table 11.10.2.

The result of the Tier 1 KCA trend assessment for Greenland for 1990/1995-2021 is shown in Table 11.10.3. For the trend assessment, ten categories were identified as key categories, see Table 11.10.3. Note that according to the GPG, the analysis implies that contributions to the trend are all calculated as mathematically positive to be able to perform the ranking. LULUCF activities are in the table included with their sign i.e., emissions: +, removals: -.

In Table 11.10.4 a summary of Key Category Analysis for Greenland is given for level assessment for year 1990/95 and 2021 and for trend for years 1990-2021. All the categories are listed by sector and key sources are shown with their ranking.

Table 11.10.1 Key Category Analysis base year 1990/1995, level assessment, Tier 1.

Table 7.A1 (of Good Practice Guidance) Tier 1 Analysis - Level Assessment GRL – inventory

A			B	C	D	E
IPCC Source Categories (LULUCF included)			Direct GHG	Base Year Estimate Ex,o Gg CO_2 eqv.	Base Year Level Assessment Lx,o	Base year Cumulative total of Col. D
Energy	Combustion excluding transport	Liquid fuels	CO_2	523.872	0.802	0.802
Energy	Domestic aviation		CO_2	38.709	0.059	0.861
Energy	Road transportation		CO_2	36.423	0.056	0.917
Energy	Domestic navigation		CO_2	20.941	0.032	0.949
Agriculture	Enteric fermentation		CH_4	7.627	0.012	0.961
Waste	Wastewater treatment and discharge		N_2O	7.154	0.011	0.972
Waste	Solid waste disposal		CH_4	4.551	0.007	0.979
Waste	Incineration and open burning of waste		CH_4	2.692	0.004	0.983
Waste	Incineration and open burning of waste		CO_2	2.551	0.004	0.987
Energy	Combustion excluding transport	Other fuels	CO_2	1.675	0.003	0.989
Energy	Combustion excluding transport		N_2O	1.339	0.002	0.991
Energy	Combustion excluding transport		CH_4	1.133	0.002	0.993
Agriculture	Manure management		N_2O	0.869	0.001	0.994
Agriculture	Agricultural soils		N_2O	0.857	0.001	0.996
Waste	Incineration and open burning of waste		N_2O	0.741	0.001	0.997
Energy	Road transportation		N_2O	0.627	0.001	0.998
Energy	Domestic aviation		N_2O	0.323	0.000	0.998
Industry	Solvent use		CO_2	0.263	0.000	0.999
Industry	Paraffin wax use		CO_2	0.251	0.000	0.999
LULUCF	Grassland remaining grassland		CO_2	0.206	0.000	0.999
Agriculture	Manure management		CH_4	0.186	0.000	1.000
Energy	Road transportation		CH_4	0.068	0.000	1.000
LULUCF	Forest land		N_2O	0.052	0.000	1.000
Energy	Domestic navigation		N_2O	0.051	0.000	1.000
Energy	Domestic navigation		CH_4	0.036	0.000	1.000
Industry	Emission of SF6		SF_6	0.034	0.000	1.000
Industry	Emission of HFC's		HFCs	0.033	0.000	1.000
Agriculture	Liming		CO_2	0.008	0.000	1.000
Energy	Domestic aviation		CH_4	0.007	0.000	1.000
LULUCF	Grassland		CO_2	0.004	0.000	1.000
Industry	Paraffin wax use		N_2O	0.001	0.000	1.000
Industry	Paraffin wax use		CH_4	0.000	0.000	1.000
LULUCF	Forest land		CH_4	0.000	0.000	1.000
Industry	Road paving with asphalt		CO_2	0.000	0.000	1.000
Industry	Road paving with asphalt		CH_4	0.000	0.000	1.000
Industry	Asphalt roofing		CO_2	0.000	0.000	1.000
Industry	Limestone and dolomite use		CO_2	0.000	0.000	1.000
LULUCF	Forest land remaining forest land		CO_2	0.000	0.000	1.000
LULUCF	Land converted to cropland		CO_2	0.000	0.000	1.000
Total				653.283	1.000	

Table 11.10.2 Key Category Analysis year 2021, level assessment, Tier 1.

Table 7.A1 (of Good Practice Guidance) Tier 1 Analysis - Level Assessment GRL – inventory

A			B	C	D	E	F
IPCC Source Categories (LULUCF included)			Direct GHG	Base Year Estimate Ex,o Gg CO_2 eqv	Year 2021 Estimate Ex,t Gg CO_2 eqv	Year 2021 Level Assessment Lx,t	Year 2021 Cumulative total of Col. E
Energy	Combustion excluding transport	Liquid fuels	CO_2	523.872	450.399	0.742	0.742
Energy	Road transportation		CO_2	36.423	40.779	0.067	0.810
Energy	Domestic aviation		CO_2	38.709	33.474	0.055	0.865
Energy	Domestic navigation		CO_2	20.941	28.529	0.047	0.912
Industry	Emission of HFC's		HFCs	0.033	12.979	0.021	0.933
Energy	Combustion excluding transport	Other fuels	CO_2	1.675	9.347	0.015	0.949
Agriculture	Enteric fermentation		CH_4	7.627	6.298	0.010	0.959
Waste	Wastewater treatment and discharge		N_2O	7.154	5.084	0.008	0.967
Waste	Solid waste disposal		CH_4	4.551	4.731	0.008	0.975
Waste	Incineration and open burning of waste		CO_2	2.551	3.474	0.006	0.981
Waste	Incineration and open burning of waste		CH_4	2.692	1.963	0.003	0.984
Agriculture	Agricultural soils		N_2O	0.857	1.898	0.003	0.987
Energy	Combustion excluding transport		N_2O	1.339	1.370	0.002	0.990
LULUCF	Grassland remaining grassland		CO_2	0.206	1.355	0.002	0.992
Energy	Combustion excluding transport		CH_4	1.133	1.110	0.002	0.994
Energy	Road transportation		N_2O	0.627	0.932	0.002	0.995
Agriculture	Manure management		N_2O	0.869	0.773	0.001	0.996
Waste	Incineration and open burning of waste		N_2O	0.741	0.578	0.001	0.997
Industry	Paraffin wax use		CO_2	0.251	0.407	0.001	0.998
Energy	Domestic aviation		N_2O	0.323	0.279	0.000	0.998
Industry	Solvent use		CO_2	0.263	0.254	0.000	0.999
Energy	Road transportation		CH_4	0.068	0.172	0.000	0.999
Agriculture	Manure management		CH_4	0.186	0.153	0.000	0.999
Energy	Domestic navigation		N_2O	0.051	0.071	0.000	1.000
LULUCF	Forest land remaining forest land		CO_2	0.000	-0.070	0.000	1.000
LULUCF	Forest land		N_2O	0.052	0.055	0.000	1.000
Industry	Limestone and dolomite use		CO_2	0.000	0.054	0.000	1.000
Energy	Domestic navigation		CH_4	0.036	0.050	0.000	1.000
LULUCF	Land converted to cropland		CO_2	0.000	0.025	0.000	1.000
LULUCF	Grassland		CO_2	0.004	0.010	0.000	1.000
Energy	Domestic aviation		CH_4	0.007	0.006	0.000	1.000
Agriculture	Liming		CO_2	0.008	0.004	0.000	1.000
Industry	Emission of SF6		SF_6	0.034	0.003	0.000	1.000
Industry	Paraffin wax use		N_2O	0.001	0.001	0.000	1.000
Industry	Paraffin wax use		CH_4	0.000	0.000	0.000	1.000
Industry	Road paving with asphalt		CO_2	0.000	0.000	0.000	1.000
Industry	Asphalt roofing		CO_2	0.000	0.000	0.000	1.000
LULUCF	Forest land		CH_4	0.000	0.000	0.000	1.000
Industry	Road paving with asphalt		CH_4	0.000	0.000	0.000	1.000
Total				653.283	606.547	1.000	

Table 11.10.3 Key Category Analysis years 1990/1995-2021, trend assessment, Tier 1.

Table 7.A1 (of Good Practice Guidance) Tier 1 Analysis - Trend Assessment GRL – inventory

A			B	C	D	E	F	G
IPCC Source Categories (LULUCF included)			Direct GHG	Base Year Estimate Ex,o Gg CO_2-eq	Year 2021 Estimate Ex,t Gg CO_2-eq	Trend Assess-ment Tx,t	Contri-Bution To Trend	Cumul. total of Col. F
Energy	Combustion excluding transport	Liquid fuels	CO_2	523.872	450.399	0.055	0.432	0.432
Industry	Emission of HFC's		HFCs	0.033	12.979	0.020	0.156	0.588
Energy	Domestic navigation		CO_2	20.941	28.529	0.014	0.109	0.697
Energy	Combustion excluding transport	Other fuels	CO_2	1.675	9.347	0.012	0.094	0.791
Energy	Road transportation		CO_2	36.423	40.779	0.011	0.084	0.874
Energy	Domestic aviation		CO_2	38.709	33.474	0.004	0.030	0.904
Waste	Wastewater treatment and discharge		N_2O	7.154	5.084	0.002	0.019	0.923
LULUCF	Grassland remaining grassland		CO_2	0.206	1.355	0.002	0.014	0.937
Waste	Incineration and open burning of waste		CO_2	2.551	3.474	0.002	0.013	0.950
Agriculture	Agricultural soils		N_2O	0.857	1.898	0.002	0.013	0.963
Agriculture	Enteric fermentation		CH_4	7.627	6.298	0.001	0.009	0.972
Waste	Incineration and open burning of waste		CH_4	2.692	1.963	0.001	0.006	0.979
Waste	Solid waste disposal		CH_4	4.551	4.731	0.001	0.006	0.985
Energy	Road transportation		N_2O	0.627	0.932	0.001	0.004	0.989
Industry	Paraffin wax use		CO_2	0.251	0.407	0.000	0.002	0.991
Energy	Combustion excluding transport		N_2O	1.339	1.370	0.000	0.002	0.993
Waste	Incineration and open burning of waste		N_2O	0.741	0.578	0.000	0.001	0.994
Energy	Road transportation		CH_4	0.068	0.172	0.000	0.001	0.995
LULUCF	Forest land remaining forest land		CO_2	0.000	-0.070	0.000	0.001	0.996
Energy	Combustion excluding transport		CH_4	1.133	1.110	0.000	0.001	0.997
Industry	Limestone and dolomite use		CO_2	0.000	0.054	0.000	0.001	0.998
Agriculture	Manure management		N_2O	0.869	0.773	0.000	0.000	0.998
Industry	Emission of SF6		SF_6	0.034	0.003	0.000	0.000	0.998
LULUCF	Land converted to cropland		CO_2	0.000	0.025	0.000	0.000	0.999
Energy	Domestic navigation		N_2O	0.051	0.071	0.000	0.000	0.999
Energy	Domestic aviation		N_2O	0.323	0.279	0.000	0.000	0.999
Agriculture	Manure management		CH_4	0.186	0.153	0.000	0.000	0.999
Energy	Domestic navigation		CH_4	0.036	0.050	0.000	0.000	1.000
Industry	Solvent use		CO_2	0.263	0.254	0.000	0.000	1.000
LULUCF	Grassland		CO_2	0.004	0.010	0.000	0.000	1.000
LULUCF	Forest land		N_2O	0.052	0.055	0.000	0.000	1.000
Agriculture	Liming		CO_2	0.008	0.004	0.000	0.000	1.000
Energy	Domestic aviation		CH_4	0.007	0.006	0.000	0.000	1.000
Industry	Paraffin wax use		N_2O	0.001	0.001	0.000	0.000	1.000
Industry	Paraffin wax use		CH_4	0.000	0.000	0.000	0.000	1.000
Industry	Asphalt roofing		CO_2	0.000	0.000	0.000	0.000	1.000
Industry	Road paving with asphalt		CO_2	0.000	0.000	0.000	0.000	1.000
Industry	Road paving with asphalt		CH_4	0.000	0.000	0.000	0.000	1.000
LULUCF	Forest land		CH_4	0.000	0.000	0.000	0.000	1.000
Total				653.283	606.547	0.127	1.000	

Table 11.10.4 Summary of Key Category Analysis for Greenland for level assessment for year 1990/95 and 2021 and for trend for the years 1990-2021.

Summary of Key Category analysis for Greenland						
IPCC Source Categories (LULUCF included)			GHG	Key categories with number according to ranking in analysis		
				Identification criteria		
				Level Tier1 1990	Level Tier1 2021	Trend Tier1 1990-2021
Energy	Combustion excluding transport	Liquid fuels	CO_2	1	1	1
Energy	Combustion excluding transport	Other fuels	CO_2		6	4
Energy	Combustion excluding transport		CH_4			
Energy	Combustion excluding transport		N_2O			
Energy	Domestic aviation		CO_2	2	3	6
Energy	Domestic aviation		CH_4			
Energy	Domestic aviation		N_2O			
Energy	Road transportation		CO_2	3	2	5
Energy	Road transportation		CH_4			
Energy	Road transportation		N_2O			
Energy	Domestic navigation		CO_2	4	4	3
Energy	Domestic navigation		CH_4			
Energy	Domestic navigation		N_2O			
Industry	Limestone and dolomite use		CO_2			
Industry	Paraffin wax use		CO_2			
Industry	Paraffin wax use		CH_4			
Industry	Paraffin wax use		N_2O			
Industry	Solvent use		CO_2			
Industry	Road paving with asphalt		CO_2			
Industry	Road paving with asphalt		CH_4			
Industry	Asphalt roofing		CO2			
Industry	Emission of HFC's		HFCs		5	2
Industry	Emission of SF6		SF_6			
Agriculture	Enteric fermentation		CH_4	5	7	
Agriculture	Manure management		CH_4			
Agriculture	Manure management		N_2O			
Agriculture	Agricultural soils		N_2O			10
Agriculture	Liming		CO_2			
Waste	Solid waste disposal		CH_4			
Waste	Incineration and open burning of waste		CO_2			9
Waste	Incineration and open burning of waste		CH_4			
Waste	Incineration and open burning of waste		N_2O			
Waste	Wastewater treatment and discharge		N_2O			7
LULUCF	Forest land remaining forest land		CO_2			
LULUCF	Forest land		CH_4			
LULUCF	Forest land		N_2O			
LULUCF	Land converted to cropland		CO_2			
LULUCF	Grassland remaining grassland		CO_2			8
LULUCF	Grassland		CO_2			

11.11 Annex 2 Detailed discussion of methodology and data for estimating CO_2 emission from fossil fuel combustion

Detailed information regarding the methodology and input data used to calculate CO_2 emissions from fossil fuel combustion is included in Section 11.3.

11.12 Annex 3 Other detailed methodological descriptions for individual source or sink categories

All methodological descriptions are included in Sections 11.3 – 11.7.

11.13 Annex 4 CO_2 reference approach and comparison with sectoral approach, and relevant information on the national energy balance

See Section 11.3.6 of this annex for the results of the comparison between the sectoral and reference approach.

11.14 Annex 5 Assessment of completeness and (potential) sources and sinks of greenhouse gas emissions and removals excluded

11.14.1 GHG inventory

The Greenlandic greenhouse gas emission inventories for 1990-2021 include all sources identified by the 2006 IPCC Guidelines and the 2000 IPCC Good Practice Guidance except the following:

In the Industrial Processes and Product Use sector, no N_2O emissions are included in (CRF category 2D3) Solvent Use. With regards to N_2O from fire extinguishers (CRF category 2G3b) the notation key NE was priorily used. However, Danish research on the matter has showed that N_2O is not used in fire extinguishers. Since Greenland imports all fireextinguishers from Denmark, the notation key on N_2O in fire extinguishers is set to NO for every year in the time series 1990-2021. With regards to aerosol cans, we are aware that N_2O is found in the products. However, since we cannot find any activity data on aerosol cans, we continue to report the notation key NE for N_2O in aerosol cans.

Direct and indirect CH_4 emissions from agricultural soils are not estimated. Direct and indirect soil emissions are considered of minor importance for CH_4.

In the LULUCF sector, emissions/removals from wetlands, settlements and other land are currently not estimated due to the lack of available data. The lack of data availability is also an issue for other aspects of LULUCF, e.i. harvested wood products. For more detail, please see Section 11.6.

In the Waste sector, CO_2 emissions from managed waste disposal on land are not estimated. According to the 2006 IPCC Guidelines: "Decomposition of organic material deriving from biomass sources (e.g., crops, wood) is the primary source of CO_2 release from waste. These CO_2 emissions are not included in national totals, because the carbon is of biogenic origin and net emissions are accounted for under the AFOLU Sector."

11.15 Annex 6 Additional information to be considered as part of the annual inventory submission or other useful reference information

No additional information for Greenland is deemed relevant.

11.16 Annex 7 Tables 6.1 and 6.2 of the IPCC good practice guidance

IPCC Source category	Gas	Base year emission	Year t emission	Activity data uncertainty	Emission factor uncertainty	Combined uncertainty	Combined uncertainty as % of total national emissions in year t	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
		Input data	Input data	Input data	Input data							
		Gg CO_2 eq	Gg CO_2 eq	%	%	%	%	%	%	%	%	%
1A Liquid fuels	CO_2	620	553	3	2	3.606	10.813	0.034	0.847	0.068	3.593	12.911
1A Municipal waste	CO_2	2	9	3	25	25.179	0.151	0.012	0.014	0.298	0.061	0.093
1A Liquid fuels	CH_4	1	1	3	100	100.045	0.037	0.000	0.002	0.008	0.008	0.000
1A Municipal waste	CH_4	0	0	3	100	100.045	0.000	0.000	0.000	0.009	0.000	0.000
1A Biomass	CH_4	0	0	3	100	100.045	0.000	0.000	0.000	0.011	0.001	0.000
1A Liquid fuels	N_2O	2	2	3	500	500.009	3.883	0.000	0.004	0.205	0.016	0.042
1A Municipal waste	N_2O	0	0	3	500	500.009	0.009	0.000	0.000	0.073	0.001	0.005
1A Biomass	N_2O	0	0	3	200	200.022	0.002	0.000	0.000	0.036	0.001	0.001
1B2 Oil exploration	CO_2	0	0	3	1000	1 000.004	0.000	0.000	0.000	0.000	0.000	0.000
1B2 Oil exploration	CH_4	0	0	3	1000	1 000.004	0.000	0.000	0.000	0.000	0.000	0.000
1B2 Oil exploration	N_2O	0	0	3	1000	1 000.004	0.000	0.000	0.000	0.000	0.000	0.000
2A4 Limestone and dolomite use	CO_2	0	0	5	5	7.071	0.000	0.000	0.000	0.000	0.001	0.000
2D2 Paraffin wax use	CO_2	0	0	5	25	25.495	0.000	0.000	0.001	0.007	0.004	0.000
2D2 Paraffin wax use	N_2O	0	0	5	25	25.495	0.000	0.000	0.000	0.000	0.000	0.000
2D2 Paraffin wax use	CH_4	0	0	5	25	25.495	0.000	0.000	0.000	0.000	0.000	0.000
2D3 Solvent use	CO_2	0	0	5	25	25.495	0.000	0.000	0.000	0.000	0.003	0.000
2D3 Road paving with asphalt	CO_2	0	0	5	25	25.495	0.000	0.000	0.000	0.000	0.000	0.000
2D3 Road paving with asphalt	CH_4	0	0	5	25	25.495	0.000	0.000	0.000	0.000	0.000	0.000
2D3 Asphalt roofing	CO_2	0	0	5	25	25.495	0.000	0.000	0.000	0.000	0.000	0.000
2F Emission of HFC	HFC	0	13	10	50	50.990	1.190	0.020	0.020	0.991	0.281	1.061
2G Emission of SF6	SF_6	0	0	10	50	50.990	0.000	0.000	0.000	0.002	0.000	0.000

Continued

IPCC Source category	Gas	Base year emission	Year t emission	Activity data uncertainty	Emission factor uncertainty	Combined uncertainty	Combined uncertainty as % of total national emissions in year t	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
		Input data	Input data	Input data	Input data							
		Gg CO_2 eq	Gg CO_2 eq	%	%	%	%	%	%	%	%	%
3A Enteric Fermentation	CH_4	8	6	10	100	100.499	1.089	0.001	0.010	0.120	0.136	0.033
3B Manure Management	CH_4	0	0	10	100	100.499	0.001	0.000	0.000	0.003	0.003	0.000
3B Manure Management	N_2O	1	1	10	100	100.499	0.016	0.000	0.001	0.005	0.017	0.000
3D Agricultural soils	N_2O	1	2	20	50	53.852	0.028	0.002	0.003	0.084	0.082	0.014
3G Liming	CO_2	0	0	5	50	50.249	0.000	0.000	0.000	0.000	0.000	0.000
4A Forest	CO_2	0	0	5	50	50.249	0.000	0.000	0.000	0.005	0.001	0.000
4A Forest	CH_4	0	0	5	50	50.249	0.000	0.000	0.000	0.000	0.000	0.000
4A Forest	N_2O	0	0	5	50	50.249	0.000	0.000	0.000	0.000	0.001	0.000
4B Cropland	CO_2	0	0	5	50	50.249	0.000	0.000	0.000	0.002	0.000	0.000
4C Grassland	CO_2	0	1	5	50	50.249	0.013	0.002	0.002	0.089	0.015	0.008
4C Grassland	CH_4	0	0	5	50	50.249	0.000	0.000	0.000	0.000	0.000	0.000
5A Solid Waste Disposal	CH_4	5	5	10	100	100.499	0.615	0.001	0.007	0.078	0.102	0.016
5C Incineration and open burning of waste	CO_2	3	3	10	25	26.926	0.024	0.002	0.005	0.042	0.075	0.007
5C Incineration and open burning of waste	CH_4	3	2	10	50	50.990	0.027	0.001	0.003	0.041	0.042	0.003
5C Incineration and open burning of waste	N_2O	1	1	10	100	100.499	0.009	0.000	0.001	0.017	0.013	0.000
5D Wastewater treatment and discharge	N_2O	7	5	30	100	104.403	0.766	0.002	0.008	0.239	0.330	0.166
Total		653	607				18,675					14,363
Total uncertainties				Overall uncertainty in the year (%):			4.321			Trend uncertainty (%):		3.790

11.17 Annex 8 Results of a technical analysis conducted on the Greenlandic gasoil

In 2013, a technical analysis has been conducted on the arctic gasoil that is by far the most dominant type of fuel in Greenland. The analysis was conducted by the Danish Technological Institute in order to gain a country specific emission factor on the Greenlandic gasoil.

Table 11.18.1 shows the results of the technological analysis on the Greenlandic gasoil. The CO_2 emission factor was revised in the 2015 submission due to an increase in the recommended oxidation factor from 0.99 to 1.0.

Table 11.18.1 Results on the technical analysis on the Greenlandic gasoil

	Test result	Method
C, %	85.4	Elementaranalyse
Upper calorific, J/g	45860	DS/CEN/TS 14918
Lower calorific, J/g	42900	Calculation
CO_2 emission factor, kg CO_2/GJ	72.967	Calculation

12 Information related to the greenhouse gas inventory for the Faroe Islands

12.1 Introduction

This report covers the Faroese part of the National Inventory Report for the Kingdom of Denmark 1990-2021.

The report is made by Umhvørvisstovan, the Faroese Environment Agency (FEA) www.us.fo.

12.1.1 Background information on greenhouse gas inventories and climate change

Each year the Faroe Islands is obligated to report its emission of greenhouse gases (GHG), according to the requirements of the United Nations Framework Convention on Climate Change (UNFCCC). The Kingdom of Denmark (which includes Denmark, Greenland and the Faroe Islands as geographical areas) has signed the UNFCCC. The Faroese emission figures are part of the emission total for the Kingdom of Denmark.

The first emission inventories for the Faroe Islands were made using an average method based upon the total use of fossil fuels in the Faroe Islands and consequently the inventories have only included total estimates of CO_2 emissions. Later, the inventories were done according to IPCC guidelines. Since 2008, the FEA has yearly reported GHG emissions to Danish Centre for Environment and Energy (DCE), Dep. of Environmental Science (ENVS), Aarhus University.

The GHGs reported are:

- Carbon dioxide CO_2
- Methane CH_4
- Nitrous Oxide N_2O
- Hydrofluorocarbons HFCs
- Perfluorocarbons PFCs
- Sulphur hexaflouride SF_6
- Nitrogen triflouride NF_3

12.1.2 A description of the institutional arrangement for inventory preparation

FEA, an agency under the Ministry of Environment (www.umhvorvi.fo), is responsible for the annual preparation and submission to the UNFCCC of the Faroe Islands' contribution to the Kingdom of Denmark's National Inventory Report and the GHG inventories in the Common Reporting Format in accordance with the UNFCCC Guidelines. The inventory is done with guidance from and in co-operation with DCE.

In January 2010, DCE and FEA made a formal agreement about data delivery.

The work concerning the annual greenhouse gas emission inventory is carried out in co-operation with other Faroese ministries, research institutes, organisations and companies:

- *Statistics Faroe Islands (Ministry of Finance)* www.hagstova.fo
  Annual statistics on liquid fuel sale, fuel usage for electricity and heat production, and statistics on livestock (sheep and cows). Fish export. Population.
- *Búnaðarstovan (Agricultural Agency of the Faroe Islands)* www.bst.fo
  Dato on usage of fertilizers, number of sheep and horses, estimations and calculations related to emissions form Agriculture
- *Landsverk* – the road authority. www.landsverk.fo.
  Data on the vehicle stock and other related data
- *Municipal Waste Plants* www.irf.fo
  Data on amount of incinerated and deponized waste.
- *Electricity producing company* www.sev.fo
  Data on import of F-gases (SF_6).
- *Airline Company* www.atlantic.fo
  Data for fuel bunkers for domestic flights and international flights to and from the Faroe Islands.
- *Refrigeration and other gas sale companies*
  Data on import of F-gases (HFCs) and N_2O.
- *Oil companies – license holders*
  Data on use of fuel oil in connection with exploration (deep water) drilling in Faroese territorial waters. Has not been relevant since 2014.

12.1.3 Brief description of the process of inventory preparation. Data collection and processing, data storage and archiving

Statistic Faroe Islands collects and stores a major part of the activity data for the inventory, e.g. fuel sale and fuel usage by combustion plants, as well as a number of livestock (sheep and cows). Each year, FEA receives new activity data for fuel sale and fuel usage and other data for the previous year. An increasing part of the data is accessible on the homepage of Statistics Faroe Islands.

Other activity data are delivered by plants owned by municipalities or private companies.

After receiving the data, the material is placed on servers at FEA. The servers are subject to routine backup services. Material that has been backed up is archived safely. All collected data is also archived in the electronic journal of the agency.

Each year updated emission factors are received from DCE. In addition to copying the factors to spread sheet files, the e-mails are archived in the electronic journal.

Since the 2008 submission, all subsequent submissions have been reported in the Common Reporting Format of UNFCCC (CRF). The new format has meant improvements, higher data security and limited the potential for errors in the reporting.

12.1.4 Brief general description of methodologies and data sources used

The GHG inventory for the Faroe Islands includes the following sectors:

- Energy (CRF sector 1)
- Industrial Processes and Product Use (CRF sector 2)
- Agriculture (CRF sector 3)

- LULUCF (CFR sector 4)
- Waste (CRF sector 5)

The applied methodologies follow the IPCC Guidelines. In some cases, the IPCC tier 1 methodologies have been used and in other a combination of tier 2 and tier 3 methodologies have been used.

The methods and the emission factors used in the inventory are shown in Table 12.1 (emission factors for CO_2, CH_4 and N_2O) and in Table 12.2 (emission factors for HFCs and SF_6). A brief general description of methodologies is included below for the different sectors.

Table 12.1 Methods applied, and emission factors used for calculating CO_2, CH_4 and N_2O emissions.

	CO_2		CH_4		N_2O	
GHG CATEGORIES	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1. Energy						
A. Fuel Combustion	T1	CS	T1	CS	T1	CS
1. Energy Industries	T1	CS	T1	CS	T1	CS
2. Manufacturing Industries and Construction	T1	CS	T1	CS	T1	CS
3. Transport	T1, T2	CS	T1, T3	CS, OTH	T1, T3	CS, OTH
4. Other Sectors	T1	CS	T1	CS	T1	CS
2. Industrial Processes and Product Use						
D. Non-energy products from fuels and solvent use	T1	D				
G. Other product manufacture and use					T1	D
3. Agriculture						
A. Enteric Fermentation			T1, T2	CS, D		
B. Manure Management			T1, T2	CS, D	T1	SC, D
D. Agricultural Soils			T1	D	T1	D
4. Land use, land-use change and forestry					T2	D
A. Forest land	T1, T2	CS, D			NA	NA
B. Cropland	T1	D	T1	CS	NA	NA
C. Grassland	T1	D	T1	CS	NA	NA
D. Wetlands	T1	D	T1	CS	NA	NA
E. Settlements	T1	D	T1	CS	NA	NA
F. Other land	T1	D	T1	CS	NA	NA
G. Harvested wood products						
H. Other						
5. Waste						
A. Solid waste disposal			T2	D		
D. Wastewater treatment and discharge			T1	D	T1	D

Table 12.2 Methods and Emission factors used for calculating HFCs and SF_6 emissions in the Industrial Processes and Product Use sector.

	HFCs		SF_6	
GHG CATEGORIES	Method applied	Emission factor	Method applied	Emission factor
2. Industrial Processes and Product Use				
F. Product Uses as Substitutes of ODS	T1	D	T1	D

Energy sector

All emissions in the Energy sector are from Fuel combustion (1.A.A), and in these categories:

- 1.A.1 Energy Industries

    - 1.A.1.a Public Electricity and Heat Production (incl. Waste incineration)
    - 1.A.1.c Manufacture of Solid Fuels and Other Energy Industries
- 1.A.2 Manufacturing Industries and Construction
    - 1.A.2.a Iron and Steel
    - 1.A.2.b Non-Ferrous Metals
    - 1.A.2.c Chemicals
    - 1.A.2.d Pulp, Paper and Print
    - 1.A.2.e Food Processing, Beverages and Tobacco
    - 1.A.2.f Non-metallic Minerals
    - 1.A.2.g v Construction
    - 1.A.2.g viii Other
- 1.A.3 Transport
    - 1.A.3.a Domestic Aviation
    - 1.A.3.b Road Transportation
        - 1.A.3.b.i Cars
        - 1.A.3.b.ii Light duty trucks
        - 1.A.3.b.iii Heavy duty trucks
        - 1.A.3.b.iv Motorcycles
    - 1.A.3.d Domestic Navigation
- 1.A.4 Other Sectors
    - 1.A.4.a Commercial/Institutional
    - 1.A.4.b Residential
    - 1.A.4.c Agriculture/Forestry/Fishing
        - 1.A.4.c.iii Fishing

Statistics Faroe Islands provides the information on fuel sales by fuel type (m^3) and divided into eight main groups (original titles: Fishing vessels, Other ships, Transportation, Industry, Trading and Service, Residential and Communities, Institutions and Public Power), each group again divided into subgroups.

The fuel data delivered by Statistics Faroe Islands originate from several sources. The main data sources are the two main oil companies in the Faroe Islands, Effo and Magn. Fuel data not included in sales information from the oil companies are delivered by the industry to FEA.

Since the delivered data on fuel sale are not fully arranged according to IPCC guidelines, the FEA rearranges the data to comply with the guidelines.

Emission factors

Emissions from fuel combustion can be divided into two main sources: stationary and mobile combustion. Stationary combustion is fuel combustion related to e.g., industry on land, house heating and oil exploration. Mobile combustion includes the combustion in engines used for propulsion in the various modes of transport such as road transport, marine activities, and aviation. The emission factors used for stationary, transport, waste and aviation are country specific and provided yearly by DCE. All emissions factors used in the inventory are found in Annex 1.

Emissions are calculated by multiplying fuel consumption data with an emission factor (e.g., in tonnes emission per GJ fuel).

Public Electricity and Heat Production (1A1a)

The activity data used for calculations of emissions of GHG from Public Electricity and Heat Production are the consumption of residual oil and diesel oil at electricity producing plants on the Faroe Islands. The emission factors are calculated and delivered by DCE, see

Table 12.24 in Annex 1.a.

Manufacture of Solid Fuels and Other Energy Industries (1A1c)

This category only covers the emissions of GHG from activities related to exploration drilling in Faroese territory. The operators deliver the activity data (usage of diesel on the rigs). The emission factors are calculated and delivered by DCE, see

Table 12.24 in Annex 1.a.

Manufacturing Industries and Construction (1A2)

Statistics Faroe Islands deliver the activity data for oil usage. The emission factors are calculated and delivered by DCE, see

Table 12.24 in Annex 1.a.

Domestic Aviation (1A3a)

The Faroese airline company, Atlantic Airways, www.atlantic.fo delivers data for jet fuel bunkered in the Faroe Islands. Since the Faroe Islands has accepted the United Nations Framework Convention on Climate Change as a part of the Kingdom of Denmark, aviation between Denmark and the Faroe Islands is to be reported as Domestic Aviation. The jet fuel data is thus divided by destination: flights to destinations inside the Kingdom of Denmark, i.e., Denmark and Greenland (Domestic Aviation), and outside the Danish Kingdom, e.g., Iceland, Norway, and Great Britain (International Aviation). Fuel refuelled outside the Faroe Islands is not included in the Faroese inventory. The emission factors for aviation are calculated and delivered by DCE, see Table 12.26 in Annex 1.b.

Road Transportation (1A3b)

The activity data for road transportation is data for sale of gasoline and diesel to all types of vehicles at all filling stations in the Faroe Islands. The data are delivered by the Statistics Faroe Islands. The emission factors for road traffic are calculated and delivered by DCE taking into account vehicle stock data from the Faroe Islands combined with assumptions on size and age distribution for each vehicle class derived from the Danish inventory. The Danish results are modified for Faroese traffic conditions such as other gross vehicle weights for heavy-duty vehicles and no highway driving conditions. The emissions factors are also modified because biofuel is not used in the Faroe Islands, unlike in Denmark. The emission factors are shown in Table 12.27 in Annex 1.b.

Domestic Navigation (1A3d)

Statistics Faroe Islands deliver the activity data for oil used in navigation. The emission factors are calculated and delivered by DCE, see Table 12.28 in Annex 1.b.

Other sectors (1A4)

The activity data for oil usage used to calculate the GHG emissions from the Commercial/Institutional (1A4a) and Residential (1A4b) sectors are delivered by Statistics Faroe Islands. The emission factors calculated and delivered by DCE are found in

Table 12.24 in Annex 1.a.

Fishing (1A4ciii)
Statistics Faroe Islands deliver the activity data (sale of oil to fishing vessels). A private oil company delivers data on oil bunkered in the Faroe Island onto foreign fishing vessels. This data is not a part of the official statistic in Statistics of the Faroe Islands. The emission factors are calculated and delivered by DCE and are found in Table 12.28 in Annex 1.b.

The inventory includes all oil bunkered on Faroese territory, though excluding oil bunkered by international companies, i.e., from a foreign supplier to a foreign customer at open sea or on near-coast sites.

Industrial Processes and Product Use sector
Emissions from Industrial processes and Product Use are allocated to these categories:

- 2.D Non-energy products from fuels and solvent use
- 2.D.1 Lubricant use
    - 2.D.2 Paraffin wax use
- 2.F Product Uses as Substitutes for ODS
    - 2.F.1 Refrigeration and Air conditioning
- 2.G Other Product Manufacture and Use
    - 2.G.1 Electrical Equipment
    - 2.G.3.a Medical applications

The inventory follows the principles in the IPCC Guidelines with a Tier 1 methodology. The emissions factors are IPPC default.

The activity data for lubricant use, wax use come from Statistics Faroe Islands. The activity data for N_2O comes from the importer.

The activity data on the consumption (import) of HFCs and SF_6 origin from FEA surveys that have been conducted annually since 2003. An estimate of the consumption has been done for the years 1990-2002.

Solvent and other product use
Since no data are available, emissions from solvent and other product use are not calculated.

Agriculture sector
GHG emissions from agriculture are calculated for following categories:

- 3.1 Livestock
    - 3.A Enteric Fermentation
    - 3.B Manure Management
        - 3.B.1 CH_4
        - 3.B.2 N_2O
- 3.D Agricultural Soils
    - 3.D.1 Direct N_2O Emissions from Managed Soils
    - 3.D.2 Indirect N_2O Emission from Managed Soils

The inventory follows the principles in the IPCC Guidelines and the IPCC Good Practice Guidance. Tier 1 and Tier 2 method are used. In cases where country specific emission factors are not used, IPCC standard values are used.

The emissions are calculated with support from DCE and Faroese Agricultural Agency. Activity data is accessible on the homepage of Statistics Faroe Islands (number of cows and sheep) and received from other sources.

Waste sector

GHG emissions from Waste are calculated for following categories:

- 5.A Solid Waste Disposal
    - 5.A.1 Managed Waste Disposal Sites
    - 5.A.2 Unmanaged Waste Disposal Sites
- 5.D Wastewater treatment and discharge

Waste incineration is done with energy recovery as such the emissions are allocated to the Energy sector. Emission factors relative to emissions of CO_2, N_2O and CH_4 from waste incineration in 1990-2021 are listed in Table 12.25 in Annex 1.a. Heating values for waste incineration are listed in Table 12.3.

Table 12.3 Heating values (GJ/t) for waste.

Year	Heating values
1990-1991	8,2
1992	9,0
1993-1994	9,4
1995	10,0
1996-2012	10,5
2013-2021	10,6

12.1.5 Brief description of key categories

No country-specific key category analysis has been carried out.

12.1.6 Information on QA/QC plan including verification and treatment of confidential issues where relevant

Several measures are in place to ensure the quality of the greenhouse gas inventory for the Faroe Islands.

The general QC activities include:

- Check that data from Statistics Faroe Islands and other data deliverers are correctly transferred to emissions spreadsheets.
- Check that data are correctly transferred between data processing steps, e.g., it is ensured that the data are imported correctly from the emission spread sheets/databases to the CRF Reporter.
- The time series are analysed. Any large fluctuations are investigated and explained/corrected.
- The completeness of the inventory is checked utilising the completeness checker incorporated in the CRF Reporter.

These types of QC checks are recommended as Tier 1 QC checks in the IPCC Guidelines (IPCC, 2006).

No confidential issues are relevant.

12.1.7 General uncertainty evaluation, including data on the overall uncertainty for the inventory totals

Uncertainty evaluation has not been made for the Faroese inventory.

12.1.8 General assessment of the completeness

In general, the inventory is complete for what is considered the significant sources.

12.1.9 References

Lastein, L. & Winther, M. 2003: Emissions of greenhouse gases and long-range transboundary air pollutants in the Faroe Islands 1990-2001. National Environmental Research Institute, Denmark. 62 p. NERI Technical Report no. 477. Available at:
http://www2.dmu.dk/1_viden/2_Publikationer/3_fagrapporter/rapporter/FR477.pdf

Winther, M. 2001: 1998 Fuel Use and Emissions for Danish IFR Flights. Environmental Project no. 628, 2001. 112 pp. Danish EPA. Prepared by the National Environmental Research Institute (NERI), Denmark. Electronic report at homepage of Danish EPA. Available at:
https://www2.mst.dk/udgiv/publications/2001/87-7944-661-2/pdf/87-7944-662-0.pdf

Umhvørvisstovan, 2022: Útlát av vakstrarhúsgassi í Føroyum 1990-2021. July 2022 (in English: Emission of greenhouse gases in the Faroe Islands). J. Only in Faroese. Available at: https://www.us.fo/Default.aspx?ID=13912

12.2 Trends in Greenhouse Gas Emissions

The trends present in this Chapter cover the emissions from the Faroe Islands.

The whole inventory, including trend tables and emission trend summary tables, can be found on the homepage of EIONET. Available at: https://cdr.eionet.europa.eu/dk/Air_Emission_Inventories/Submission_UNFCCC/

12.2.1 Description and interpretation of emission trends for aggregated greenhouse gas emissions

The greenhouse gas emissions are estimated according to the IPCC guidelines and are aggregated into five main sectors: Energy, Industrial Processes and Product Use, Agriculture, Land Use, Land-Use Change and Forestry and Waste. Emissions from waste incineration are allocated to the Energy sector. The main part, 85 %, of the emissions is from the fuel consumption in the energy sector. Figure 12.1 shows the estimated total greenhouse gas emissions in CO_2 equivalents from 1990 to 2021. The total greenhouse gas emission in CO_2 equivalents has increased by 66 % from 1990 to 2021. Comments on the overall trends etc. are given in the sections below.

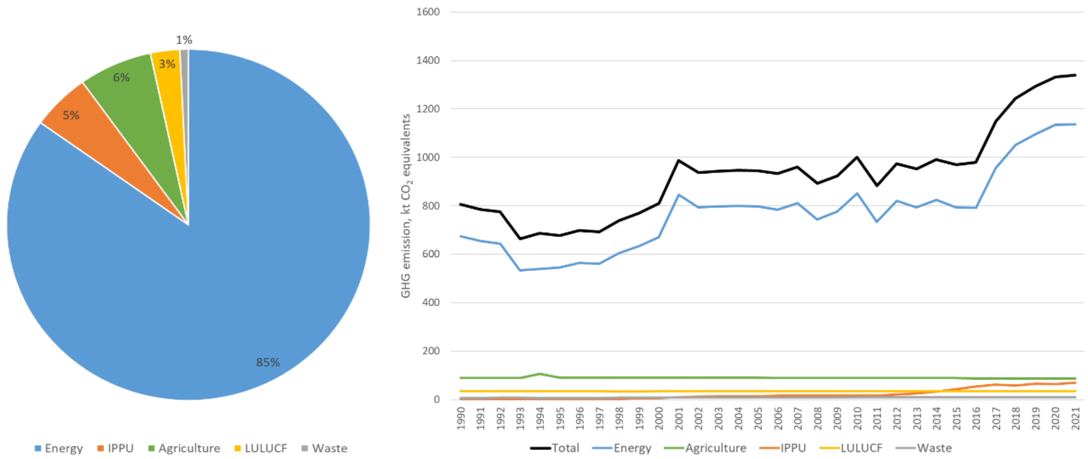

Figure 12.1 Greenhouse gas emissions in CO_2 equivalents distributed on main sectors for 2021 and time series for 1990 to 2021.

The greenhouse gases include CO_2, CH_4, N_2O, HFCs and SF_6. Figure 12.2 shows the composition of greenhouse gas emissions (CO_2, N_2O, CH_4 and F-gases) in 2021, calculated in GWP values. CO_2 is the most important greenhouse gas contributing with 87%, followed by F-gases (HFCs and SF_6) with 5.1 %, N_2O with 5.0 % and CH_4 with 2.8 %.

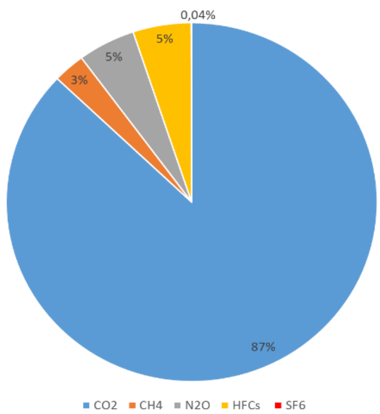

Figure 12.2 Emissions of GHG in CO_2 equivalents in 2021, distributed on type of gas.

Figure 12.3 shows the total emissions of greenhouse gases and the emission of CO_2, N_2O, CH_4 and F-gases (in CO_2 equivalents) in the time period 1990-2021. From 1990 to 1993, a decrease is observed, due to an economic crisis in the Faroe Islands, which lasts for 6-8 years. From 2001 to 2007, the emissions were rather stabile. In 2008-2011, the emissions from Faroese fishing ship were significantly lower than previous years, especially due to rising oil prices and lower prices on fish. The decrease is concealed by emissions related to new bunkering activity starting in 2009 that has led to a substantial increase in the number of foreign fishing vessels bunkering in the Faroe Island. In general, the total emission of greenhouse gases on the Faroe Islands were relative stabile from 2001 until 2016, around and above 900 thousand tonnes of CO_2 equivalents pr. year. A significant and step rise in the emission was seen in 2017 and in the following three years, increasing the emissions to more than 1.3 million CO_2 equivalents in 2020. The yearly increase was decreasing each year though, and in 2021, the emission was nearly the same as in 2020.

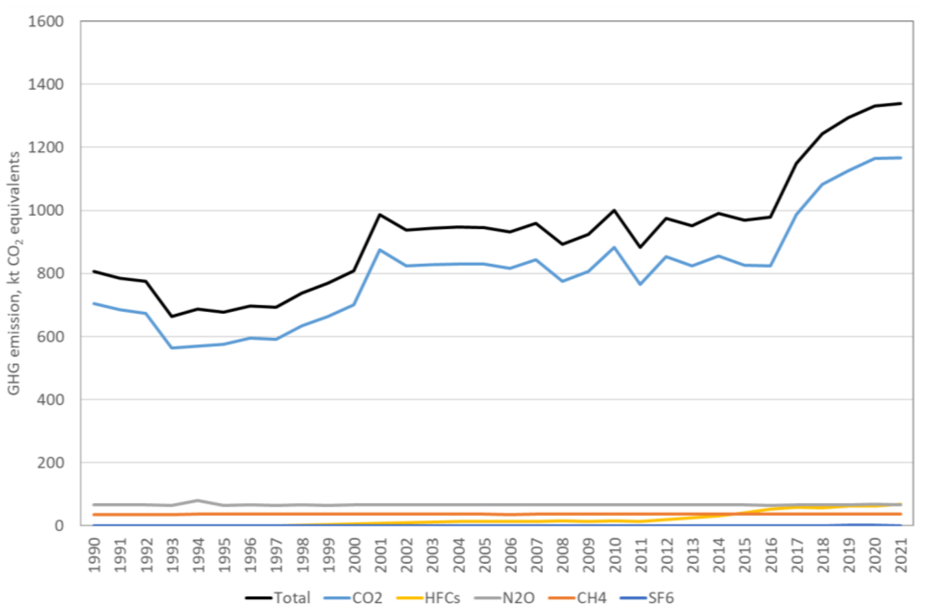

Figure 12.3 GHG emission by gas in CO_2 equivalents, time series 1990-2021.

12.2.2 Description and interpretation of emission trends by gas

Carbon dioxide

The emission of CO_2 on the Faroe Islands is primarily from fuel consumption but also from LULUCF and other sources. The trend in the total emission of CO_2 (Figure 12.4) is nearly identical with the trend of the total emission of GHG in the Faroe Islands (Figure 12.3) showing the trends in CO_2 emissions in the period from 1990 to 2021. After the economic decline in the 1990's, the emissions rose and were rather constant until 2007. From 2008 to 2011, the effort in the Faroese fishing fleet was significantly lower than previous years, also meaning a significant reduction in oil consumption. The reduction in the emissions for fisheries in 2009 and 2011 is not visible because a new oil bunkering activity (mostly used by foreign fishing vessels) started up in 2009, increasing the emissions. As seen in Figure 12.4, the rise in the total emission in 2017 and 2018 is due to more energy usage on fishing vessels, whereas the rise in 2019 and 2020 is mainly due to increase in use of fuel in fishing vessels and in production of public electricity.

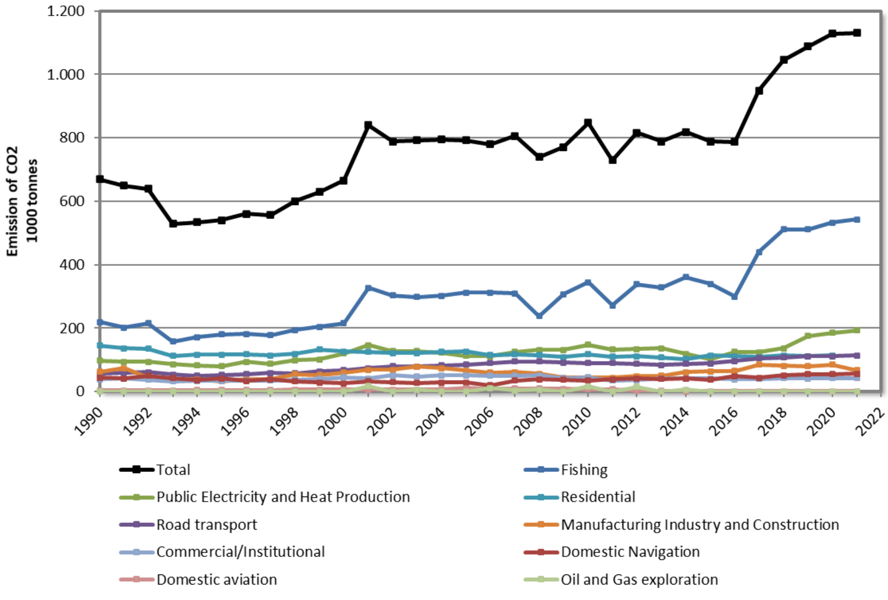

Figure 12.4 Total CO_2 emissions, by sector, time series for 1990-2021.

Figure 12.5 shows how the emissions are distributed between categories. In 2021, 42 % of the emissions of CO_2 came from fishing vessels. Public Electricity and Heat Production, Residential and Road Transportation accounted for 15 %, 9 % and 9 % of the total CO_2 emission.

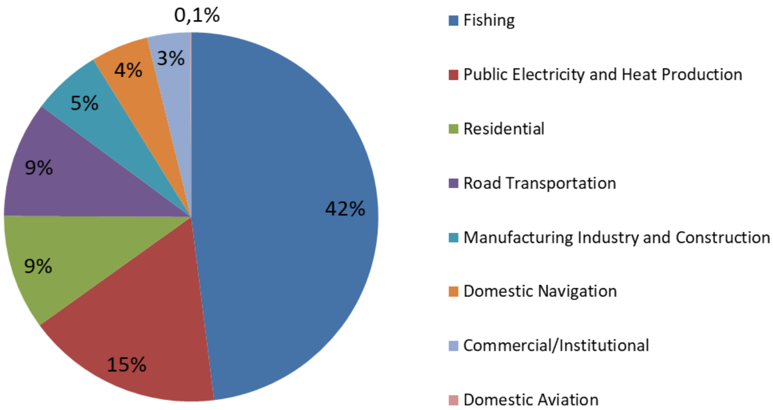

Figure 12.5 Emissions of CO_2 in the Energy sector, divided in fuel consumption categories, in CO_2 equivalents, 2021.

Nitrous oxide

Figure 12.6 shows the emissions of nitrous oxide in the Faroe Islands 1990-2021. Almost all of the N_2O emissions are from the Agricultural sector (89 %), i.e. from animals grazing on agricultural soils, but much less from manure management. A smaller contribution comes from energy and wastewater treatment. The peak in 1994 will be further investigated for the next submission. There is an apparent inconsistency in the area of grassland causing the peak in emissions related to crop residues.

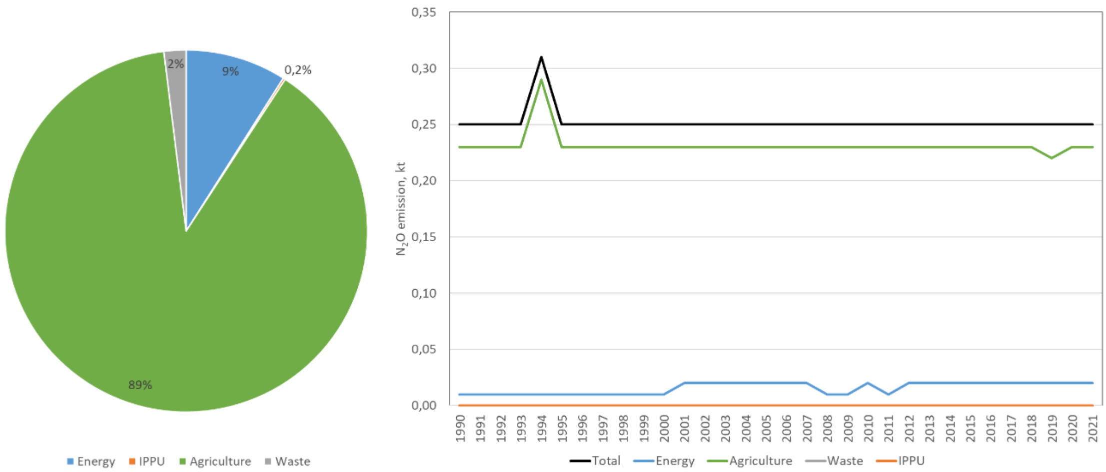

Figure 12.6 N_2O emissions in tonnes distributed on sector and time series for 1990-2021.

Methane

Figure 12.7 shows the emissions of methane in the Faroe Islands 1990-2021. Most of the methane emission is from the agriculture sector (75 %), especially from enteric fermentation. The second source is the waste sector, landfills and wastewater treatment, accounting for 24 %. Most of the emission of CH_4 in the energy sector (1%) is due to aviation activity.

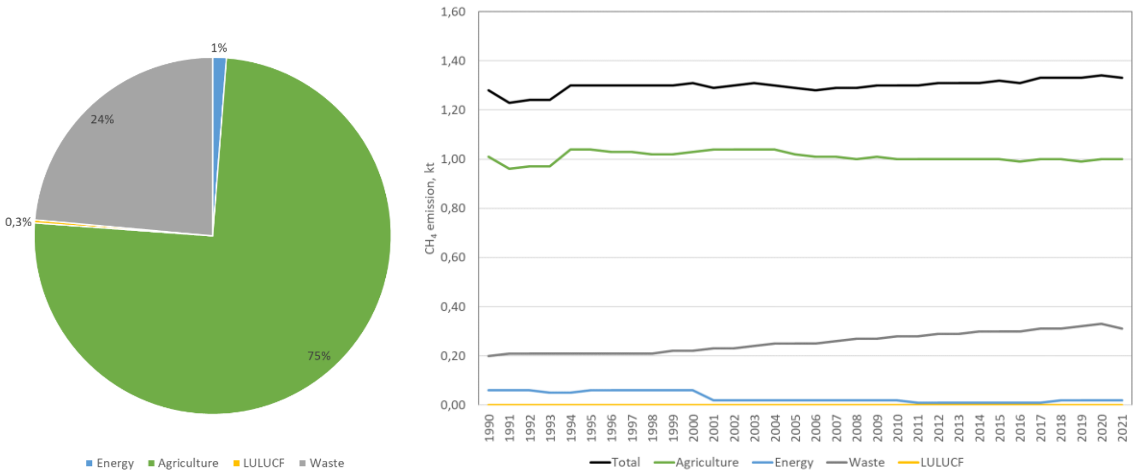

Figure 12.7 CH_4 emissions in tonnes distributed on sectors and time series for 1990-2021.

HFCs, PFCs, SF_6 and NF_3

Figure 12.8 shows the emissions of F-gases, HFCs and SF_6 respectively, in the years 1990-2021. Most of the emission is HFCs, used for refrigeration purposes, as substitutes for HCFCs. After the emissions increased in the period 1996-2005, the emissions were rather stable at around 14,000 tonnes of CO_2 equivalents pr. year until 2011. Since then, the emission has increased each year, and in 2021, the emissions of HFC have four-folded since 2012, to in total around 70 kt of CO_2 equivalents in 2021. This is due to higher use of HFC-125 and HFC-143a, both components in the HFC-blend HFC-507a, which in recent years has been used as a substitute when phasing out HCFC-22 (ozone depleting substance, freezing agent) on fishing vessels. See also Table 12.4.

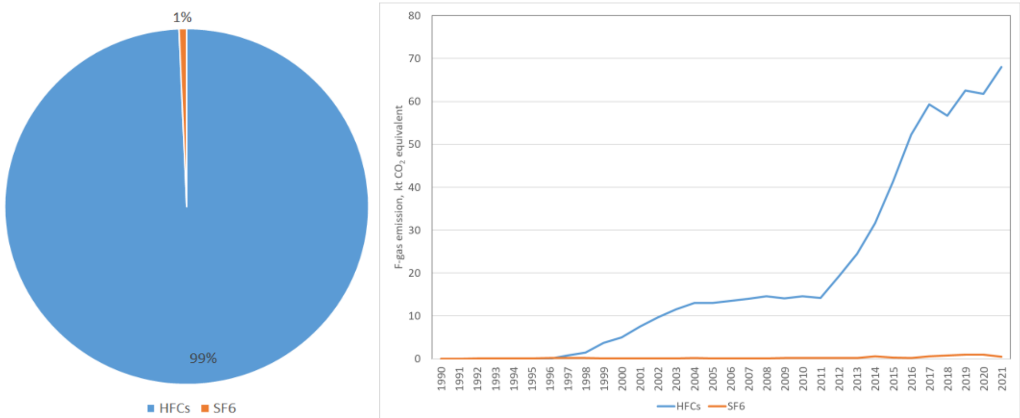

Figure 12.8 F-gas emissions in CO_2 equivalents, contribution from type of F-gas and time series for 1990-2021.

Neither PFCs nor NF_3 have been in use in the Faroe Islands.

12.2.3 Description and interpretation of emission trends by source

In 2021, 85 % of all GHG emissions were from the Energy sector, including waste incineration. Approximately 5 % were from Industrial Processes and Product Use, and around 6 % from Agriculture 12.1. The remaining emission is from LULUCF (3 %) and the waste sector (1 %), see Figure 12.9 (and Figure 12.1)

The fluctuations in the GHG emissions in the Energy sector are decisive for the fluctuations in the total GHG emissions, see Figure 12.9. The emissions from the Agriculture sector, Industrial Processes and Product Use sector, LULUCF sector and the Waste sector are relatively small and constant.

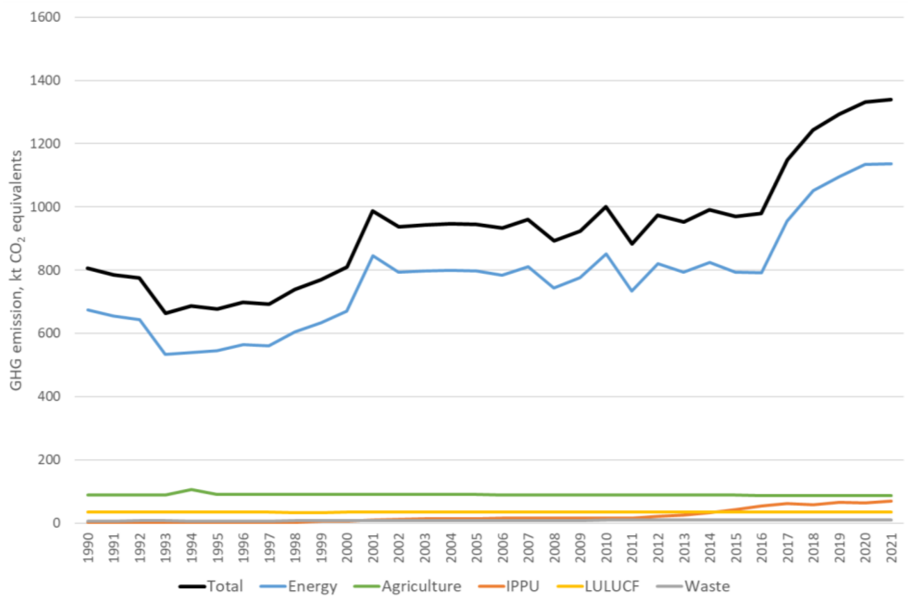

Figure 12.9 GHG emissions in CO_2 equivalents, main sectors, time series 1990-2021.

12.2.4 Description and interpretation of emission trends for indirect greenhouse gases and SO_2

Emission trends for indirect greenhouse gases and SO_2 have not been made for the Faroe Islands.

12.3 Energy (CRF sector 1)

12.3.1 Overview of the sector

Fuel consumption on the Faroe Islands, 1990-2021, can be seen in Figure 12.10. Most of the fuel is used by fishing vessels.

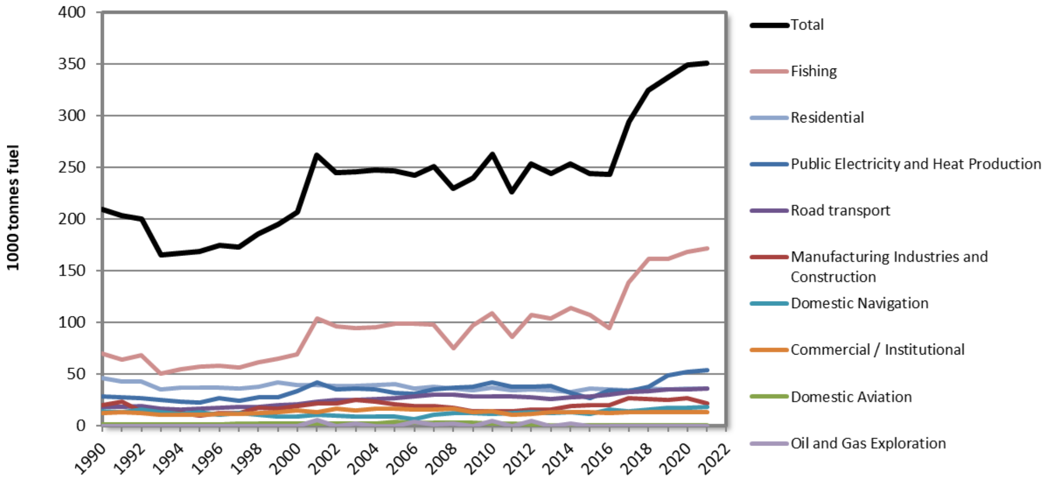

Figure 12.10 Fuel consumption (tonnes) in the Energy sector, including waste incineration, 1990-2021.

Figure 12.11 shows the GHG emissions in the Energy sector on the Faroe Islands 1990-2021. The trend is just the same as in Figure 12.10.

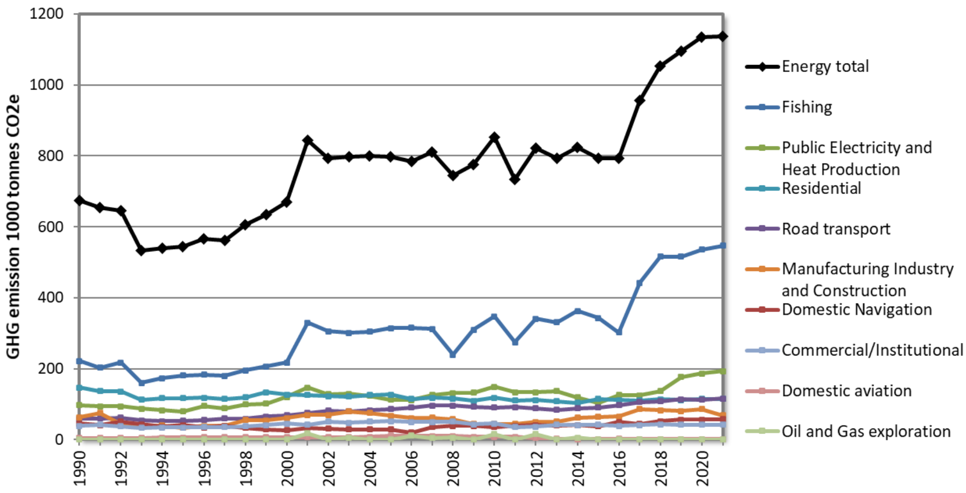

Figure 12.11 GHG emissions in CO_2 equivalents, categories in the Energy sector, 1990-2021.

Figure 12.12 shows how the emission of GHG in 2021 was distributed between groups of fuel users. Fishing vessels, Public Electricity and Heat Production, Residential and Road transportation had 42, 15, 9 and 9 %, respectively, of the emissions in the Energy sector in 2021.

Waste Incineration has been included under category 1.A.1.a (Public Electricity and Heat Production), comprising 10 % of the total emissions in the category in 2021.

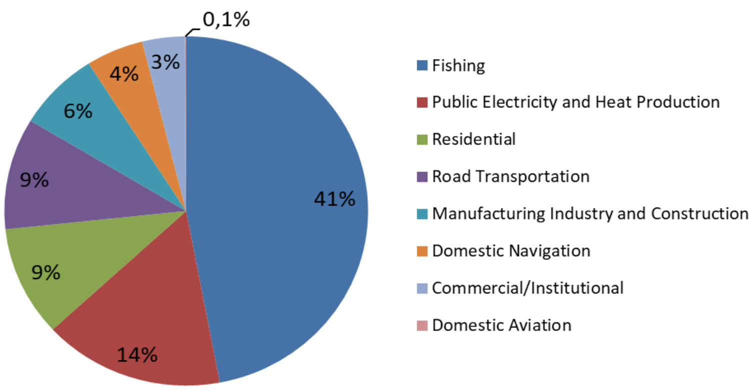

Figure 12.12 GHG emissions in CO_2 equivalents; Energy sector divided in categories, 2021.

12.3.2 Reference approach

In the 2022 submission, the reference approach was reported for the first time. Further improvements need to be made as it relates to incorporation of data on international bunkers and to investigate the differences between the sectoral and reference approaches.

12.3.3 Fugitive emissions (CRF sector 1B)

Fugitive emissions of GHG gases are estimated to be very limited on the Faroe Islands. These emissions have not been estimated.

12.3.4 Uncertainty

The uncertainties have not been calculated.

12.3.5 Recalculations and improvements

See 12.9 Recalculations and improvements

12.4 Industrial Processes and Product Use (CRF Sector 2)

There is no chemical industry, no metal production, no production of F-gases and no mineral production in the Faroe Islands.

12.4.1 Overview of the sector

The only industrial processes leading to GHG emissions on the Faroe Islands is the use of f-gases and use of lubricants, paraffin wax and N_2O. Of the total emissions in 2021, 5.2 % are emissions related to Industrial Processes and Product Use.

Figure 12.13 shows the f-gas emissions from Industrial Processes and Product Use sector on the Faroe Islands 1990-2021. The increase in f-gas emissions, starting in 1996, is due to use of HFCs in refrigeration, as substitute for ODS. See also Figure 12.8.

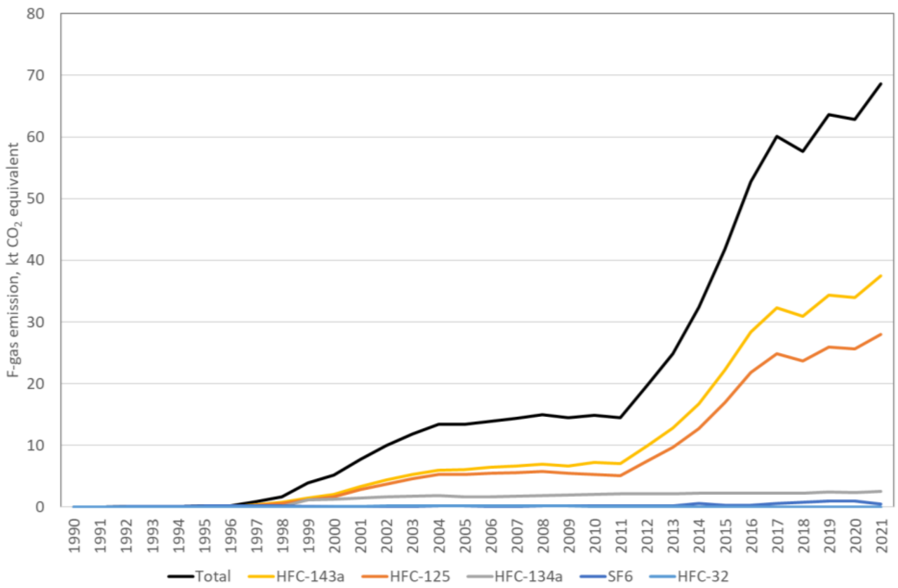

Figure 12.13 Emissions of f-gases, in CO_2 equivalents, Industrial processes and Product Use, 1990-2021.

Mineral Industry (2A)

There is no mineral production in the Faroe Islands, other than paving roads with asphalt, which does not lead to direct greenhouse gas emissions.

Chemical Industry (2B)

No chemical industry with GHG emission is in the Faroe Islands.

Metal Industry (2C)

No metal production industry is in the Faroe Islands.

Non-energy products from fuels and solvent use (2D)

CO_2 emissions from lubricant use and paraffin wax use have been estimated and reported. The activity data are from Statistics Faroe Islands and the methodologies used are the IPCC tier 1 methodologies. In the calculation is used the IPCC default net calorific values for lubricants and paraffin wax as well as the default carbon content. The IPCC default percentage of carbon oxidised during use (ODU) is 20 % and this value has been used.

Production of Halocarbons and SF_6 (2E)

There is no production of halocarbons and SF_6 in the Faroe Islands.

Product Uses as Substitutes for ODS (2F)

Of the total emissions of f-gases, nearly all (99 %) is HFC gasses used as substitutes for ozone depleting substance HCFC-22, used for refrigeration purposes domestically, commercially and in the industry. Four different types of HFCs are used on the Faroe Islands, mostly in HFC gas blends, such as HFC-507. Time series of the emission (tonnes) of the four different HFC for the years 1990, 2000, 2005, 2010-2021, are seen in Table 12.4.

The HFC emissions are reported with the following assumptions:

- Domestic refrigeration is use in freezers and refrigerators.
- Commercial refrigeration is use in land-based units.
- Industrial refrigeration is use on ships.
- Mobile air conditioning is use in cars, buses, and trucks.

Table 12.4 Emissions of HFCs from refrigeration and air conditioning, 1990, 2000, 2005, 2010-2021 (tonnes).

	1990	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Domestic refrigeration															
HFC-134a	0,00	0,003	0,007	0,012	0,012	0,012	0,012	0,012	0,011	0,010	0,010	0,009	0.008	0.007	0.006
Commercial refrigeration															
HFC-134a	0,00	0,04	0,14	0,15	0,19	0,17	0,19	0,25	0,28	0,26	0,23	0,20	0,23	0,23	0,23
HFC-32	0,00	0,09	0,32	0,08	0,08	0,08	0,08	0,07	0,06	0,04	0,03	0,02	0,02	0,03	0,04
HFC-125	0,00	0,15	0,51	0,55	0,58	0,68	0,77	0,87	1,00	1,11	1,19	1,23	1,42	1,37	1,32
HFC-143a	0,00	0,06	0,19	0,51	0,56	0,67	0,77	0,89	1,04	1,15	1,25	1,32	1,56	1,50	1,43
Industrial refrigeration															
HFC-134a	0,00	0,16	0,43	0,35	0,35	0,29	0,30	0,28	0,27	0,25	0,30	0,31	0,38	0,35	0,51
HFC-125	0,00	0,34	1,00	0,96	0,87	1,43	1,97	2,77	3,84	5,11	5,91	5,53	5,97	5,94	6,67
HFC-143a	0,00	0,40	1,17	1,10	0,99	1,53	2,08	2,85	3,93	5,19	5,98	5,58	6,11	6,09	6,96
Mobile Air Conditioning															
HFC-134a	0,00	0,70	0,59	0,94	0,97	1,00	1,02	1,03	1,04	1,04	1,05	1,08	1,08	1,06	1,06

Other Product Manufacture and Use (2G)

Figure 12.14 shows the emissions of SF_6 from Electrical Equipment on the Faroe Islands 1990-2021.

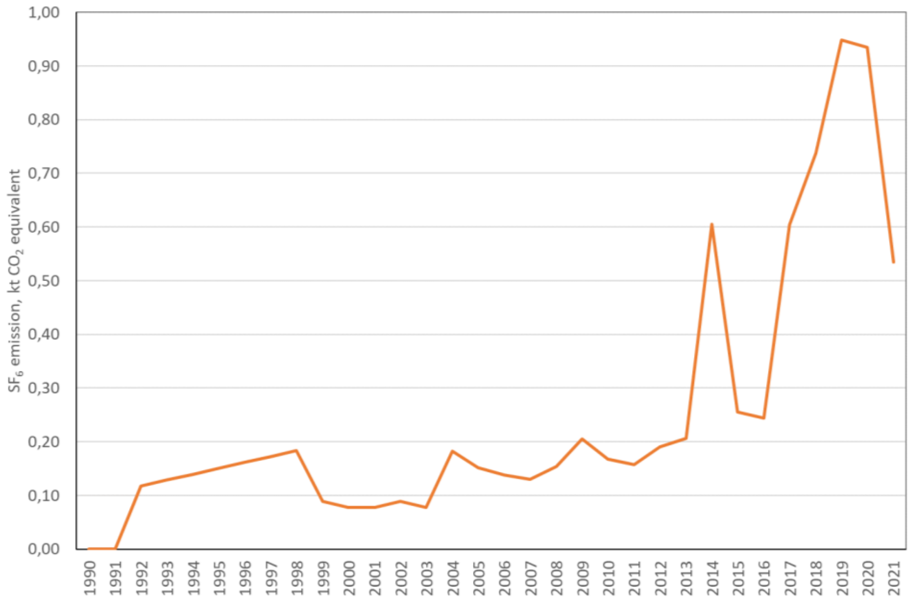

Figure 12.14 Emission of SF_6, in CO_2 equivalents, time series for Electrical Equipment, 1990-2021.

In 2014, a significant increase was in the actual emission of SF_6. The increase was due to establishment of a new windmill park in Húsahagi, just outside the capital Tórshavn, owned by SEV, the public electricity company. The high usage in 2017 was due to establishment of a new switchyard "innan Eið", near Fuglafjørð.

In addition to the SF_6, N_2O emissions are estimated based on the imported amounts. There is no production of N_2O in the Faroe Islands. In accordance with the 2006 IPCC Guidelines, an emission factor of 1 is assumed. All emissions are reported under 2G3a Medical applications as this is considered the main (perhaps only) use.

12.4.2 Uncertainty

Estimations of the uncertainties for emission calculations in the sector Industrial processes and Product Use have not been done.

12.4.3 Recalculations and improvements

See 12.9 Recalculations and improvements

12.5 Agriculture (CRF Sector 3)

6.5 % of the total GHG emissions on the Faroe Islands in 2021 are due to agriculture. The sources are primarily cattle and sheep. The agricultural sector at the Faroe Islands is a relatively small contributor to the total greenhouse gas emission. In the Faroe Islands, only 5-6% of the total area is cultivated and less than 1% of Faroese are today full-time farmers. However, sheep-keeping and hay cultivation is common in the countryside.

Figure 12.15 shows the total emissions from the Agriculture sector. The emissions are very constant. The peak in 1994 will be further investigated for the next submission. There seems to be an inconsistency in the grassland area causing the peak in emissions from crop residues.

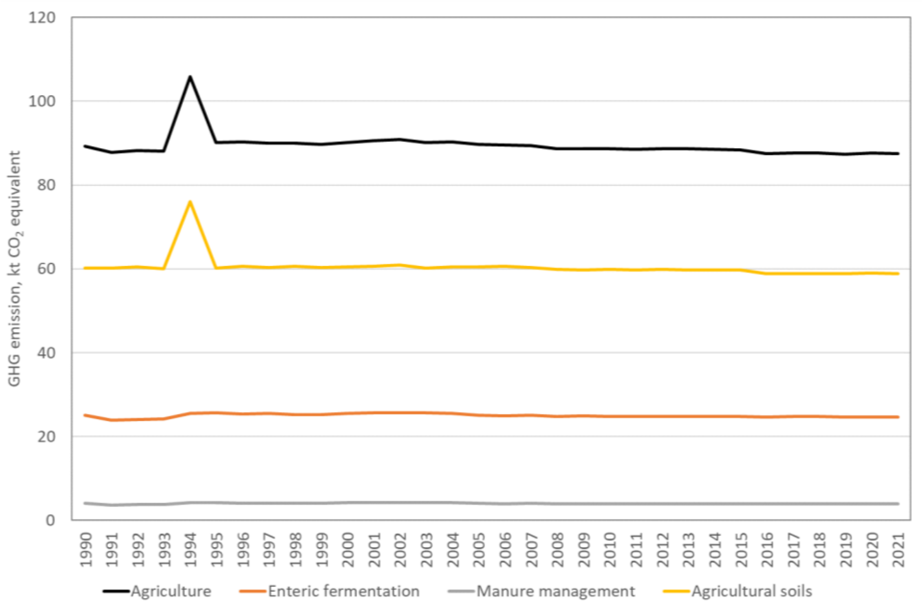

Figure 12.15 GHG emissions in CO_2 equivalents, in the Agriculture sector, 1990-2021.

12.5.1 Overview

The emission of greenhouse gases from agricultural activities includes:

- CH_4 emission from manure management and enteric fermentation.
- N_2O emission from manure management and agricultural soil (direct and indirect N_2O emission from managed soils).

12.5.2 CH_4 and N_2O emission from the livestock production

Number of animals

There are no official requirements for registration of the individual sheep, and there is no slaughterhouse at the Faroes Islands, which is a challenge for estimation of the population. The sheep management is not driven by an intensively production, thus the sheep farmers slaughter their sheep themselves and the products is used by the farmers themselves or their family members, and only a small part of the meat may be sold within the Faroes (Austrheim et al., 2008).

In the Faroese national emission inventory, the number of sheep is estimated to approximately 80,000 for all years 1990 – 2021; approximately 75,000 mother sheep and 5,000 rams. Furthermore, the Agricultural Agency estimated the number of lambs to 52,500 based on the assumption that each mother sheep in average produce 0.7 lamb, see Table 12.5.

In this year's reporting, lamb as well as rams are not included.

Table 12.5 Number of sheep in the Faroe Islands.

	Winther	Spring	Summer	Autumn
Ewe/Áseyður/Moderfår	75 000	75 000	75 000	75 000
Rams/Young rams Veðrar/veðragjólingar Væddere/ Unge væddere	2 500	2 500	2 500	2 500
Lamb in the autumn and sheep that grazes on grass-covered terraces in bird cliffs Heystlomb, skoraseyður	2 500	2 500	2 500	2 500

Efterårsfår og får, som græsser på terrasser i fuglebjerge				
Lamb/Lomb/Lam	-	-	52 500	52 500
Inside in sheephouse Inni í fjósi, seyðahúsi / Inde i stald, fårehus	2 500	6 000	-	-
In the outfield / Haga / I udmarken/	77 500	74 000	132 500	132 500
Sheep in total Seyður í alt / Får i alt	80 000	80 000	132 500	132 500

Reference: Jens Ivan í Gerðinum, The Agricultural Agency of the Faroe Islands.

The number of dairy cattle and non-dairy cattle is based on data from Statistics of Faroe Islands. The national emission inventory distinguishes between dairy cattle and non-dairy cattle (all other cattle), see Table 12.6.

Table 12.6 Number of cattle at the Faroe Islands, 1990-2021.

IPCC code	Livestock category, no. of cattle	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
3A1	Total cattle	2.070	2.322	2.306	2.135	1.990	1.872	1.826	1.895	1.873	1.801	1837	1837
3A1a	Dairy cattle	1.040	1.206	1.101	1.048	919	1.113	1.116	1.104	1.115	1.116	1148	1147
3A1b	Non-Dairy	1.030	1.116	1.205	1.087	1.071	759	710	791	758	685	689	690

Reference: Hagstova Føroya, Statistics of Faroe Islands.

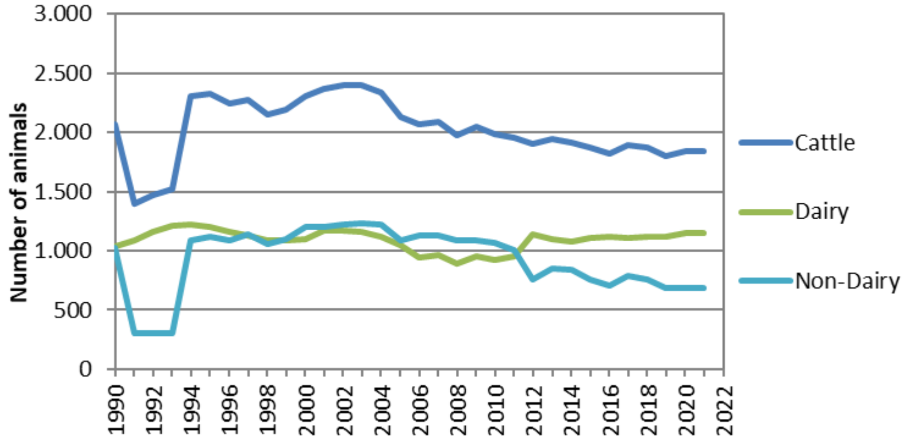

Figure 12.16 Number of cattle (dairy and non-dairy), time series for 1990-2021.

Figure 12.16 shows the number of cattle in the Faroe Islands from 1990 to 2021.

12.5.3 CH_4 emission from Enteric Fermentation (CRF Sector 3A)

The calculation of CH_4 production from the animals' digestive process is based on the total gross energy intake (GE) in feed and the CH_4 conversion factor (Ym), which is the fraction of gross energy in feed converted to CH_4 (see IPCC 2006 calculation equation below).

EQUATION 10.21
CH_4 EMISSION FACTORS FOR ENTERIC FERMENTATION FROM A LIVESTOCK CATEGORY

$$EF = \left[\frac{GE \bullet \left(\frac{Y_m}{100} \right) \bullet 365}{55.65} \right]$$

Where:

EF = emission factor, kg CH_4 head^{-1} yr^{-1}

GE = gross energy intake, MJ head^{-1} day^{-1}

Y_m = methane conversion factor, per cent of gross energy in feed converted to methane

The factor 55.65 (MJ/kg CH_4) is the energy content of methane

Table 12.7 lists the GE factors used in the calculations. The value for dairy cattle, 215 is based on the mean production of 30 kg milk and 600 kg dairy cow (McDonald et al.). MJ/animal/day is from the Agriculture Agency of the Faroe Islands. Since the GE for non-dairy cattle and sheep was not complete this year, the GE for these has been estimated by scaling the value relative to the corresponding Icelandic values[1]. In Table 12.7 GE for cattle, where the calculated values are in italic.

Table 12.7 GE values for Cattle and sheep (MJ/head/day).

	Dairy cattle	Non-dairy cattle	Sheep
Faroe Islands	215^R	*151*^{R}	*22*^{R}
Iceland	250	175	25

(R) Recalculated

[1] ICELAND National Inventory Report. https://unfccc.int/documents/273420.

Table 12.8 lists the Ym factor recommend in IPCC 2006.

Table 12.8 Methane conversion factor – Ym.

Livestock category	Ym, %
Dairy cattle	6.5
Non-Dairy	6.5
Mature sheep	6.5
Lamb	4.5

Reference: IPCC 2006, Table 10.12 and 10.13.

Figure 12.17 shows emissions of CH_4 from enteric fermentation in livestock on the Faroe Islands, 1990-2021.

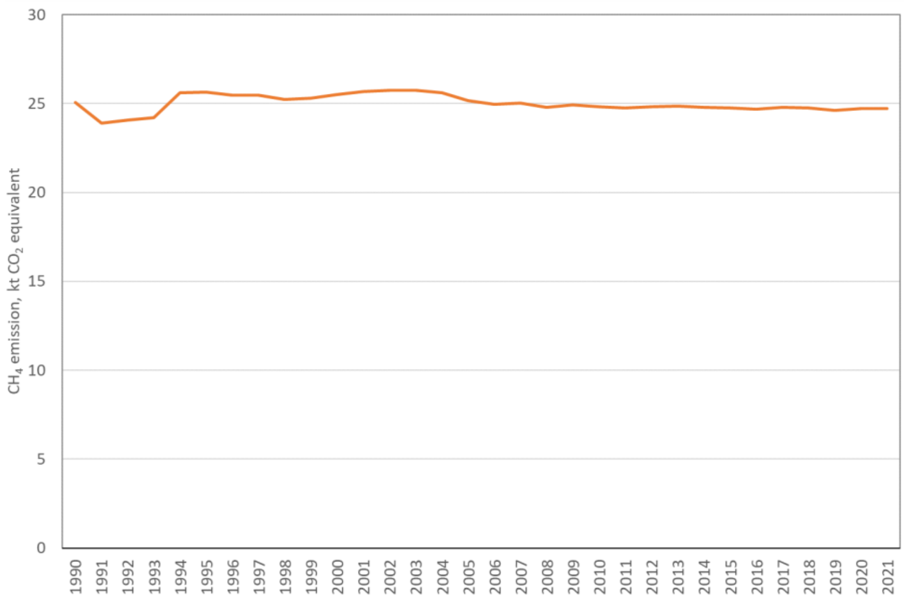

Figure 12.17 CH_4 emissions in CO_2 equivalents from enteric fermentation, 1990-2021.

12.5.4 CH_4 emission from Manure Management (CRF Sector 3B)

To calculate the CH_4 emission from manure management, information is needed about:

- The content of volatile solid (VS) in manure
- Allocation on manure management system

Based on this information an average CH_4 emission per animal per year has been estimated. See IPCC 2006 calculation equation below:

EQUATION 10.23
CH_4 EMISSION FACTOR FROM MANURE MANAGEMENT

$$EF_{(T)} = \left(VS_{(T)} \bullet 365\right) \bullet \left[B_{o(T)} \bullet 0.67\, kg/m^3 \bullet \sum_{S,k} \frac{MCF_{S,k}}{100} \bullet MS_{(T,S,k)} \right]$$

Where:

$EF_{(T)}$ = annual CH_4 emission factor for livestock category T, kg CH_4 animal^{-1} yr^{-1}

$VS_{(T)}$ = daily volatile solid excreted for livestock category T, kg dry matter animal^{-1} day^{-1}

365 = basis for calculating annual VS production, days yr^{-1}

$B_{o(T)}$ = maximum methane producing capacity for manure produced by livestock category T, m^3 CH_4 kg^{-1} of VS excreted

0.67 = conversion factor of m^3 CH_4 to kilograms CH_4

$MCF_{(S,k)}$ = methane conversion factors for each manure management system S by climate region k, %

$MS_{(T,S,k)}$ = fraction of livestock category T's manure handled using manure management system S in climate region k, dimensionless

The content of volatile solid (VS) in manure has been calculated, see the IPCC equation below.

EQUATION 10.24
VOLATILE SOLID EXCRETION RATES

$$VS = \left[GE \bullet \left(1 - \frac{DE\%}{100}\right) + (UE \bullet GE) \right] \bullet \left[\left(\frac{1 - ASH}{18.45} \right) \right]$$

Where:

VS = volatile solid excretion per day on a dry-organic matter basis, kg VS day^{-1}

GE = gross energy intake, MJ day^{-1}

DE% = digestibility of the feed in percent (e.g. 60%)

(UE • GE) = urinary energy expressed as fraction of GE. Typically 0.04GE can be considered urinary energy excretion by most ruminants (reduce to 0.02 for ruminants fed with 85% or more grain in the diet or for swine). Use country-specific values where available.

ASH = the ash content of manure calculated as a fraction of the dry matter feed intake (e.g., 0.08 for cattle). Use country-specific values where available.

18.45 = conversion factor for dietary GE per kg of dry matter (MJ kg^{-1}). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

Table 12.9 shows the values used in the calculation of VS. For DE is used IPCC default, 70% for dairy cattle and 60% for non-dairy cattle, mother sheep and lamb. Furthermore, IPCC default is used for UE, 0.04 and ASH content, 8% for all animal categories.

Table 12.9 Values used to estimate the volatile solid (VS) in manure.

	GE	DE - Digestibility	UE - urinary energy	ASH	VS
Livestock category	MJ/head/yr	%		%	kg dry matter /head/day
Dairy cattle	215^{R}	70	0,04	8	3.6^{R}
Non-Dairy	151^{R}	60	0,04	8	3.3^{R}
Mature sheep	22^{R}	60	0,04	8	0.5^{R}
Lamb	(*)	60	0,04	8	(*)

(*) Lamb will be included in next year's reporting.

(R) Recalculated

The estimate for VS is used as input data for calculation of the CH_4 emission factor from manure management. The emission is depending on the manure type, which must be reflected, thus emission from liquid manure is higher compared to solid manure.

Table 12.10 presents the parameters used in the calculations of the $EF_{(T)}$. The values for the methane conversion factor (MCF) and the maximum methane producing capacity (B_o) are based on the IPCC default. The allocation of manure management system is based on information from the Faroese Agriculture Agency.

Table 12.10 Parameters used to calculate the average CH_4 emission per animal (Dairy, Non-Dairy and Sheep) per year.

	MMS	VS	B_0	MCF	CH_4 EF
Dairy cattle	% allocation	kg dry matter/ head/day	m^3/kg CH_4/ VS excreted	%	kg CH_4/ head/yr
Total	100				
Liquid/slurry	*17*	*3.6*[R]	0.24	17	36.4
Solid storage	*0*	*3.6*[R]	0.24	17[R]	36.4
Dry lot	*0*	*3.6*[R]	0.24	1	2.1
Pasture	*0*	*3.6*[R]	0.24	1	2.1
Daily spread	*0*	*3.6*[R]	0.24	.,1	0.2
Digester	*83*	*3.6*[R]	0.24	10	21.4
Burned for fuel	*0*	*3.6*[R]	0.24	10	21.4
Other	*0*	*3.6*[R]	0.24	1	2.1
CH_4 weighted EF, kg CH_4/head/yr					23.9

	MMS	VS	B_0	MCF	CH_4 EF
Non-Dairy cattle	% allocation	kg dry matter/ head/day	m^3/kg CH_4/ VS excreted	%	kg CH_4/ head/yr
Total	100				
Liquid/slurry	*17*	*3.3*[R]	0.18	17	24.8
Solid storage	*0*	*3.3*[R]	0.18	17[R]	24.8
Dry lot	*0*	*3.3*[R]	0.18	1	1.5
Pasture	*0*	*3.3*[R]	0.18	1	1.5
Daily spread	*0*	*3.3*[R]	0.18	0.1	0.1
Digester	*83*	*3.3*[R]	0.18	10	14.6
Burned for fuel	*0*	*3.3*[R]	0.18	10	14.6
Other	*0*	*3.3*[R]	0.18	1	1.5
CH_4 weighted EF, kg CH_4/head/yr					16.3

	MMS	VS	B_0	MCF	CH_4 EF
Mature sheep	% allocation	kg dry matter/ head/day	m^3/kg CH_4/ VS excreted	%	kg CH_4/ head/yr
Total	100				
Liquid/slurry	*0*	*0.5*[R]	0.19	17	3.8
Solid storage	*20*	*0.5*[R]	0.19	17[R]	3.8
Dry lot	*0*	*0.5*[R]	0.19	1	0.2
Pasture	*80*	*0.5*[R]	0.19	1	0.2
Daily spread	*0*	*0.5*[R]	0.19	0.1	0.02
Digester	*0*	*0.5*[R]	0.19	10	2.2
Burned for fuel	*0*	*0.5*[R]	0.19	10	2.2
Other	*0*	*0.5*[R]	0.19	1	0.2
CH_4 weighted EF, kg CH_4/head/yr					0.9

(R) Recalculated.

Figure 12.18 shows emissions of N_2O and CH_4 from manure management on the Faroe Islands, 1990-2021, in CO_2 eqv. The emissions are very stable. The total yearly emission in recent years is around 4,000 tonnes of CO_2 eqv. The total GHG emission is comprised of roughly half CH_4 and half N_2O.

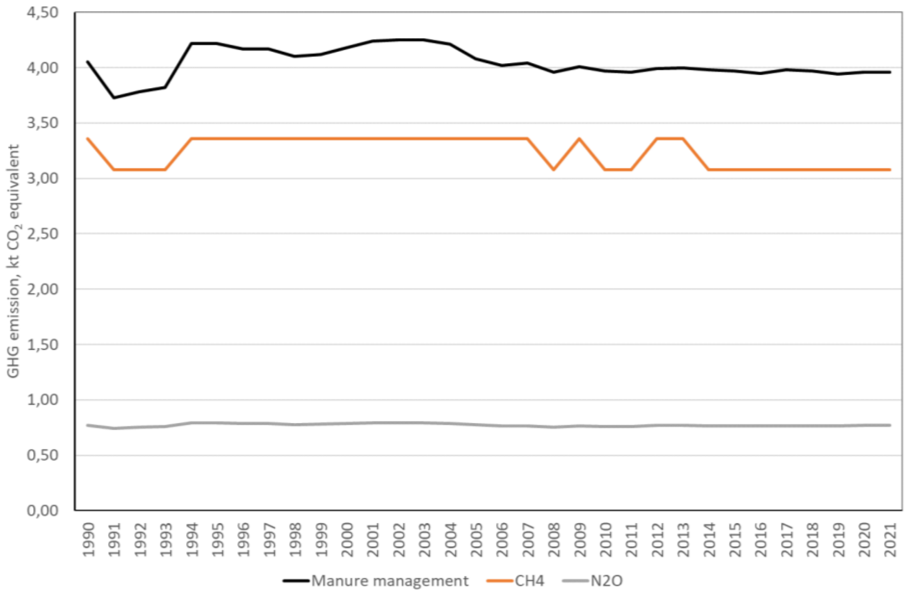

Figure 12.18 N_2O and CH_4 emission in CO_2 eqv. from Manure management, time series 1990-2021.

12.5.5 N_2O emission from Manure Management (CRF Sector 3B2)

The N_2O emission from manure management is divided into the direct emission and the indirect emission. The direct emission is depended on the manure type, while the indirect emission is from the volatilization of NH_3 and NO_2 (housing and storage), which also leads to N_2O emission. The emissions needed to have information on the animals N-excretion in manure and allocation of manure management system.

Conversion of N_2O–N emissions to N_2O emissions for reporting purposes is performed by using the following equation: $N_2O = N_2O\text{–}N * 44/28$.

Direct N_2O emission

The animal N-excretion is calculated based on the IPCC 2006 equation 10.30 (see below).

EQUATION 10.30
ANNUAL N EXCRETION RATES

$$Nex_{(T)} = N_{rate(T)} \bullet \frac{TAM}{1000} \bullet 365$$

Where:

$Nex_{(T)}$ = annual N excretion for livestock category *T*, kg N animal^{-1} yr^{-1}

$N_{rate(T)}$ = default N excretion rate, kg N (1000 kg animal mass)$^{-1}$ day^{-1} (see Table 10.19)

$TAM_{(T)}$ = typical animal mass for livestock category *T*, kg animal^{-1}

Information on typical animal mass for cattle and sheep is from Faroese Agricultural Agency. The values are: Dairy Cattle: 650 kg. Non-dairy cattle 400 kg and sheep 45 kg. The values for N-rate (kg N exc. per 1000 kg animal weight) refer to IPCC 2006 default (Table 10.19) for Western Europe. The weighted N-excretion for mature sheep and lamb is 10 kg N/head/yr, which match the average N-exr. for sheep for Iceland, Norway, and Finland. See

Table 12.11

Table 12.11 Variable used for estimation the N-excretion.

	N-rate	TAM	N-excretion
	Kg N-ex/1000 kg animal weight/day	Animal weight	Kg N-ex/head/yr
Dairy Cattle	0.48	650	114
Non-dairy cattle	0.33	400	48
Mature sheep	0.85	45	14

Besides the animals N-excretion, the direct N_2O emission depends on the allocation of manure management system, because the emissions factor varies between the manure types. Se IPCC equation below.

EQUATION 10.25
DIRECT N_2O EMISSIONS FROM MANURE MANAGEMENT

$$N_2O_{D(mm)} = \left[\sum_S \left[\sum_T \left(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)}\right)\right] \bullet EF_{3(S)}\right] \bullet \frac{44}{28}$$

Where:

$N_2O_{D(mm)}$ = direct N_2O emissions from Manure Management in the country, kg N_2O yr^{-1}

$N_{(T)}$ = number of head of livestock species/category T in the country

$Nex_{(T)}$ = annual average N excretion per head of species/category T in the country, kg N $animal^{-1}$ yr^{-1}

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the country, dimensionless

$EF_{3(S)}$ = emission factor for direct N_2O emissions from manure management system S in the country, kg N_2O-N/kg N in manure management system S

S = manure management system

T = species/category of livestock

44/28 = conversion of $(N_2O\text{-}N)_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions

The distribution on different manure management systems for cattle and sheep are provided by the Agriculture Agency of the Faroe Islands.

The N_2O emission factor for each manure type is based on the IPCC 2006 default, Table 10.21 and Table 11.1 for grassing animals. Note that N_2O for animal on grass is reported in CRF Table 3D (agricultural soils).

Indirect N_2O emission (housing + storage)

The indirect N_2O emission depends on the amount of N, which are volatilities as NH_3 and NO_2- see IPCC equation below. The volatilization is estimated based on NH_3 and NO_2 emission factor from the EMEP Guidebook 2019 Table 3.2 and Table 3.3, which distinguish between liquid and solid manure.

EQUATION 10.27
INDIRECT N_2O EMISSIONS DUE TO VOLATILISATION OF N FROM MANURE MANAGEMENT

$$N_2O_{G(mm)} = \left(N_{volatilization-MMS} \bullet EF_4\right) \bullet \frac{44}{28}$$

Where:

$N_2O_{G(mm)}$ = indirect N_2O emissions due to volatilization of N from Manure Management in the country, kg N_2O yr^{-1}

EF_4 = emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N_2O-N (kg NH_3-N + NO_x-N volatilised$)^{-1}$; default value is 0.01 kg N_2O-N (kg NH_3-N + NO_x-N volatilised$)^{-1}$, given in Chapter 11, Table 11.3

Figure 12.18 shows emissions of N_2O (and CH_4) from manure management on the Faroe Islands, 1990-2021, in CO_2 eqv. The emission is very constant from 1990-2021.

12.5.6 N_2O emission from Agricultural Soils (CRF Sector 3D)

Figure 12.19 shows the N_2O emissions from agricultural soil. Since the number of animals is constant, the emissions are constant also. The peak in 1994 will be further investigated for the next submission. There seems to be an inconsistency in the grassland area causing the peak in emissions from crop residues.

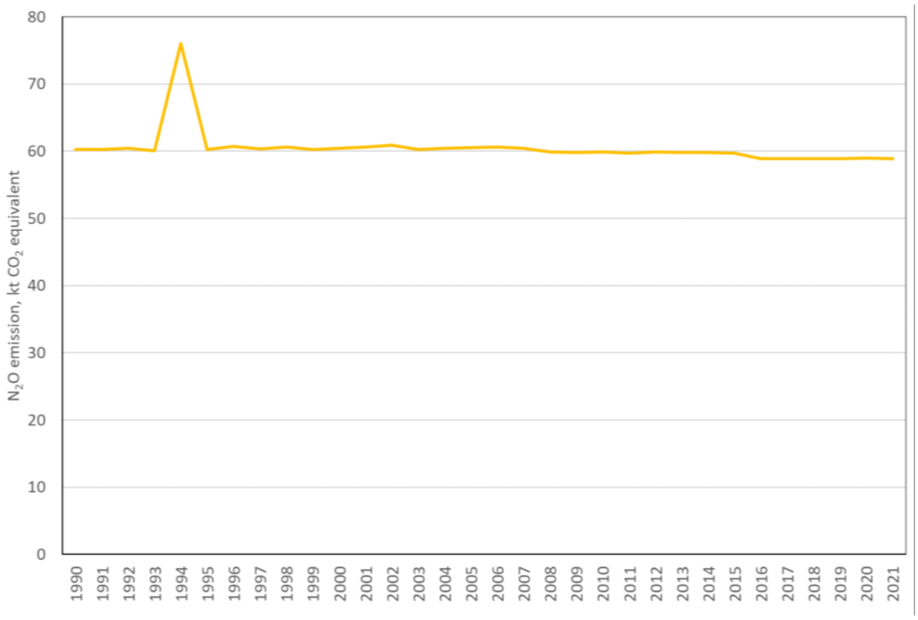

Figure 12.19 N_2O emissions (tonnes CO_2 eqv.) from Agricultural Soils, time series 1990-2021.

All N applied to the agricultural soil will leads to emission of N_2O. The N_2O emission from cultivation of agricultural soils is divided in to two groups, direct and indirect emission. The direct emissions include sources which are related directly to nitrogen applied on soil as fertilized during inorganic fertilizer or animal manure applied or during grassing, this also includes N from N turnover from crop residues. The indirect emission includes N_2O emission from the emission sources where a volatilization of NH_3 and NO_2 take place (atmospheric deposition). Furthermore, a N_2O emission also occurs from leaching of N to the groundwater, water streams and the sea.

12.5.7 Direct N_2O emissions

Inorganic fertilizers

Data on import of NPK fertilizer to the Faroe Islands are used to calculate the N_2O emission from use of inorganic fertilizer. Most of the fertilizers are of the type "19-3-13" i.e., with 19 % N. See Table 12.12. The N_2O emission factor 0.01 kg N_2O-N/kg N applied is the default value from the IPCC 2006 Table 11.1.

Table 12.12 Import of inorganic fertilizers to the Faroe Islands (kt), 1990, 2000, 2010-2021.

	1990	2000	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Import (kt)	1.097	1.373	1.005	869	966	883	942	856	12	4	2	8	117	10
19 % N (kt)	208	261	191	165	184	168	179	163	2	1	0	1	22	2

The import numbers will be revised in next year's reporting.

The emissions of NH_3 and NO_2 are calculated because these values are part of the calculation of atmospheric deposition. These emission factors are based on EMEP Guidebook 3D 2019 Table 3.1, corresponding to 0.05 kg NH_3/kg N applied and 0.04 kg NO_2/kg N applied and converted to 0.04 kg NH_3-N/kg N applied and 0.01 kg NO_2-N/kg N applied.

Organic fertilizers

This source includes products used for fertilizes the soil, e.g., animal manure or other products with nitrogen content.

The amount of N applied in form of animal depends on the livestock category. The N applied to agricultural soils are N excreted minus the emission of NH_3, NO_2 and N_2O, which has taken place in housing and storage. The N_2O emission factor is 0.01 kg N_2O-N/kg N applied based on the IPCC default (IPCC 2006, Table 11.1). The allocation of manure management system (MMS) in the Faroe Islands is in **Error! Reference source not found.**. The emission factor for NH_3 is based on the EMEP GB 3B Table 3.2 and emission factor for NO_2 is based on EMEP GB 3B Table 3.3.

Sewage sludge applied to soils and other organic fertilizers applied to soils

In the Faroe Islands, the soil is sometimes in certain areas fertilized with salmon ensilage and with biofertilizers from the new biogas plant Förka. The production of organic matter from the biogas plant in 2020 and 2021 is in Table 12.13. Since manure is included in the calculation of N_2O from Manure Management, only 15 % are included in other organic fertilizers applied to soils.

Input data is the amount of N applied to the soil. The N_2O emission factor is 0.01 kg N_2O-N/kg N applied based on the IPCC default (IPCC 2006, Table 11.1).

Table 12.13 Type and amount of organic matter delivered to the biogas plant Förka in 2020-2021.

Type of organic matter	2020		2021	
	m^3	%	m^3	%
Manure	18,170	85	25,163	64
Ensilage, salmon	3,165	15	13,724	35
Excrements from salmon hatchery	37	0,2	0	0
Other – fish	80	0,4	144	0,4
Total	21,452	100	21,452	100

The N-content in the biofertilizers, which is used to calculate the amount of N, is 5.2 kg/t. Salmon ensilage is not reported this year, due to lack of data on N-content. Sewage sludge is not used as fertilizers on the Faroe Islands.

The emission of NH_3 and NO_2 from applied organic fertilizer are estimated and included in "atmospheric deposition". The emission factor for NH_3 and NO_2 is based on default values from the EMEP Guidebook 2019 3D, Table 3.1.

Urine and dung deposited by grazing animals

The N_2O emission from grassing animals is estimated as the total N excreted multiply with the default N_2O emission factor, which is 0.02 kg N_2O-N/kg N excreted for cattle and 0.01 N_2O-N/kg N excreted for sheep (IPCC Table 11.1).

The emission of NH_3 and NO_2 from grassing animal is included in emission source "Atmospheric deposition" (3.D.b.1). The NH_3 emission factor is default values from the EMEP guidebook 2019 3B Table 3.2 and the NO_2 emission factor is based on EMEP GB 2019 3D Table 3.1

Mineralization/immobilization associated with loss/gain of soil organic matter

The N_2O emission from the mineralization is considered as a relatively small emission source, because the Faroe Island has a limited cultivated area, only some potatoes and grassing fields. The emissions will be considered for next year's reporting.

Crop residues

The turnover from nitrogen in crop residues, from roots and leaf, will over time lead to a N_2O emission, and the emission depends on the N content in the crop residue. Due to Búnaðarstovan (BST) the total agricultural area is estimated to 97,800 hectares, mostly grassland and few potatoes, between 80 – 116 hectares (FAO Statistics). The calculation of N_2O emission from crop residues is based on the 2006 IPCC Guidelines methodology, where default values are given for the N content per dry matter, and the fraction of the dry matter content between the crop residue below and above ground (IPCC 2006, Table 11.2). The yield for potato and grass in the Faroe Islands is in Table 12.14.

Table 12.14 Data for harvest (kg/ha), Dry matter fraction of harvest product (kg dry matter/kg harvest) and harvest (kg dry matter/ha).

	Above ground residue		
2021 - Total N in residue, mill. kg N	Harvest	Dry matter fraction of harvest product	Harvest
	kg/ha	*kg dm/kg harvest*	*kg dm/ha*
Potato	40,000	0.20	8,000
Perennial grasses	22,000	0.22	4,840

Potatoes

With a dry matter (dm) content of 0.20 kg dm/kg harvest, the kg dm content is estimated to approximately 8.000 kg dm/hectare. Calculation by the IPPC methodology and values, this leads to an N content by 40 kg N per hectare potato.

Perennial grasses

For grassland is assumed a yield by 4.840 kg dm per hectare. Calculation by the IPPC methodology and values, this leads to a N content by 82 kg N per hectare grassland.

The default N_2O emission factor at 0.01 kg N_2O-N per kg N in crop residues is used, based on IPCC default (IPCC Table 11.1).

Table 12.15 The agricultural area.

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Agricultural area. cropland + grassland	98 345	98 225	98 121	98 053	97 916	97 831	97 816	97 811	97 811	97 810	97 810	97 810
Potatoes, ha	106	109	107	102	100	97	89	85	82	80	80	80
Grassland, ha	98 239	98 116	98 014	97 951	97 816	97 734	97 727	97 726	97 729	97 730	97 730	97 730

Reference: Total agricultural area and potato and grass: Búnaðarstovan.

12.5.8 Indirect N_2O emissions

Atmospheric deposition

Volatilization of NH_3 and NO_2 and the deposition of these gases and products onto soils and the surface of lakes and other water bodies cause N_2O emission. Emission of N_2O is calculated based on all:

- NH_3 emission sources; manure applied to soil, inorganic N fertilizer, and other organic matter used as fertilizer and grazing animals.
- NO_2 emission sources; manure applied to soil, inorganic N fertilizer, and other organic matter fertilizer.

The N_2O emission factor, 0.01 kg N_2O-N per kg NH_3 and NO_2 volatilized is based on the IPPC default (IPCC 2006, Table 11.3).

Table 12.16 Calculation of N_2O emission from atmospheric deposition.

kg N volatilise as NH_3-N and NO_2-N	1990	1995	2000	2005	2010	2015	2020	2021
Inorganic N fertilizers	11,119	11,040	13,916	14,942	10,187	8,675	1,186	105
Animal manure applied to soils (application)	56,065	58,769	57,734	56,444	54,583	55,801	55,956	55,947
Urine and dung deposited by grazing animals	70,104	70,104	70,104	70,104	70,104	70,104	70,104	70,104
Sewage sludge applied to soils	0	0	0	0	0	0	0	0
Other organic fertiliser	0	0	0	0	0	0	1	5
Total kg N volatilise as NH_3-N and NO_2-N	137,288	139,913	141,754	141,490	134,873	134,579	127,246	126,161
N_2O EF, kg N_2O-N/kg NH_3–N + NO_X–N volatilised*	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Emission, kt N_2O	0.0021	0.0022	0.0022	0.0022	0.0021	0.0021	0.0020	0.0020

Nitrogen leaching and run-off

The emission of N_2O from N-leaching and runoff is calculated based on the total amount of N applied to the agricultural soils, multiplied with the share N amount which expects to be lost to leaching and runoff, multiplied with the N_2O emission factor. The N applied is the sum of all sources contribute to N application as shown in

Table 12.17. The IPCC default for FRacLeach, which is 0.3 kg N/ kg N applied is used (IPCC Table 11.3). The IPCC default is also used regarding the N_2O emission factor, 0.0075 kg N_2O–N/kg N leaching/runoff (IPCC Table 11.3).

Table 12.17 The calculation of N_2O emission from N-leaching and runoff, 2020-2021.

Kg N applied	2020	2021
N applied from inorganic fertilizer	22,231	1,970
N applied from animal manure applied	1,822,624	1,822,570
N applied from sewage sludge	0	0
N applied from other organic fertilizer	6,867	63
N applied from animal on grass	1,481,146	1,481,146
N applied from crop residue	8,034,955	8,034,930
N applied from mineralization	0	0
N applied total	11,360,964	11,340,679
FracLeach, kg N/ kg N applied (IPCC default)	0.3	0.3
N-leached and run-off	3,408,289	3402,204
kg N_2O–N/kg N leaching/runoff (IPCC default)	0.0075	0.0075
Emission, kt N_2O	0.4	0.4

12.5.9 Uncertainty

The uncertainties have not been calculated.

12.5.10 Recalculations and improvements

See 12.9 Recalculations and improvements

12.5.11 References

Animal Nutrition, eight edition, 2022. McDonald, P. Edwards, R. A. Greenhalgh, J. F. D. Morgan, C. A. Sinclair, L. A. Wilkinson, R. G.

12.6 Land Use, Land-Use Change and Forestry (CRF Sector 4)

The Faroe Islands are located in the Atlantic Ocean between Great Britain and Iceland with the Capitol, Tórshavn on 62.01°N and -6.87°E. The Faroe Islands consist of 18 islands, in total 1394 km² (app. 36*36 km²). The islands are rocky where perennial grass is the dominating plant cover. The highest point, Slættaratindur, translated as “flat summit”, is the highest mountain in the Faroe Islands, towering at 880 meters.

The climate is cold and wet with an annual average temperature of 7 °C (1991-2020). Due to its position in the Atlantic Ocean and the Gulf Stream there is only a small variation in the temperatures between winter and summer (DMI, 2021). The mean winter temperature is around 4 °C and the mean summer temperature is around 11 °C, Figure 12.20, which according to the IPCC 2006 Guidelines classification is “Cool Temperate Moist.” The annual precipitation is high and around 1400 mm yr-1 with most rain in November to January.

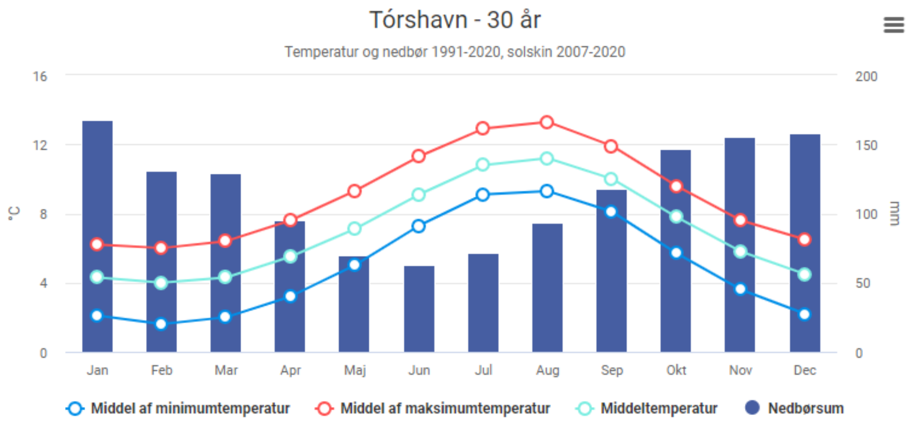

Figure 12.20 Average climate data for Tórshavn on the Faroe Islands, 1991-2020 (DMI, 2021, https://www.dmi.dk/vejrarkiv/normaler-faroerne/

Due to the rather cold climate and grazing sheep (see the agricultural sector, 3.A) perennial wooden plants seldom occur. Minor areas with primarily pine (*Pinus spp*.) can be found in plantations/parks, which often also are protected areas. To facilitate and protect wooden crops/afforestation, the Faroe Islands implemented protection of some areas with fencing and include these in the legislation (in Faroese, "Skógfriðing."). The mild climate facilitate year around grazing in the outfield. At the same time ase the sheep are excluded from designated high value grassland areas (indmark, bøur). During the spring period and while the sheep give birth to lambs, the sheep are allowed to graze in these more fertile areas which cover around 6 % of the total Grassland area. Grassland or "hagi" in Faroese, where sheep are roaming, is unfertilized and with medium to sparse grass vegetation where the rocky underground is approaching the surface, see Figure 12.22.

12.6.1 Land Use Matrix

The land use matrix is based on the best available data. The Faroe Islands has been grazed for the last 1000 years and annual agricultural crops is limited due to the low temperatures. Therefore, the dominating land use is Grassland with only minor changes over time and mainly to Settlement such as houses and infrastructures. Over the past decades, more permanent grassland has been established to improve the grass quality, but although limited.

A new National Forest Definition has been defined for the purpose of the reporting to UNFCCC.

A GIS analysis was performed in 2021 (Umhvørvisstovan, 2021) to establish a classification of the six IPCC land use classes defined as per 31. December 2020. In 2016 topographic vector data was collected with an intended chart scale of 1:20 000. The topographic dataset was captured using mainly satellite images (Pleiades) and orthophotos. However, some national source data was included, e.g., roads and buildings. The data was coded according to the Multinational Geospatial Co-production Program Technical Reference Documentation 4.3, with some additions. When tasked to complete the land use matrix, the topographic dataset was considered to be the best available source.

In order to fit the classification of the land use matrix, some feature classes of the topographic dataset had to be grouped, e.g., for Wetlands and Other land, and all included land use features needed to be managed logically and geometrically. Buffers had to be created for points and line features and the new area geometry subtracted from the underlying and overlapping land use coverage. This procedure was performed using ESRI ArcGIS software.

Wetlands

Natural Pool Point Features were estimated to have a radius of 4 m. River Line Features and Ditch Line Features were given buffers according to the width encoded for each feature.

Other land

Road Line Features were given a buffer of 6 m. Road areas inside built-up areas (settlements) were not included in the area calculation of Other land.

As the Faroe Islands is not fully matriculated and roads are only lines on a map, GIS analyses were performed to achieve area estimates. The outcome per 31. December 2020 is shown in Table 12.18. Forest covers only 0.02 %, Wetland only 0.002% and Grassland 70 % of the area. Settlements 1.5 % and Other Land 27 %.

Table 12.18 Area estimates and changes in hectares for the six IPCC land use classes from 1. January 1990 to 31. December 2020.

1990\2020	Forest	Cropland	Grassland	Wetlands	Settlements	Other	Sum
Forest	28	0	0	0	0	0	28
Cropland	0	0	0	0	0	0	0
Grassland	6	3	97.807	0	276	0	98.090
Wetlands	0	0	0	2.037	0	0	2.037
Settlements	0	0	0	0	1.722	0	1.722
Other	0	0	0	0	92	37.629	37.724
Sum	34.7	3	97.807	2.037	2.090	37.629	139.600
Percentage	0.02 %	0.002 %	70 %	1.5 %	1.5 %	27 %	100 %

The forest area has been estimated to 34.7 ha, Cropland to 3, Grassland to 97.807 ha, Wetlands to 2.037 ha, Settlement to 2.090 ha and Other land to 37.629 ha. The Faroe Islands is using a 20 yr transition period in the UNFCCC reporting as recommended by IPCC (IPCC, 2006). To achieve this combined with a full reporting from 1990, a land use matrix has been extrapolated back to 1971 based on existing data. These are often based on expert judgment. However, for land converted to SE has a GIS analyse been performed including information on road constructions. Conversion of Grassland to Cropland is based on expert judgment. Afforestation is based on information from Umhvørvisstovan (Umhvørvisstovan, 2021).

12.6.2 Total emission from the LULUCF sector

The total emission from the LULUCF sector on the Faroe Islands has been estimated to 34.9 kt CO_2 eqv., see

Table 12.19. The emission is primarily due to emissions from drained organic grassland. Forest land is a very minor sink on the Faroe Islands. Cropland consists of only a few hectares in 2021 and no emissions have been reported from here as well as from managed Wetlands. Settlements are reported as a minor source due to clearance of living biomass when housing and roads are reported.

Table 12.19 Total emissions from the LULUCF sector, kt CO_2 eqv.

	1990	2000	2010	2015	2016	2017	2018	2019	2020
A. Forest land	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.001	-0.001
B. Cropland	NA	NA	NA	NA	NA	NA	NA	NA	NA
C. Grassland	33.98	34.52	35.16	35.28	35.30	35.33	35.35	35.37	34.92
D. Wetlands	NA	NA	NA	NA	NA	NA	NA	NA	NA
E. Settlements	0.05	0.05	0.09	0.05	0.05	0.001	0.001	0.001	0.001
F. Other land	NA	NA	NA	NA	NA	NA	NA	NA	NA
G. Harvested wood products	NE	NE	NE	NE	NE	NE	NE	NE	NE
H. Other	NA	NA	NA	NA	NA	NA	NA	NA	NA
4. Land use, land-use change and forestry	34.03	34.57	35.25	35.33	35.35	35.33	35.35	35.37	34.92

Forest land

The area with forest on the Faroe Islands is limited. For the purpose of reporting, the Faroe Islands has made the following forest definition.

1) All areas which are protected by a forest reserve declaration (“Skógfriðað”)
2) Other not protected areas with forest/woody vegetation excluding minor areas inside
    a) Some areas within Settlements like “Sjómansskúlatrøðin”, “Müllerstrøð” and “Debesartrøð”
    b) Areas which are part of nurseries (“Gróðurstøðin”)
    c) Some private areas like “Viðarlundin í Sortudýki”

Per 31. December 2020, the total estimated afforested area was 34.7 ha. For estimating the actual carbon stock and due to the sparse vegetation, a Danish developed model for hedges is used where the carbon stock estimation is based on vegetation volume, which is converted to carbon. It is not assumed that forest growth takes place on organic soils. Area and emission from organic forest soils is hence reported as Not Occurring (NO) and with zero emission (NA). As default no changes is assumed to occur in the soil organic carbon pool (IPCC, 2006), both for Forest Land remaining Forest Land and in land converted to Forest Land. Deforestation does not occur on the Faroe Islands. No dead wood can be found in the small areas with trees and is therefore reported as NO. The same for litter.

FL remaining FL and Land converted to FL

By the end of 2020, the total Forest area was estimated to 34.7 hectare. This is based on the GIS analysis made by Umhvørvisstovan in 2021. The area will be updated every fifth year. The total forest area consists of 76 individual forest parcels, each having been assigned a planting year with the earliest planting in 1914.

Figure 12.21   Successful afforestation near Tórshavn (left), partly successful afforestation near Tórshavn (middle) and on-going afforestation (and restoration) near the village Kirkjubøur. (*Photo: Steen Gyldenkærne, Aarhus University, Denmark*).

For the purpose of estimating the carbon stock, all parcels have been assigned with a plant cover and plant height in 1970, 1990, 2010 and 2021. Height at planting has as default been set to 0.5 meter. For the mentioned years, a linear interpolation of plant cover and plant height has been used to estimate the canopy volume. The canopy volume has been converted to biomass with a conversion factor of 2.538 kg dry matter biomass per m^3 canopy (Levin et al. 2020), a carbon content of 0.48 and a root:shoot-factor of 0.192 (IPCC, 2006). For conversion to CO_2 eqv., the recommended conversion factors for 100 years of 28 for CH_4 and 265 for N_2O (AR5) are used. Conversion of N_2O-N to N_2O is made with multiplying with the atomic weight, i.e. 44/28.

Table 12.20   Parameters used to estimate emission from LULUCF. No changes in mineral soils are expected.

	Aboveground kg dry matter m^{-3} biotope		Root:Shoot, fraction	C fraction	C loss organic soils, kg C ha^{-1} yr^{-1}	CH_4 emission organic soils, kg CH_4 ha^{-1} yr^{-1}	N_2O-N emission organic soils, kg N_2O-N ha^{-1} yr^{-1}
4.A. Forest land	2.538		0.192	0.48	NA	7	NA
	Dry matter stock, Aboveground biomass, kg DM ha^{-1}	**Total dry matter stock, kg DM ha^{-1}**	**Root:Shoot, fraction**	**C-content, kg C kg^{-1} OM, fraction**	**C loss organic soils, kg C ha^{-1} yr^{-1}**	**CH_4 emission organic soils, kg CH_4 ha^{-1} yr^{-1} organic soils**	**N_2O-N emission organic soils, kg N_2O-N ha^{-1} yr^{-1}**
4.B.1.1 Cropland, Annual crops	2,400	13,600	0.24	0.48	-3,600	1.4	1.6
4.C.1.1. Grassland, Intensive Managed	2,400	13,600	0.24	0.48	-3,600	1.4	1.6
4.C.1.2. Grassland, Slightly Managed	1,200	6,800	0.24	0.48	-1,800	0.7	0.8
4.C.1.3 Grassland, Unmanaged, where sheep roam	240	1360	0.24	0.48	0	0	0
4.D.1.1 Wetlands, Lakes and streams	NE	NE	NE	NE	NE	NE	NE
4.D.1.2 Wetlands, Bogs and swamps	NE	NE	NE	NE	NE	NE	NE
4.E. Settlement	600	3,400	0.24	0.48	NA	NA	NA
4.F. Other land	NO	NO	NO	NO	NA	NA	NA

When land use conversion is taking place the standing stock of living biomass on the afforested area is removed. In the case of the Faroe Islands, afforestation is only taking place on fertile grassland.

Table 12.21 shows the estimated emission from Forestry on the Faroe Islands in 2020 in CO_2 eqv.

Table 12.21 Estimated Forest area and emissions from the forests. Emissions are positive (+) and sinks are negative (-).

Forest land	1990	2000	2010	2015	2018	2019	2020
Forest Land remaining Forest Land, ha	20.30	28.35	34.07	34.07	34.07	34.07	34.49
Emission, kt CO_2	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Land converted to Forest land, ha	13.78	6.14	0.42	0.42	0.58	0.58	0.16
Emission, kt CO_2	0.000	0.000	0.000	0.000	-0.001	0.000	0.000
Forest area, total, ha	34.07	34.49	34.49	34.49	34.66	34.66	34.66
Emissions, total, kt CO_2	-0.001	-0.001	-0.001	-0.001	-0.002	-0.001	-0.001

No N_2O and CH_4 emissions has been estimated from the unfertilized forestland.

Cropland

The climate on the Faroe Islands is not suitable for annual crops. Only three hectares are reported with annual crops, primarily potatoes. It is assumed that all three hectares are grown on mineral soils.

No emission is assumed in living biomass except during Land use conversion. Default parameters for living biomass in the six different land use classes are shown in Table 12.20.

CL remaining CL and Land converted to CL

The total area CL remaining CL has in 1990 been estimated to 0 ha and increased to 3 ha in 2020. No changes in the carbon stock are assumed in living biomass and in mineral soils. The default C stock on Cropland is assumed the same as for Grassland (IPCC, 2006). Despite the three hectares first were reported in 2006 all Cropland is reported under Cropland remaining Cropland.

In 1986, a thoroughly soil sampling was made on improved grassland on the Faroe Islands on all islands. In total, 296 soil samples, Table 12.22 (https://www.bst.fo/Default.aspx?Id=14337). Soil sampling depth was approximately 20 cm (Jens Ivan í Gerðinum, BST, personal communication).

Table 12.22 Result of soil sampling on the most fertile grassland in 1986 (Data from Búnaðarstovan, 2021).

	No of Samples	% distribution	Average % OM	Average bulk density, g/cm^3
>= 20 % OM	193	65 %	27.9	0.5
<20 % OM	103	35 %	14.1	0.7
Total	296	100 %	22.9	0.59

Organic soils are identified based on criteria 1 and 2, or 1 and 3 listed below (FAO 1998):

1. Thickness of organic horizon greater than or equal to 10 cm. A horizon of less than 20 cm must have 12 percent or more organic carbon when mixed to a depth of 20 cm.
2. Soils that are never saturated with water for more than a few days must contain more than 20 percent organic carbon by weight (i.e., about 35 percent organic matter).
3. Soils are subject to water saturation episodes and has either:
   a. At least 12 percent organic carbon by weight (i.e., about 20 percent organic matter) if the soil has no clay; or

b. At least 18 percent organic carbon by weight (i.e., about 30 percent organic matter) if the soil has 60% or more clay; or
c. An intermediate, proportional amount of organic carbon for intermediate amounts of clay.

All other types of soils are classified as mineral. As can be seen from Table 12.22, 65 % out of 296 soil samples have 20 % Organic Matter (OM) or higher which qualify them as organic soils according to IPCC (2006). The soils are quite acidic with an average pH of 4.9 (Búnaðarstovan, 2021). For the three hectares with Cropland, it is assumed that they all are on mineral soils.

Although that the good part of the Cropland may contain some organic matter it is difficult to classify these as organic in terms of the IPCC guidelines (IPCC, 2006; IPCC, 2014) as many of them do not fulfil the FAO soil classification as having a depth of > 30 cm. Furthermore, the established emission factors in the IPCC 2013 Wetland Supplement (IPCC, 2014) seems not to be comprehensive for the Faroe conditions.

Grassland and Land converted to Grassland

Grassland on the Faroe Islands is divided into three categories. Intensively managed grassland, slightly managed grassland, and unmanaged grassland where sheep is roaming. Intensive managed Grassland has been estimated to around 1,000 hectares, slightly managed to 6,000 hectares and grassland where sheep is roaming to about 90,000 ha, see Table 12.23. The marginal roaming grassland is called "hagi." The sheep may also roam on Other Land. In total, 97,807 ha is classified as Grassland in 2020.

Animal manure and fertilization may take place on both intensively and slightly managed Grassland. The difference between intensive managed Grassland and slightly managed is that on the intensive managed Grassland, stone has been removed and new seeding of grass has been made. This occurs maybe with an interval of 30-50 years and is subsidized. The slightly managed grassland has not been tilled and only slightly ditched (see Figure 12.22). For reporting purposes, an emission factor of 50 % of the intensively managed soils has been elected.

Figure 12.22 Grassland turned into Intensive Managed Grassland (left), Ditch drained Grassland (middle), slightly managed Grassland (right) on the Faroe Islands (*Photo: Steen Gyldenkærne*, *Aarhus University*, *Denmark*).

For Grassland it is assumed that 65 % is on organic soils and 35 % on mineral soils based on the soil sampling made in 1986, Table 12.22.

The Unmanaged marginal Grassland is rocky and with a shallow soil layer. Very little data on the soils are available.

For Intensive managed organic grassland soils is assumed an annual emission of 3.6 tonnes C ha^{-1} yr^{-1} a CH_4 emission of 1.4 kg CH_4 ha^{-1} yr^{-1} and a N_2O emission of 1.6 kg N_2O-N ha^{-1} yr^{-1} (IPCC, 2014). Slightly managed Grassland is assumed to have an emission of 50 % of the intensive managed Grassland. No CH_4 emission is assumed. It is assumed that none of the marginal grassland qualifies as being organic. In the reporting is thus all Unmanaged Grassland reported as mineral with no changes in the amount of living biomass and soil carbon stock.

As the Faroe Islands are hilly, no Cropland and Grassland areas occur with stagnant water. Thus, the likelihood for CH_4 emission from ditches is not likely and hence no CH_4 emission from ditches is reported. No estimates have been made for dissolved organic matter (DOC). This is therefore reported as NE.

Table 12.23 shows the estimated area and emissions from all Grassland on the Faroe Islands. In 2020, it is estimated that 4,648 hectares of organic soils may emit greenhouse gases. The total emission has been estimated to 36.9 kt CO_2 eqv. of which 0.007 kt N_2O (2.0 kt CO_2 eqv.) is reported in the agricultural sector in Table 3.D under 3.D.a.6.

Table 12.23 Area with Grassland and estimated emissions.

	1990	2000	2010	2015	2018	2019	2020
Grassland Land, total, ha	98,075	97,965	97,854	97,814	97,808	97,807	97,807
Grassland, Managed, ha	744	870	1,022	1,049	1,066	1,071	965
Grassland, Unmanaged, ha	6,409	6,283	6,129	6,101	6,085	6,079	6,185
Grassland Land, mineral soils, ha	93,426	93,315	93,206	93,166	93,160	93,160	93,159
Grassland Land, organic soils, ha	4,650	4,650	4,648	4,648	4,648	4,648	4,648
Emission, kt CO_2-C	9.240	9.387	9.561	9.593	9.612	9.619	9.495
Emission, kt CH_4	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Emission, kt N_2O (reported under Agriculture)	0.006	0.007	0.007	0.007	0.007	0.007	0.007
Emission, kt CO_2 eqv.	34,030	34,570	35,250	35,330	35,350	35,370	34,920

Wetlands

Based on the most recent GIS analysis performed by Umhvørvisstovan in 2021, Wetlands on the Faroe Islands consist of 1749 ha flooded land (inland lakes and streams) and 287 ha partly flooded land such as swamps. In total 2037 ha. The occurring wetlands are reported as unmanaged although some of the flooded land is water reservoirs for drinking water. No peat extraction is taking place and reported area with swamp.

No changes in the area with wetlands is reported and no emissions are reported from WE.

Settlements and Land converted to Settlements

Settlement consists of built-up areas, roads, and quarries. A GIS analysis performed in 2021 has estimated the area with built-up areas to 1,823 hectare and roads and quarries to 267 hectares.

In 1990, the area with Settlement was estimated to 1,733 hectares increasing to 2,090 hectares in 2020. New dwellings are mainly taking place on former Grassland whereas road construction takes place both on Grassland and Other Land. It is assumed that 75 % of new SE is conversion of Grassland to SE and the remaining area is from Other land.

The GIS analysis performed in 2021 has also analysed road constructions and in this work the many tunnel constructions has been excluded from the land use change.

For Other Land converted to SE, no changes in the carbon stock in all reported carbon pools are assumed. For Grassland converted to SE, a conversion from slightly managed Grassland to SE having a default of 50 % in living biomass of slightly managed Grassland is assumed. No changes in soil carbon stock are assumed, mainly due to the likely very thin layer of soil above the rock, combined with the cold and wet climate, which reduce the turnover of organic matter. It is thus assumed that the recommendation of an 80 % value of the original carbon stock in Grassland in paved areas (IPCC, 2006, Chapter 8, Settlements, page 8.24) is not applicable for Faroese conditions.

Other Land

The GIS analyse has estimated the total Other Land area to 37,629 hectares. From 1990 to 2020, the area has decreased due to road constructions and new dwellings. By definition, Other Land do not have any carbon stock.

12.6.3 Uncertainty

Estimations of the uncertainties for emission calculations in the LULUCF have not been done.

12.6.4 Recalculations

No recalculation was made in this year's reporting.

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12.7 Waste Sector (CRF Sector 5)

12.7.1 Overview of the Waste sector

Waste incineration is the only source in the Waste sector with significant emission. The emissions have been allocated to the energy sector in accordance with the IPCC Guidelines.

12.7.2 Solid Waste Disposal (CRF Source Category 5A)

Several land-based solid waste disposals facilities are located on the Faroe Islands.

In estimating emissions, the first order decay model included in the 2006 IPCC Guidelines has been used. The activity data (amounts and types of waste) are based on data and expert judgement from the Faroe Islands. For DOC, DOCf, MCF and T½, the default values from the 2006 IPCC Guidelines are used. Climate is considered as wet and temperate. Most of the landfilled waste are inert materials, as combustible waste generally is incinerated and in prior times discarded directly into the sea. In 2021, the composition of the landfilled waste is assumed to be 67 % inert materials, 23 % sludge and 10 % garden waste.

12.7.3 Biological Treatment of Solid Waste (CRF Source Category 5B)

The first biogas facility on the Faroe Island, FORKA, did open in Hoyvík in 2020. Primarily receiving organic waste from the aquaculture industry and from agriculture.

Composting in the Faroes is primarily a small-scale activity in private households only.

12.7.4 Incineration and Open Burning of Waste (CRF Source Category 5C)

There are two waste incineration plants on the Faroe Islands, one in Hoyvík and one in Leirvík. Both plants perform energy recovery operations and therefore the emissions from the plants have been allocated to the energy sector (Public Electricity and Heat Production, 1A1a) in accordance with the IPCC Guidelines. Figure 12.23 shows the amounts of waste incinerated on the Faroe Islands 1990-2021. . For the first time in a decade, the amount of waste incinerated decreased in 2021.

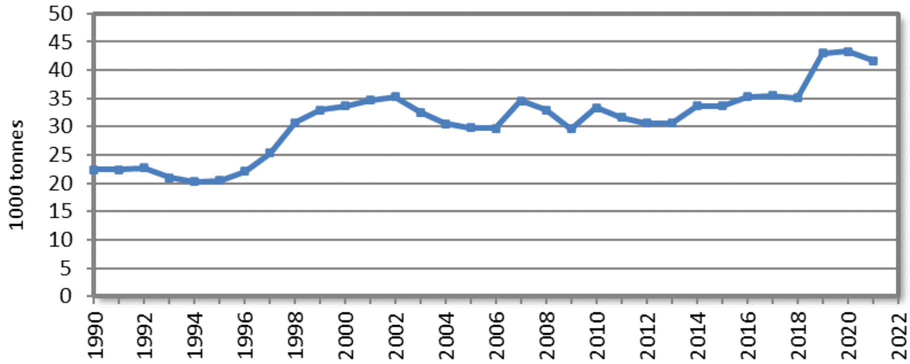

Figure 12.23 Incineration of municipal waste on the Faroe Islands, 1990-2021.

Open burning of waste is prohibited and is not occurring in the Faroes.

12.7.5 Wastewater Treatment and Discharge (CRF Source Category 5D)

In the Faroe Islands, many households have a septic tank through which domestic wastewater (sewage) flows for basic mechanical treatment. Industrial wastewater, e.g., from the fishing industry, is treated mechanically (oil/fat separation). Only a very few wastewater handling plants are treating the wastewater chemically and/or biologically.

For CH_4 emissions from domestic wastewater, the TOW is estimated based on the population and the default value for BOD of 62 gram per person per day, the default value for additional industrial BOD discharged to sewers (1.25) and the B0 default value (0.6 kg CH_4 per kg BOD). MCF values are the IPCC default values. The pathways for the wastewater are based on expert judgement and are under review. In this submission, it is assumed that 50 % of the wastewater is treated aerobically in plants, 40 % of the wastewater is treated in septic systems and the remaining 10 % is discharged directly into the sea. There are no anaerobic wastewater treatment systems in the Faroe Islands.

For industrial wastewater, only a few industries have separate wastewater treatment, especially the fishing industry. All treatment is done in aerobic plants and since the default MCF value is zero, there is no emissions reported from industrial wastewater treatment.

The N_2O emission is estimated both for the effluents and for the plants. As mentioned above, it is assumed that 50 % of the wastewater is treated in modern plants. The default EF of 3.2 g N_2O per person is used. For the N_2O from effluents, the emission is calculated based on the population, protein consumption data for Denmark and default values for fraction of nitrogen in protein, factor for non-consumed protein added to the wastewater and factor for industrial and commercial co-discharged protein into the sewer system. The EF is also the IPCC default of 0.005 kg N_2O-N per kg N.

12.7.6 Waste Other (CRF Source Category 5E)

There are no activities and emissions in the category Waste Other.

12.7.7 Uncertainty

Estimations of the uncertainties for emission calculations in the Waste sector have not been done.

12.7.8 Recalculations

No recalculation was made in this year's reporting.

12.8 Other (CRF sector 6)

There are no activities, emissions or removals for the Other category in the inventory of the Faroe Islands.

12.9 Recalculations and improvements

Since last year's report, a significant change has been made in the AD for f-gases in IPPU, see 12.9.1

Otherwise, most of the recalculations in the 2023 submission for the Faroe Islands are due to changes in emissions factors, and in all these cases, the changes are the same as in the inventory for Denmark, and thus explained in the main part of this report. These recalculations led to very small or nearly no changes in the total emission. Also, some minor corrections have been made, with no substantial effect on the emissions trends or levels.

12.9.1 Explanations and justifications for recalculations

The following recalculations and improvements to the emission inventory have been made since the reporting in 2022.

Energy
Public Electricity and Heat Production
No changes in the emission factors.

Manufacturing Industries and Construction
No changes in the emission factors.

Domestic Aviation
No changes in the emission factors, except for N_2O and CH_4 in 2012.

Road Transportation
No changes in the emission factors

Navigation
The emission factors for diesel, CO_2, N_2O and CH_4, has been updated for 1990-2020.

Commercial/Institutional
No changes in the emission factors.

Residential
No changes in the emission factors

Fishing
The emission factors for diesel, CO_2, N_2O and CH_4, has been updated for 1990-2019.

International bunkers
The emission factors for diesel, CO_2 has been updated for 1990-2019. Activity data for 2019 has been corrected.

International aviation

These emission factors for International aviation, Jet fuel, have been updated for CH_4 and N_2O, 1990-2019.

Industrial Processes and Product Use

An evaluation of the stock of HFC-gases on-board ships and other usages has been made in 2022, strongly indicate that the amount of HFC-gases in stock on ships is much less than the amount used in the emission calculation. Thus, the amount of stock was reduced for HFC-507 (50/50 blend of HFC-125 and HFC-143a) in the years 2018-2020, see tables below here. The result was an around 50 % reduction in the emission of HFC-507. Since this gas is the most used, this change had a significant impact on the emission of f-gases. From being 9.7% of the total emissions of GHG in 2020, f-gases are 5.2 % if the total emission of GHG in 2021.

Before change:

Industrial refrigeration	1990	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
HFC-125	0,00	0,34	1,00	0,96	0,87	1,43	1,97	2,77	3,84	5,11	5,91	9,53	12,93	15,11
HFC-143a	0,00	0,40	1,17	1,10	0,99	1,53	2,08	2,85	3,93	5,19	5,98	9,59	13,07	15,26

After change (as in Table 12.4):

Industrial refrigeration	1990	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
HFC-125	0,00	0,34	1,00	0,96	0,87	1,43	1,97	2,77	3,84	5,11	5,91	5,53	5,97	5,94
HFC-143a	0,00	0,40	1,17	1,10	0,99	1,53	2,08	2,85	3,93	5,19	5,98	5,58	6,11	6,09

Emissions from use of lubricants, paraffin wax and N_2O was included for the first time in last year's reporting. The estimates cover the entire time-series. This year an error in AD for N_2O was corrected.

Agriculture

These recalculations have been made since the reporting in 2022:

- The GE value for Dairy cattle is recalculated since previous reporting, from 118 to 215 MJ/head/day. This causes an around 1 kt increase in the CH_4 emission from Enteric fermentation The recalculations have caused the CH_4 emission to increase from around 0.8 to 3.1 kt CO_2e/year.
- MCF for 'Solid storage' changed from 2 to 17 % (for Dairy, Non-dairy and Sheep).
- VS for Dairy cattle, Non-dairy cattle and sheep changed from respectively 2, 1.8 and 0.3 to 3.6, 3.3 and 0.5 dry matter/head/day.

Waste

No change in the emission factors.

12.9.2 Implications for emission levels

Most of the recalculations have only had small implication for the emissions levels, except the emission level for f-gases, see 12.9.1 (previous page).

12.9.3 Implications for emission trends, including time series consistency

No significant changes.

12.9.4 Improvements

As part of a project funded by the Danish Ministry for Climate, Energy and Utilities, several improvements have been included in previous year's inventory. As a follow up some recalculations have been made as well as some additional improvements are planned to be implemented in next year's submission:

- In the 2014 delivery, the recalculation made for fishing vessels, for certain reasons could only be done for the time-series 2001-2012. Therefore, the time series for fishing vessels, 2001-2019, is inconsistent with the time series 1990-2000. Oil sold to foreign fishing vessels for 1990-2000 will be estimated, and the activity data will be corrected correspondently.
- For agriculture data and emissions from horses and lamb will be included
- Correct the area for potatoes (due to error in FAO database)
- Change harvest (kg/ha) for potatoes to 30.000 kg/ha
- An uncertainty assessment using IPCC approach 1 will be included.
- Key categories will be described and discussed.
- In the 2022 submission, the reference approach was reported for the first time. Further improvements need to be made as it relates to incorporation of data on international bunkers and to investigate the differences between the sectoral and reference approaches.

12.10 Annexes

All emissions factors used in the inventory are found in this Annex.

12.10.1 Annex 1.a. Emissions factors – Stationary combustion

The emissions factors used for calculating the Faroese emission of GHG in following stationary combustion categories are found in Table 12.24:

- 1A1a Public Electricity and Heat Production
- 1A2 Manufacturing Industry and Construction
- 1A4a Commercial/Institutional
- 1A4b Residential

Table 12.24 Emission Factors for Stationary Combustion, 1990-2021.

Category	Fuel	Pollutant	1990-2006	2007-2021
Public Electricity and Heat Production	Gas/diesel oil	CH_4 (g/GJ)	0.9	0.9
		CO_2 (kg/GJ)	74.1	74.1
		N_2O (g/GJ)	0.4	0.4
	Heavy fuel oil	CH_4 (g/GJ)	0.8	0.8
		CO_2 (kg/GJ)	78.7	78.6-79.4
		N_2O (g/GJ)	0.3	0.3
Manufacturing Industries and Construction	Gas/diesel oil	CH_4 (g/GJ)	0.2	0.2
		CO_2 (kg/GJ)	74.1	74.1
		N_2O (g/GJ)	0.4	0.4
	Heavy fuel oil	CH_4 (g/GJ)	1.3	1.3
		CO_2 (kg/GJ)	78.7	78.6
		N_2O (g/GJ)	5	5
	Kerosene	CH_4 (g/GJ)	3	3
		CO_2 (kg/GJ)	71.9	71.9
		N_2O (g/GJ)	0.6	0.6
Commercial/Institutional	Gas/diesel oil	CH_4 (g/GJ)	0.7	0.7
		CO_2 (kg/GJ)	74.1	74.1
		N_2O (g/GJ)	0.4	0.4
	Kerosene	CH_4 (g/GJ)	10	10
		CO_2 (kg/GJ)	71.9	71.9
		N_2O (g/GJ)	0.6	0.6
Residential	Gas/diesel oil	CH_4 (g/GJ)	0.7	0.7
		CO_2 (kg/GJ)	74.1	74.1
		N_2O (g/GJ)	0.6	0.6
	Kerosene	CH_4 (g/GJ)	10	10
		CO_2 (kg/GJ)	71.9	71.9
		N_2O (g/GJ)	0.6	0.6

The emissions factors for calculating the Faroese emissions from the waste sector are found in Table 24.

Table 12.25 Emission factors for Waste Incineration, 1990-2021.

Year	Fossil Waste %	CO_2 EMF-fossil kg/GJ	CO_2 EMF-biogen kg/GJ	CH_4 EMF-total g/GJ	N_2O EMF-total g/GJ
1990	32.2	37	86.7	0.59	1.2
1991	32.2	37	86.7	0.59	1.2
1992	35.4	37	84.2	0.59	1.2
1993	36.9	37	83	0.59	1.2
1994	36.9	37	83	0.59	1.2
1995	39.3	37	81.1	0.59	1.2
1996	41.2	37	79.6	0.59	1.2
1997	41.2	37	79.6	0.59	1.2
1998	41.2	37	79.6	0.59	1.2
1999	41.2	37	79.6	0.59	1.2
2000	41.2	37	79.6	0.59	1.2
2001	41.2	37	79.6	0.59	1.2
2002	41.2	37	79.6	0.59	1.2
2003	41.2	37	79.6	0.59	1.2
2004	41.2	37	79.6	0.51	1.2
2005	41.2	37	79.6	0.42	1.2
2006	41.2	37	79.6	0.34	1.2
2007	41.2	37	79.6	0.34	1.2
2008	41.2	37	79.6	0.34	1.2
2009	41.2	37	79.6	0.34	1.2
2010	41.2	37	79.6	0.34	1.2
2011	41.2	37.5	79.6	0.34	1.2
2012	41.2	40	79.6	0.34	1.2
2013	41.2	42.5	79.6	0.34	1.2
2014	41.2	42.5	79.6	0.34	1.2
2015	41.2	42.5	79.6	0.34	1.2
2016	41.2	42.5	79.6	0.34	1.2
2017	41.2	42.5	79.6	0.34	1.2
2018	41.2	42.5	79.6	0.34	1.2
2019	41.2	42.5	79.6	0.34	1.2
2020	41.2	42.5	79.6	0.34	1.2
2021	41.2	42.5	79.6	0.34	1.2

12.10.2 Annex 1.b. Emissions factors – Mobile combustion

The emissions factors used for calculating the Faroese emission of GHG in following mobile combustion categories are found in Table 12.26, Table 12.27 and Table 12.28:

- 1A3a Domestic Aviation
- 1A3b Road Transportation
- 1A3d Domestic Navigation
- 1A4c Agriculture, Forestry and Fishing

Table 12.26 Emission factors for Domestic Aviation, 1990-2021.

	CH_4 g/GJ	CO_2 kg/GJ	N_2O g/GJ
1990	485.3	72	2.68
1991	485.3	72	2.68
1992	485.3	72	2.68
1993	485.3	72	2.68
1994	485.3	72	2.68
1995	485.3	72	2.68
1996	485.3	72	2.68
1997	485.3	72	2.68
1998	485.3	72.	2.68
1999	485.3	72	2.68
2000	485.3	72	2.68
2001	0.13	72	2.58
2002	0.13	72	2.58
2003	0.13	72	2.58
2004	0.13	72	2.59
2005	0.15	72	2.62
2006	0.15	72	2.62
2007	0.15	72	2.63
2008	0.15	72	2.63
2009	0.15	72	2.63
2010	0.15	72	2.63
2011	0.15	72	2.63
2012	0.20	72	2.62
2013	0.23	72	2.61
2014	0.25	72	2.61
2015	0.26	72	2.60
2016	0.26	72	2.60
2017	0.23	72	2.55
2018	0.24	72	2.56
2019	0.23	72	2.55
2020	0.22	72	2.53
2021	0.21	73	2.52

Table 12.27 Emission factors for Road Transportation, Example for diesel passenger cars, 1990-2021. EFs in g/km for urban and rural driving.

	Year	co2u_g_km	ch4u_g_km	n2ou_g_km	co2r_g_km	ch4r_g_km	n2or_g_km
Diesel PC	1990	234.0	0.022	0.000	130.2	0.012	0.000
Diesel PC	1991	237.0	0.021	0.000	131.6	0.012	0.000
Diesel PC	1992	235.1	0.021	0.000	133.8	0.012	0.000
Diesel PC	1993	237.9	0.021	0.000	135.3	0.012	0.001
Diesel PC	1994	235.5	0.021	0.000	136.9	0.011	0.001
Diesel PC	1995	236.0	0.021	0.001	138.3	0.011	0.001
Diesel PC	1996	238.8	0.020	0.001	139.9	0.011	0.001
Diesel PC	1997	234.6	0.020	0.001	141.9	0.010	0.002
Diesel PC	1998	234.8	0.017	0.001	144.2	0.009	0.002
Diesel PC	1999	232.1	0.015	0.001	146.2	0.008	0.003
Diesel PC	2000	228.9	0.014	0.002	147.3	0.007	0.004
Diesel PC	2001	229.5	0.012	0.003	148.0	0.006	0.004
Diesel PC	2002	223.2	0.010	0.006	147.5	0.005	0.004
Diesel PC	2003	220.2	0.009	0.007	146.9	0.004	0.004
Diesel PC	2004	215.1	0.008	0.009	146.3	0.003	0.004
Diesel PC	2005	216.5	0.007	0.010	145.9	0.003	0.004
Diesel PC	2006	214.7	0.006	0.011	145.7	0.002	0.004
Diesel PC	2007	211.7	0.005	0.012	145.0	0.001	0.004
Diesel PC	2008	211.0	0.004	0.014	142.9	0.001	0.004
Diesel PC	2009	205.7	0.003	0.014	140.6	0.001	0.004
Diesel PC	2010	208.6	0.003	0.014	139.0	0.001	0.004
Diesel PC	2011	197.9	0.002	0.015	135.7	0.000	0.004
Diesel PC	2012	199.9	0.002	0.015	135.6	0.000	0.004
Diesel PC	2013	198.4	0.001	0.015	134.3	0.000	0.004
Diesel PC	2014	194.8	0.001	0.015	134.4	0.000	0.004
Diesel PC	2015	195.2	0.001	0.015	133.0	0.000	0.004
Diesel PC	2016	196.2	0.001	0.015	132.7	0.000	0.004
Diesel PC	2017	198.2	0.001	0.014	133.5	0.000	0.004
Diesel PC	2018	200.4	0.000	0.014	135.2	0.000	0.004
Diesel PC	2019	204.5	0.000	0.014	136.9	0.000	0.004
Diesel PC	2020	204.5	0.000	0.014	136.9	0.000	0.004
Diesel PC	2021	204.5	0.000	0.04	136.9	0.000	0.004

Table 12.28 Emission factors for Domestic Navigation (diesel and residual) and Fisheries (diesel), 1990-2021.

	Navigation - diesel			Navigation and Fisheries - Residual			Fisheries - diesel		
	CH_4 g/GJ	CO_2 kg/GJ	N_2O g/GJ	CH_4 g/GJ	CO_2 kg/GJ	N_2O g/GJ	CH_4 g/GJ	CO_2 kg/GJ	N_2O kg/GJ
1990	1,030	74	1,852	1,088	78	1,932	0,900	74	1,833
1991	1,036	74	1,854	1,091	78	1,936	0,900	74	1,834
1992	1,041	74	1,855	1,091	78	1,936	0,903	74	1,834
1993	1,041	74	1,855	1,088	78	1,935	0,905	74	1,833
1994	1,044	74	1,855	1,079	78	1,930	0,906	74	1,831
1995	1,053	74	1,854	1,080	78	1,930	0,907	74	1,831
1996	1,099	74	1,856	1,088	78	1,925	0,908	74	1,832
1997	1,062	74	1,860	1,105	78	1,917	0,913	74	1,832
1998	1,069	74	1,861	1,129	78	1,923	0,916	74	1,831
1999	1,059	74	1,864	1,139	78	1,922	0,918	74	1,832
2000	1,110	74	1,866	1,150	78	1,924	0,926	74	1,830
2001	1,115	74	1,866	1,164	78	1,928	0,931	74	1,832
2002	1,143	74	1,867	1,182	78	1,934	0,935	74	1,831
2003	1,142	74	1,868	1,203	78	1,934	0,945	74	1,830
2004	1,137	74	1,867	1,208	78	1,930	0,955	74	1,829
2005	1,138	74	1,868	1,236	78	1,942	0,959	74	1,829
2006	1,136	74	1,868	1,257	78	1,950	0,972	74	1,828
2007	1,138	74	1,867	1,265	78	1,950	0,992	74	1,827
2008	1,149	74	1,868	1,270	78	1,950	1,003	74	1,827
2009	1,153	74	1,868	1,279	78	1,949	1,013	74	1,827
2010	1,148	74	1,867	1,285	78	1,949	1,034	74	1,827
2011	1,130	74	1,867	1,291	78	1,949	1,039	74	1,828
2012	1,195	74	1,867	1,296	78	1,949	1,038	74	1,829
2013	1,210	74	1,867	1,303	78	1,949	1,049	74	1,826
2014	1,193	74	1,865	1,308	78	1,949	1,053	74	1,827
2015	1,191	74	1,865	1,304	78	1,946	1,069	74	1,824
2016	1,186	74	1,867	1,308	78	1,946	1,065	74	1,825
2017	1,224	74	1,867	1,316	78	1,947	1,078	74	1,823
2018	1,208	74	1,867	1,320	78	1,947	1,090	74	1,822
2019	1,198	74	1,867	1,336	78	1,949	1,094	74	1,822
2020	1,208	74	1,867	1,347	78	1,950	1,106	74	1,822
2021	1,230	74	1,867	1,360	78	1,951	1,111	74	1,825

13 Information regarding the aggregated submission for the Kingdom of Denmark

This chapter contains information on the aggregated submission for Denmark, Greenland and the Faroe Islands submitted to the UNFCCC. This chapter contains a trend discussion, information on the aggregated reference approach, information relating to key categories and information on recalculations. Sector specific information is included for Denmark in Chapter 3-8, for Greenland in Chapter 11 and for the Faroe Islands in Chapter 12.

The institutional arrangements and the overall QA/QC plan are described in Chapter 1. This description covers all the Danish submissions to the European Union and the UNFCCC, and therefore information regarding the national system is not presented in this chapter. Information on the specific QA/QC activities concerning the aggregated submission is presented in Chapter 13.5.

In Chapter 13.4, a description of the aggregation process is provided. The chapter explains the technical issues in aggregating different CRF submissions, including the software used in the process and the handling of background data.

13.1 Trends in emissions

Due to the small emissions originating from Greenland and the Faroe Islands, the trends for Denmark, Greenland and the Faroe Islands are practically identical to the trends for Denmark presented in Chapter 2. Therefore, they are not further described here.

13.2 The reference approach

In addition to the sector-specific CO_2 emission inventories (the national approach), the CO_2 emission is also estimated using the reference approach described in the 2006 IPCC Guidelines. The reference approach is based on data for fuel production, import, export and stock change. The CO_2 emission inventory based on the reference approach is reported to the Climate Convention and used for verification of the official data in the national approach.

The reference approach for the Kingdom of Denmark is an aggregation of the individual reference approaches. The reference approach for Denmark is described in Chapter 3.4, the reference approach for Greenland is included in Chapter 11 and for the Faroe Islands in Chapter 12. The reference approach for the Faroe Islands show large differences for some years, see Chapter 12 for more information.

The difference between the two methods is almost exclusively caused by the difference between the Danish sectoral and reference approach. Please refer to Chapter 3.4 for more information.

13.3 Recalculations

13.3.1 Implications for emission levels

The impact of recalculations in the Greenlandic and Faroese inventories is insignificant compared to the recalculations in the Danish inventory. Therefore, the explanations and justifications are not repeated in this Chapter. Detailed information on the recalculations in the Danish inventory is provided in Chapter 9 and in the sectoral Chapters 3-7. The recalculations carried out for the Greenlandic inventory are described in Chapter 11 and the recalculations carried out for the Faroese inventory are described in Chapter 12.

13.4 Technical description of the aggregation of the emission inventories

In order to accommodate the request of the ERT of full inclusion of the Greenlandic emission data in the full CRF format, Denmark operates separate installations for Denmark and Greenland (and the Faroe Islands). The country identification codes provided by the UNFCCC secretariat are DNM for Denmark, GRL for Greenland and FRO for the Faroe Islands. An additional installation is necessary to enable the submission of an aggregated submission under the UNFCCC (Denmark, Greenland and the Faroe Islands). Previously, a further installation was used to provide the aggregated submission under the Kyoto Protocol. The country identification code provided by the UNFCCC secretariat is DNK for the UNFCCC submission (Denmark, Greenland and the Faroe Islands). DKE was used for the aggregated submission of Denmark and Greenland under the Kyoto Protocol.

For the aggregation of the submissions, an IT tool is used; 'CRF Aggregator DNK' developed by DCE.

The three main work processes in connection with the aggregation of the submissions are:

- In the CRF Aggregator DNK the following work processes take place:
    - Aggregation of variables; sum of emissions and activity data, notation keys and comments
    - As input data the xml submission files from the CRF Reporter installations for DNM (Denmark), GRL (Greenland) and FRO (Faroe Islands) are used
    - As output file, a CRF Reporter xml import file is generated. This file is then imported into the CRF Reporter website.

13.5 QA/QC of the aggregated submission

The QA/QC procedures for the Danish inventory are described in Chapter 1.6 and the sectoral chapters. Please refer to Chapter 1.6 for a general description of the QA/QC system, and the structural setup of the Danish QA/QC system for the greenhouse gas inventory. The QA/QC procedures carried out by Greenlandic authorities for the Greenlandic inventory are described in Chapter 11. The following focuses on the specific QA/QC measures carried out at DCE both on the data (CRF tables and documentation) received from Greenland and the Faroe Islands and the QC checks carried out for the aggregated versions of the inventory for reporting to the UNFCCC. The PM's relevant for this are listed in Table 13.1.

Table 13.1 PM's specific to the handling of Greenlandic emission data and the aggregated submissions.

Data Storage level 4	3.Completeness	DS.4.3.3	Check that no sources where methodology exists in the IPCC guidelines are reported as NE by Greenland and the Faroe Islands.
	4.Consistency	DS.4.4.2	Check time series consistency of the reporting by Greenland and the Faroe Islands prior to aggregating the final submissions.
	5.Correctness	DS.4.5.1	Check that the aggregated submissions for Denmark under the UNFCCC match the sum of the individual submissions.
		DS.4.5.2	Check that additional information and information related to land-use changes has been correctly aggregated compared to the individual submissions of Denmark, Greenland and the Faroe Islands.
	7.Transparency	DS.4.7.2	Perform QA on the documentation report provided by the Governments of Greenland and the Faroe Islands.

Data Storage level 4	3.Completeness	DS.4.3.3	Check that no sources where methodology exists in the IPCC guidelines are reported as NE by Greenland and the Faroe Islands.

A check is made to filter any NE's from the CRF tables. If any greenhouse gas emissions are reported as NE, it is checked whether methodologies exist in the IPCC guidelines. If methodologies do exist, efforts are made to quickly estimate and report emissions. No categories where methodology exists were identified for the submission of Denmark and Greenland. For the Faroe Islands, some minor categories are still under investigation, e.g. composting. More information is provided in Chapter 12.

Data Storage level 4	4.Consistency	DS.4.4.2	Check time series consistency of the reporting by Greenland and the Faroe Islands prior to aggregating the final submissions.

The time series for all pollutants in the submissions from Greenland and the Faroe Islands are checked at the CRF 3 level for large variations in the time series. Any large variations are explained or corrected in cooperation with the authorities in Greenland and the Faroe Islands.

Data Storage level 4	5.Correctness	DS.4.5.1	Check that the aggregated submissions for Denmark under the UNFCCC match the sum of the individual submissions.

To ensure that the submission for Denmark under the UNFCCC matches the sum of the submissions of Denmark, Greenland and the Faroe Islands a spreadsheet check has been implemented to ensure complete correctness of the submitted inventory. Special attention is paid to the additional information provided in the CRF, e.g. for the agricultural sector. Certain parameters cannot simply be added, e.g. animal weights. In these cases, a weighted average is reported in the CRF tables.

Data Storage level 4	5.Correctness	DS.4.5.2	Check that additional information and information related to land-use changes has been correctly aggregated compared to the individual submissions of Denmark, Greenland and the Faroe Islands.

The CRF submission under the UNFCCC is checked to see if the additional information has been aggregated correctly. The additional information is mainly related to the agricultural and waste sectors.

Data Storage level 4	7.Transparency	DS.4.7.2	Perform QA on the documentation report provided by the Governments of Greenland and the Faroe Islands.

The documentation report is received by DCE from the Governments of Greenland and the Faroe Islands in the early spring every year. The documentation reports are included in the NIR as Chapters 11 and 12. DCE experts read and provide comments on the reports, so that any questions are resolved prior to the UNFCCC reporting deadline of April 15.

Annexes

Annex 1 – Key category analysis

Annex 2 – Assessment of uncertainty

Annex 3 – Other detailed methodological descriptions for individual source or sink categories (where relevant)

Annex 3A – Stationary combustion

Annex 3B – Transport and other mobile sources

Annex 3C – Industrial processes and product use

Annex 3D - Agriculture

Annex 3E – LULUCF

Annex 3F - Waste

Annex 4 – Information on the energy statistics

Annex 5 – Assessment of completeness and (potential) sources and sinks of greenhouse gas emissions and removals excluded

Annex 6 – Comparison of fuel data from Eurostat and CRF

Annex 7 – Information on accounting of Kyoto units

Annex 8 – Additional information to be considered as part of the annual inventory submission and the supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol or other useful reference

Annex 1 - Key category analysis

Description of the methodology used for identifying key categories

Key Category Analysis (KCA) approach 1 and 2 for year 1990 and 2021 for Denmark (excluding Greenland and Faroe Islands) has been carried out in accordance with the IPCC Guidelines (2006). The KCA has been carried out excluding and including the LULUCF sector. An approach 1 KCA has also been worked out for Greenland, see Chapter 11.

The base year in the analysis is the year 1990 for the greenhouse gases CO_2, CH_4, N_2O and 1995 for the F-gases HFC, PFC and SF_6. The KCA approaches are:

- A quantitative analysis, approach 1 KCA.
- An analysis based on uncertainties, approach 2 KCA.

The level assessment of the approach 1 KCA is a ranking of the source categories in accordance to their relative contribution to the national total of greenhouse gases calculated in CO_2 equivalent units. The level key categories are found from the list of source categories ranked according to their contribution in descending order. Level key categories are those from the top of the list and of which the sum constitutes 95 % of the national total.

The trend assessment of the approach 1 KCA is a ranking of the source categories according to their contribution to the trend of the national total of greenhouse gases, calculated in CO_2 equivalents, from the base year to the latest year. The trend of the source category is calculated relative to that of the national totals and the trend is then weighted with the contribution, according to the level assessment. The ranking is in descending order. As for the level assessment, the cut-off point for the sum of contribution to the trend is 95 % and the source categories from the top of the list to the cut-off line are trend key categories.

In addition, an approach 2 KCA has been carried out to provide additional insight into categories being key sources. The categorisation used is as for the approach 1 analysis and the uncertainties used are approach 1 uncertainties as listed in Annex 2.

The level approach 2 KCA is a ranking of the categories according to their relative contribution to the national total multiplied by the uncertainty of the emission of the category as the combined uncertainty on activity data and on emission factor. Chosen for cut of for key categories in the analysis is 90 %.

The trend approach 2 KCA is a ranking of the categories according to their relative contribution to the trend 1990-2021 of the national total multiplied by the uncertainty of the emission of the category. Chosen for cut of for key categories in the analysis is 90 %.

Since the level KCA is carried out for 1990, 2021 and trend, for data exclusive and inclusive LULUCF and based on approach 1 and approach 2, a total of 12 KCA tables for Denmark (excluding Greenland and Faroe Islands) has been worked out.

In addition, two[1] overview tables based on the Guidebook (2006), Vol. 1, Table 4.4 are shown. The overview tables show summary results of the KCAs for 1990, for 2021, and for the trend 1990-2021.

The inclusion of the LULUCF sector in the level analysis implies that the emissions in this sector are all calculated positive, i.e. the absolute value of removals are included. Note also that according to the Guidebook, the analysis implies that contributions to the trend are all calculated as mathematically positive to be able to perform the ranking.

Emission source categories

The emission source categories are identical to the emission source categories applied in the uncertainty analysis. The KCA is based on 224 emission source categories including 35 LULUCF source categories.

Result of the Key Category Analysis for Denmark

An overview of results of the KCA excluding LULUCF is shown in Table A1-1 and results of the KCA including LULUCF is shown in Table A1-2. The number of key source categories for each of the KCA are shown in Table A1-3.

The 12 different KCA for Denmark point out 22-48 key source categories each and a total of 75 different key source categories. The number of key categories in each of the main sectors is: energy 35, IPPU 4, agriculture 15, LULUCF 15 and waste 6.

Approach 1 point out mainly the large emission sources as key categories and thus CO_2 emission from stationary and mobile combustion are important key categories. Approach 2 point out some of the sources with larger uncertainty rates.

The list below gives an overview of the different KCA for Denmark (not including Greenland and Faroe Islands) that are presented in Table A1-4 – Table A1-15.

Table A1-4 KCA for Denmark, level assessment, base year excl. LULUCF, approach 1.
Table A1-5 KCA for Denmark, level assessment base year incl. LULUCF, approach 1.
Table A1-6 KCA for Denmark, level assessment 2021 excl. LULUCF, approach 1.
Table A1-7 KCA for Denmark, level assessment 2021 incl. LULUCF, approach 1.
Table A1-8 KCA for Denmark, trend assessment 1990-2021 excl. LULUCF, approach 1.
Table A1-9 KCA for Denmark, trend assessment 1990-2021 incl. LULUCF, approach 1.
Table A1-10 KCA for Denmark, level assessment base year excl. LULUCF, approach 2.
Table A1-11 KCA for Denmark, level assessment base year incl. LULUCF, approach 2.
Table A1-12 KCA for Denmark, level assessment 2021 excl. LULUCF, approach 2.
Table A1-13 KCA for Denmark, level assessment 2021 incl. LULUCF, approach 2.
Table A1-14 KCA for Denmark, trend assessment 1990-2021 excl. LULUCF, approach 2.
Table A1-15 KCA for Denmark, trend assessment 1990-2021 incl. LULUCF, approach 2.

[1] Including and excluding LULUCF.

Table A1-1 Summary of KCA for Denmark, level and trend for 1990-2021, excl. LULUCF, approach 1 and approach 2.

IPCC Source Categories (LULUCF excluded)		**GHG**	**Key categories with number according to ranking in analysis**					
			Level Approach 1 1990	**Level Approach 1 2021**	**Trend Approach 1 1990-2021**	**Level Approach 2 1990**	**Level Approach 2 2021**	**Trend Approach 2 1990-2021**
Energy	1A Stationary combustion, Coal, ETS data, CO_2	CO_2		3	3			
Energy	1A Stationary combustion, Coal, no ETS data, CO_2	CO_2	1		1	13		5
Energy	1A Stationary combustion, BKB, CO_2	CO_2						
Energy	1A Stationary combustion, Coke oven coke, CO_2	CO_2						
Energy	1A Stationary combustion, Fossil waste, ETS data, CO_2	CO_2		7	9			34
Energy	1A Stationary combustion, Fossil waste, no ETS data, CO_2	CO_2	20	19	25			
Energy	1A Stationary combustion, Petroleum coke, ETS data, CO_2	CO_2		16	11			
Energy	1A Stationary combustion, Petroleum coke, no ETS data, CO_2	CO_2	25		23			
Energy	1A Stationary combustion, Residual oil, ETS data, CO_2	CO_2		27	24			
Energy	1A Stationary combustion, Residual oil, no ETS data, CO_2	CO_2	6		6			37
Energy	1A Stationary combustion, Gas oil, CO_2	CO_2	3	12	4	22		29
Energy	1A Stationary combustion, Kerosene, CO_2	CO_2	26		22			
Energy	1A Stationary combustion, LPG, CO_2	CO_2		29				
Energy	1A1b Stationary combustion, Petroleum refining, Refinery gas, CO_2	CO_2	13	10	17			
Energy	1A Stationary combustion, Natural gas, onshore, CO_2	CO_2	5	4	5			
Energy	1A1c_ii Stationary combustion, Oil and gas extraction, Off shore gas turbines, Natural gas, CO_2	CO_2	24	11	12			
Energy	1A1 Stationary Combustion, Solid fuels, CH_4	CH_4						
Energy	1A1 Stationary Combustion, Liquid fuels, CH_4	CH_4						
Energy	1A1 Stationary Combustion, not engines, gaseous fuels, CH_4	CH_4						
Energy	1A1 Stationary Combustion, Waste, CH_4	CH_4						
Energy	1A1 Stationary Combustion, not engines, Biomass, CH_4	CH_4						
Energy	1A2 Stationary Combustion,solid fuels, CH_4	CH_4						
Energy	1A2 Stationary Combustion,Liquid fuels, CH_4	CH_4						
Energy	1A2 Stationary Combustion, not engines, gaseous fuels, CH_4	CH_4						
Energy	1A2 Stationary Combustion, Waste, CH_4	CH_4						
Energy	1A2 Stationary Combustion, not engines, Biomass, CH_4	CH_4						
Energy	1A4 Stationary Combustion, Solid fuels, CH_4	CH_4						
Energy	1A4 Stationary Combustion, Liquid fuels, CH_4	CH_4						
Energy	1A4 Stationary Combustion, not engines, gaseous fuels, CH_4	CH_4						
Energy	1A4 Stationary Combustion, Waste, CH_4	CH_4						
Energy	1A4 Stationary Combustion, not engines, not residential wood and not residential/agricultural straw, Biomass, CH_4	CH_4						
Energy	1A4b_i Stationary combustion, Residential wood combustion, CH_4	CH_4						
Energy	1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion, CH_4	CH_4						

IPCC Source Categories (LULUCF excluded)		GHG	Key categories with number according to ranking in analysis					
			Level Approach 1 1990	Level Approach 1 2021	Trend Approach 1 1990-2021	Level Approach 2 1990	Level Approach 2 2021	Trend Approach 2 1990-2021
Energy	1A Stationary combustion, Natural gas fuelled engines, gaseous fuels, CH_4	CH_4		3	3			
Energy	1A Stationary combustion, Biogas fuelled engines, Biomass, CH_4	CH_4	1		1	14		6
Energy	1A1 Stationary Combustion, Solid fuels, N_2O	N_2O						
Energy	1A1 Stationary Combustion, Liquid fuels, N_2O	N_2O						
Energy	1A1 Stationary Combustion, Gaseous fuels, N_2O	N_2O		7	9			34
Energy	1A1 Stationary Combustion, Waste, N_2O	N_2O	20	19	25			
Energy	1A1 Stationary Combustion, Biomass, N_2O	N_2O		16	11			
Energy	1A2 Stationary Combustion, Solid fuels, N_2O	N_2O	25		23			
Energy	1A2 Stationary Combustion, Liquid fuels, N_2O	N_2O		27	24			
Energy	1A2 Stationary Combustion, Gaseous fuels, N_2O	N_2O	6		6			
Energy	1A2 Stationary Combustion, Waste, N_2O	N_2O	3	12	4	22		29
Energy	1A2 Stationary Combustion, Biomass, N_2O	N_2O	26		22			
Energy	1A4 Stationary Combustion, Solid fuels, N_2O	N_2O		29				
Energy	1A4 Stationary Combustion, Liquid fuels, N_2O	N_2O	13	10	17			
Energy	1A4 Stationary Combustion, Gaseous fuels, N_2O	N_2O	5	4	5			
Energy	1A4 Stationary Combustion, Waste, N_2O	N_2O	24	11	13			
Energy	1A4 Stationary Combustion, not residential wood and not residential/agricultural straw, Biomass, N_2O	N_2O						
Energy	1A4b_i Stationary Combustion, Residential wood combustion, N_2O	N_2O						
Energy	1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion, N_2O	N_2O						
Energy	1.A.2.g Industry (mobile)	CO_2						
Energy	1.A.3.a Civil aviation	CO_2						
Energy	1.A.3.b Road Transport	CO_2						
Energy	1.A.3.c Railways	CO_2						
Energy	1.A.3.d Navigation (large vessels)	CO_2						
Energy	1.A.4.a Commercial/Institutional (mobile)	CO_2						
Energy	1.A.4.b Residential (mobile)	CO_2						
Energy	1.A.4.c ii Agriculture (mobile)	CO_2						
Energy	1.A.4.c ii Forestry (mobile)	CO_2						
Energy	1.A.4.c iii Fisheries	CO_2						
Energy	1.A.5.b Other (military)	CO_2						
Energy	1.A.5.b Other (small boats)	CO_2						
Energy	1.A.2.g Industry (mobile)	CH_4						
Energy	1.A.3.a Civil aviation	CH_4						
Energy	1.A.3.b Road Transport	CH_4						
Energy	1.A.3.c Railways	CH_4						

IPCC Source Categories (LULUCF excluded)		GHG	Key categories with number according to ranking in analysis					
			Level Approach 1 1990	Level Approach 1 2021	Trend Approach 1 1990-2021	Level Approach 2 1990	Level Approach 2 2021	Trend Approach 2 1990-2021
Energy	1.A.3.d Navigation (large vessels)	CH_4				18		19
Energy	1.A.4.a Commercial/Institutional (mobile)	CH_4						
Energy	1.A.4.b Residential (mobile)	CH_4						
Energy	1.A.4.c ii Agriculture (mobile)	CH_4						36
Energy	1.A.4.c ii Forestry (mobile)	CH_4					14	12
Energy	1.A.4.c iii Fisheries	CH_4						
Energy	1.A.5.b Other (military)	CH_4				15		18
Energy	1.A.5.b Other (small boats)	CH_4					17	17
Energy	1.A.2.g Industry (mobile)	N_2O						
Energy	1.A.3.a Civil aviation	N_2O						
Energy	1.A.3.b Road Transport	N_2O						
Energy	1.A.3.c Railways	N_2O						30
Energy	1.A.3.d Navigation (large vessels)	N_2O						
Energy	1.A.4.a Commercial/Institutional (mobile)	N_2O						
Energy	1.A.4.b Residential (mobile)	N_2O						
Energy	1.A.4.c ii Agriculture (mobile)	N_2O					15	14
Energy	1.A.4.c ii Forestry (mobile)	N_2O						
Energy	1.A.4.c iii Fisheries	N_2O	23	15	18	17	13	15
Energy	1.A.5.b Other (military)	N_2O						
Energy	1.A.5.b Other (small boats)	N_2O	2	1	2	13	9	5
Energy	1.B.2.a.1 Exploration	CO_2	29	28				
Energy	1.B.2.a.2 Production	CO_2	16	17	28			
Energy	1.B.2.a.4 Refining/storage	CO_2		30				
Energy	1.B.2.b.1 Exploration	CO_2						
Energy	1.B.2.b.2 Production	CO_2	22	14	19	21	16	25
Energy	1.B.2.b.4 Transmission and storage	CO_2						
Energy	1.B.2.b.5 Distribution	CO_2	19	24				
Energy	1.B.2.c.1.ii Venting	CO_2						
Energy	1.B.2.c.2.i Flaring, oil	CO_2		32				
Energy	1.B.2.c.2.ii Flaring, gas	CO_2						
Energy	1.B.2.c.2.iii Flaring, combined	CO_2						
Energy	1.B.2.a.1 Exploration	CH_4						
Energy	1.B.2.a.2 Production	CH_4						
Energy	1.B.2.a.3 Transport	CH_4						
Energy	1.B.2.a.4 Refining/storage	CH_4						
Energy	1.B.2.b.1 Exploration	CH_4						
Energy	1.B.2.b.2 Production	CH_4						

IPCC Source Categories (LULUCF excluded)		GHG	Key categories with number according to ranking in analysis					
			Level Approach 1 1990	Level Approach 1 2021	Trend Approach 1 1990-2021	Level Approach 2 1990	Level Approach 2 2021	Trend Approach 2 1990-2021
Energy	1.B.2.b.4 Transmission and storage	CH_4						
Energy	1.B.2.b.5 Distribution	CH_4						
Energy	1.B.2.c.1.ii Venting	CH_4						
Energy	1.B.2.c.2.i Flaring, oil	CH_4						
Energy	1.B.2.c.2.ii Flaring, gas	CH_4					25	33
Energy	1.B.2.c.2.iii Flaring, combined	CH_4						
Energy	1.B.2.a.1 Exploration, oil	N_2O						
Energy	1.B.2.c.2.i Flaring, oil	N_2O						
Energy	1.B.2.c.2.ii Flaring, gas	N_2O						
Energy	1.B.2.c.2.iii Flaring, combined	N_2O						
IPPU	2A1 Cement production	CO_2						
IPPU	2A2 Lime production	CO_2					24	32
IPPU	2A3 Glass production	CO_2						
IPPU	2A4a Ceramics	CO_2						
IPPU	2A4b Other uses of soda ash	CO_2						
IPPU	2A4d Other process uses of carbonates	CO_2						
IPPU	2B10 Production of catalysts	CO_2						
IPPU	2C1a Steel	CO_2						
IPPU	2C5 Lead production	CO_2						
IPPU	2D1 Lubricant use	CO_2						
IPPU	2D2 Paraffin wax use	CO_2						
IPPU	Paint Application	CO_2						
IPPU	Degreasing, dry cleaning and electronics	CO_2						
IPPU	Chemical products manufacturing or processing	CO_2						
IPPU	Other use of solvents and related activities	CO_2						
IPPU	Printing industry	CO_2						
IPPU	Domestic solvent use (other than paint application)	CO_2	28					
IPPU	2D3 Road paving with asphalt	CO_2						
IPPU	2D3 Asphalt roofing	CO_2						
IPPU	2D3 Urea based catalysts	CO_2						
IPPU	2G4 Fireworks	CO_2						
IPPU	2D2 Paraffin wax use	CH_4						
IPPU	2D3 Road paving with asphalt	CH_4						
IPPU	2G4 Fireworks	CH_4						
IPPU	2G4 Tobacco	CH_4						
IPPU	2G4 Charcoal	CH_4						
IPPU	2B2 Nitric acid production	N_2O						

IPCC Source Categories (LULUCF excluded)		GHG	Key categories with number according to ranking in analysis					
			Level Approach 1 1990	Level Approach 1 2021	Trend Approach 1 1990-2021	Level Approach 2 1990	Level Approach 2 2021	Trend Approach 2 1990-2021
IPPU	2D2 Paraffin wax use	N_2O						
IPPU	2G3a Medical application of N_2O	N_2O						
IPPU	2G3b N_2O as propellant for pressure and aerosol products	N_2O						
IPPU	2G4 Fireworks	N_2O						
IPPU	2G4 Tobacco	N_2O						
IPPU	2G4 Charcoal	N_2O						
IPPU	2E Electronics industry	HFCs	14	6	10			
IPPU	2F1 Refrigeration and air conditioning	HFCs						
IPPU	2F2 Foam blowing agents	HFCs						
IPPU	2F4 Aerosols	HFCs						
IPPU	2E Electronics industry	PFCs						
IPPU	2F1 Refrigeration and air conditioning	PFCs						
IPPU	2C4 Magnesium production	SF_6						
IPPU	2G1 Electrical equipment	SF_6						
IPPU	2G2 SF6 and PFCs from other product use	SF_6						
Agriculture	3A Enteric Fermentation	CH_4						
Agriculture	3B Manure Management	CH_4						
Agriculture	3F Field Burning of Agricultural Residues	CH_4						
Agriculture	3B Manure Management	N_2O						
Agriculture	3B5 Atmospheric deposition	N_2O						
Agriculture	3Da1 Inorganic N fertilizer	N_2O						
Agriculture	3Da2a Animal manure applied to soils	N_2O						
Agriculture	3Da2b Sewage sludge applied to soils	N_2O						
Agriculture	3Da2c Other organic fertilizer applied to soils	N_2O						
Agriculture	3Da3 Urine and dung deposited by grazing animals	N_2O						
Agriculture	3Da4 Crop Residues	N_2O						
Agriculture	3Da5 Mineralization	N_2O						
Agriculture	3Da6 Cultivation of organic soils	N_2O						
Agriculture	3Db1 Atmospheric deposition	N_2O						
Agriculture	3Db2 Leaching	N_2O						
Agriculture	3F Field Burning of Agricultural Residues	N_2O						
Agriculture	3G Liming	CO_2						
Agriculture	3H Urea applicaton	CO_2	10		12	16		13
Agriculture	3I Other carbon-containing fertilizers	CO_2						
Waste	5.E Accidental fires	CO_2						
Waste	5.A Solid waste disposal	CH_4	9	22	14	7	11	3
Waste	5.B.1 Composting	CH_4					22	24

IPCC Source Categories (LULUCF excluded)		GHG	Key categories with number according to ranking in analysis					
			Level Approach 1 1990	Level Approach 1 2021	Trend Approach 1 1990-2021	Level Approach 2 1990	Level Approach 2 2021	Trend Approach 2 1990-2021
Waste	5.B.2. Anaerobic digestion at biogas facilities	CH_4		23	16		23	21
Waste	5.C.1 Incineration of corpses	CH_4						
Waste	5.C.2 Incineration of carcasses	CH_4						
Waste	5.D.1 Domestic wastewater	CH_4						
Waste	5.E Accidental fires	CH_4						
Waste	5.B.1 Composting	N_2O						31
Waste	5.C.1 Incineration of corpses	N_2O						
Waste	5.C.2 Incineration of carcasses	N_2O						
Waste	5.D.1 Domestic wastewater	N_2O		33				
Waste	5.D.2 Industrial wastewater	N_2O			27			26

Table A1-2 Summary of KCA for Denmark, level and trend for 1990-2021, incl. LULUCF, approach 1 and approach 2.

IPCC Source Categories (LULUCF included)		**GHG**	**Key categories with number according to ranking in analysis**					
			Level Approach 1 1990	**Level Approach 1 2021**	**Trend Approach 1 1990-2021**	**Level Approach 2 1990**	**Level Approach 2 2021**	**Trend Approach 2 1990-2021**
Energy	1A Stationary combustion, Coal, ETS data, CO_2	CO_2		3	3			
Energy	1A Stationary combustion, Coal, no ETS data, CO_2	CO_2	1	46	1	17		10
Energy	1A Stationary combustion, BKB, CO_2	CO_2						
Energy	1A Stationary combustion, Coke oven coke, CO_2	CO_2						
Energy	1A Stationary combustion, Fossil waste, ETS data, CO_2	CO_2		10	9			42
Energy	1A Stationary combustion, Fossil waste, no ETS data, CO_2	CO_2	24	26	31			
Energy	1A Stationary combustion, Petroleum coke, ETS data, CO_2	CO_2		21	14			
Energy	1A Stationary combustion, Petroleum coke, no ETS data, CO_2	CO_2	30		29			
Energy	1A Stationary combustion, Residual oil, ETS data, CO_2	CO_2		35	30			
Energy	1A Stationary combustion, Residual oil, no ETS data, CO_2	CO_2	7		8			48
Energy	1A Stationary combustion, Gas oil, CO_2	CO_2	3	16	4	28		32
Energy	1A Stationary combustion, Kerosene, CO_2	CO_2	31		28			
Energy	1A Stationary combustion, LPG, CO_2	CO_2	38	37				
Energy	1A1b Stationary combustion, Petroleum refining, Refinery gas, CO_2	CO_2	17	14	21			
Energy	1A Stationary combustion, Natural gas, onshore, CO_2	CO_2	6	4	5			
Energy	1A1c_ii Stationary combustion, Oil and gas extraction, Off shore gas turbines, Natural gas, CO_2	CO_2	28	15	15			
Energy	1A1 Stationary Combustion, Solid fuels, CH_4	CH_4						
Energy	1A1 Stationary Combustion, Liquid fuels, CH_4	CH_4						
Energy	1A1 Stationary Combustion, not engines, gaseous fuels, CH4	CH_4						
Energy	1A1 Stationary Combustion, Waste, CH_4	CH_4						
Energy	1A1 Stationary Combustion, not engines, Biomass, CH_4	CH_4						
Energy	1A2 Stationary Combustion,solid fuels, CH_4	CH_4						
Energy	1A2 Stationary Combustion,Liquid fuels, CH_4	CH_4						
Energy	1A2 Stationary Combustion, not engines, gaseous fuels, CH_4	CH_4						
Energy	1A2 Stationary Combustion, Waste, CH_4	CH_4						
Energy	1A2 Stationary Combustion, not engines, Biomass, CH_4	CH_4						
Energy	1A4 Stationary Combustion, Solid fuels, CH_4	CH_4						
Energy	1A4 Stationary Combustion, Liquid fuels, CH_4	CH_4						
Energy	1A4 Stationary Combustion, not engines, gaseous fuels, CH_4	CH_4						
Energy	1A4 Stationary Combustion, Waste, CH_4	CH_4						
Energy	1A4 Stationary Combustion, not engines, not residential wood and not residential/agricultural straw, Biomass, CH_4	CH_4						
Energy	1A4b_i Stationary combustion, Residential wood combustion, CH_4	CH_4				29		
Energy	1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw combustion, CH_4	CH_4						

IPCC Source Categories (LULUCF included)		GHG	Key categories with number according to ranking in analysis					
			Level Approach 1 1990	Level Approach 1 2021	Trend Approach 1 1990-2021	Level Approach 2 1990	Level Approach 2 2021	Trend Approach 2 1990-2021
Energy	1A Stationary combustion, Natural gas fuelled engines, gaseous fuels, CH_4	CH_4						
Energy	1A Stationary combustion, Biogas fuelled engines, Biomass, CH_4	CH_4						
Energy	1A1 Stationary Combustion, Solid fuels, N_2O	N_2O				22		22
Energy	1A1 Stationary Combustion, Liquid fuels, N_2O	N_2O						
Energy	1A1 Stationary Combustion, Gaseous fuels, N_2O	N_2O						
Energy	1A1 Stationary Combustion, Waste, N_2O	N_2O						47
Energy	1A1 Stationary Combustion, Biomass, N_2O	N_2O					17	13
Energy	1A2 Stationary Combustion, Solid fuels, N_2O	N_2O						
Energy	1A2 Stationary Combustion, Liquid fuels, N_2O	N_2O				19		20
Energy	1A2 Stationary Combustion, Gaseous fuels, N_2O	N_2O					22	18
Energy	1A2 Stationary Combustion, Waste N_2O	N_2O						
Energy	1A2 Stationary Combustion, Biomass, N_2O	N_2O						
Energy	1A4 Stationary Combustion, Solid fuels, N_2O	N_2O						
Energy	1A4 Stationary Combustion, Liquid fuels, N_2O	N_2O						34
Energy	1A4 Stationary Combustion, Gaseous fuels N_2O	N_2O						
Energy	1A4 Stationary Combustion, Waste, N_2O	N_2O						
Energy	1A4 Stationary Combustion, not residential wood and not residential/agricultural straw, Biomass, N_2O	N_2O						
Energy	1A4b_i Stationary Combustion, Residential wood combustion, N_2O	N_2O					18	14
Energy	1A4b_i/1A4c_i Stationary Combustion, Residential and agricultural straw com-bustion, N_2O	N_2O						
Energy	1.A.2.g Industry (mobile)	CO_2	27	20	23	21	16	16
Energy	1.A.3.a Civil aviation	CO_2	36					
Energy	1.A.3.b Road Transport	CO_2	2	1	2	16	11	7
Energy	1.A.3.c Railways	CO_2	34	36				
Energy	1.A.3.d Navigation (large vessels)	CO_2	20	23	33			
Energy	1.A.4.a Commercial/Institutional (mobile)	CO_2		38				
Energy	1.A.4.b Residential (mobile)	CO_2						
Energy	1.A.4.c ii Agriculture (mobile)	CO_2	26	18	24	27	19	26
Energy	1.A.4.c ii Forestry (mobile)	CO_2						
Energy	1.A.4.c iii Fisheries	CO_2	23	31				
Energy	1.A.5.b Other (military)	CO_2						
Energy	1.A.5.b Other (small boats)	CO_2		41				
Energy	1.A.2.g Industry (mobile)	CH_4						
Energy	1.A.3.a Civil aviation	CH_4						
Energy	1.A.3.b Road Transport	CH_4						
Energy	1.A.3.c Railways	CH_4						

IPCC Source Categories (LULUCF included)		GHG	Key categories with number according to ranking in analysis					
			Level Approach 1 1990	Level Approach 1 2021	Trend Approach 1 1990-2021	Level Approach 2 1990	Level Approach 2 2021	Trend Approach 2 1990-2021
Energy	1.A.3.d Navigation (large vessels)	CH_4						
Energy	1.A.4.a Commercial/Institutional (mobile)	CH_4						
Energy	1.A.4.b Residential (mobile)	CH_4						
Energy	1.A.4.c ii Agriculture (mobile)	CH_4						
Energy	1.A.4.c ii Forestry (mobile)	CH_4						
Energy	1.A.4.c iii Fisheries	CH_4						
Energy	1.A.5.b Other (military)	CH_4						
Energy	1.A.5.b Other (small boats)	CH_4						
Energy	1.A.2.g Industry (mobile)	N_2O					33	39
Energy	1.A.3.a Civil aviation	N_2O						
Energy	1.A.3.b Road Transport	N_2O		45				
Energy	1.A.3.c Railways	N_2O						
Energy	1.A.3.d Navigation (large vessels)	N_2O						
Energy	1.A.4.a Commercial/Institutional (mobile)	N_2O						
Energy	1.A.4.b Residential (mobile)	N_2O						
Energy	1.A.4.c ii Agriculture (mobile)	N_2O					32	37
Energy	1.A.4.c ii Forestry (mobile)	N_2O						
Energy	1.A.4.c iii Fisheries	N_2O						
Energy	1.A.5.b Other (military)	N_2O						
Energy	1.A.5.b Other (small boats)	N_2O						
Energy	1.B.2.a.1 Exploration	CO_2						
Energy	1.B.2.a.2 Production	CO_2						
Energy	1.B.2.a.4 Refining/storage	CO_2						
Energy	1.B.2.b.1 Exploration	CO_2						
Energy	1.B.2.b.2 Production	CO_2						
Energy	1.B.2.b.4 Transmission and storage	CO_2						
Energy	1.B.2.b.5 Distribution	CO_2						
Energy	1.B.2.c.1.ii Venting	CO_2						
Energy	1.B.2.c.2.i Flaring, oil	CO_2						
Energy	1.B.2.c.2.ii Flaring, gas	CO_2						
Energy	1.B.2.c.2.iii Flaring, combined	CO_2	33					
Energy	1.B.2.a.1 Exploration	CH_4						
Energy	1.B.2.a.2 Production	CH_4						
Energy	1.B.2.a.3 Transport	CH_4						
Energy	1.B.2.a.4 Refining/storage	CH_4						
Energy	1.B.2.b.1 Exploration	CH_4						
Energy	1.B.2.b.2 Production	CH_4						

IPCC Source Categories (LULUCF included)		GHG	Key categories with number according to ranking in analysis					
			Level Approach 1 1990	**Level Approach 1 2021**	**Trend Approach 1 1990-2021**	**Level Approach 2 1990**	**Level Approach 2 2021**	**Trend Approach 2 1990-2021**
Energy	1.B.2.b.4 Transmission and storage	CH_4						
Energy	1.B.2.b.5 Distribution	CH_4						
Energy	1.B.2.c.1.ii Venting	CH_4						
Energy	1.B.2.c.2.i Flaring, oil	CH_4						
Energy	1.B.2.c.2.ii Flaring, gas	CH_4						
Energy	1.B.2.c.2.iii Flaring, combined	CH_4						
Energy	1.B.2.a.1 Exploration, oil	N_2O						
Energy	1.B.2.c.2.i Flaring, oil	N_2O						
Energy	1.B.2.c.2.ii Flaring, gas	N_2O						
Energy	1.B.2.c.2.iii Flaring, combined	N_2O						
IPPU	2A1 Cement production	CO_2	18	9	12			
IPPU	2A2 Lime production	CO_2						
IPPU	2A3 Glass production	CO_2						
IPPU	2A4a Ceramics	CO_2						
IPPU	2A4b Other uses of soda ash	CO_2						
IPPU	2A4d Other process uses of carbonates	CO_2						
IPPU	2B10 Production of catalysts	CO_2						
IPPU	2C1a Steel	CO_2						
IPPU	2C5 Lead production	CO_2						
IPPU	2D1 Lubricant use	CO_2						
IPPU	2D2 Paraffin wax use	CO_2						
IPPU	Paint Application	CO_2						
IPPU	Degreasing, dry cleaning and electronics	CO_2						
IPPU	Chemical products manufacturing or processing	CO_2						
IPPU	Other use of solvents and related activities	CO_2						
IPPU	Printing industry	CO_2						
IPPU	Domestic solvent use (other than paint application)	CO_2						
IPPU	2D3 Road paving with asphalt	CO_2						
IPPU	2D3 Asphalt roofing	CO_2						
IPPU	2D3 Urea based catalysts	CO_2						
IPPU	2G4 Fireworks	CO_2						
IPPU	2D2 Paraffin wax use	CH_4						
IPPU	2D3 Road paving with asphalt	CH_4						
IPPU	2G4 Fireworks	CH_4						
IPPU	2G4 Tobacco	CH_4						
IPPU	2G4 Charcoal	CH_4						
IPPU	2B2 Nitric acid production	N_2O	14		16	20		15

IPCC Source Categories (LULUCF included)		GHG	Key categories with number according to ranking in analysis					
			Level Approach 1 1990	Level Approach 1 2021	Trend Approach 1 1990-2021	Level Approach 2 1990	Level Approach 2 2021	Trend Approach 2 1990-2021
IPPU	2D2 Paraffin wax use	N_2O						
IPPU	2G3a Medical application of N_2O	N_2O						
IPPU	2G3b N_2O as propellant for pressure and aerosol products	N_2O						
IPPU	2G4 Fireworks	N_2O						
IPPU	2G4 Tobacco	N_2O						
IPPU	2G4 Charcoal	N_2O						
IPPU	2E Electronics industry	HFCs						
IPPU	2F1 Refrigeration and air conditioning	HFCs		33	27		23	17
IPPU	2F2 Foam blowing agents	HFCs			34			31
IPPU	2F4 Aerosols	HFCs						
IPPU	2E Electronics industry	PFCs						
IPPU	2F1 Refrigeration and air conditioning	PFCs						
IPPU	2C4 Magnesium production	SF_6						
IPPU	2G1 Electrical equipment	SF_6						
IPPU	2G2 SF_6 and PFCs from other product use	SF_6						
Agriculture	3A Enteric Fermentation	CH_4	4	2	7	10	8	9
Agriculture	3B Manure Management	CH_4	8	5	6	15	10	6
Agriculture	3F Field Burning of Agricultural Residues	CH_4						
Agriculture	3B Manure Management	N_2O	21	28	38	12	12	21
Agriculture	3B5 Atmospheric deposition	N_2O				23	27	
Agriculture	3Da1 Inorganic N fertilizer	N_2O	10	12		1	1	19
Agriculture	3Da2a Animal manure applied to soils	N_2O	15	17	25	2	3	2
Agriculture	3Da2b Sewage sludge applied to soils	N_2O						46
Agriculture	3Da2c Other organic fertilizer applied to soils	N_2O					34	30
Agriculture	3Da3 Urine and dung deposited by grazing animals	N_2O				24	26	
Agriculture	3Da4 Crop Residues	N_2O	22	13	17	5	2	1
Agriculture	3Da5 Mineralization	N_2O				14	24	11
Agriculture	3Da6 Cultivation of organic soils	N_2O	19	25	36	4	4	8
Agriculture	3Db1 Atmospheric deposition	N_2O	32	39		7	9	12
Agriculture	3Db2 Leaching	N_2O	16	27		3	5	
Agriculture	3F Field Burning of Agricultural Residues	N_2O						
Agriculture	3G Liming	CO_2	25	32		13	15	28
Agriculture	3H Urea applicaton	CO_2						
Agriculture	3I Other carbon-containing fertilizers	CO_2						
LULUCF	4.A.1 Forest land remaining forest land, Living biomass	CO_2	35	8	11		36	35
LULUCF	4.A.1 Forest land remaining forest land, Dead organic matter	CO_2		19	20			
LULUCF	4.A.1 Forest land remaining forest land, Mineral soils	CO_2						

IPCC Source Categories (LULUCF included)		GHG	Key categories with number according to ranking in analysis					
			Level Approach 1 1990	Level Approach 1 2021	Trend Approach 1 1990-2021	Level Approach 2 1990	Level Approach 2 2021	Trend Approach 2 1990-2021
LULUCF	4.A.1 Forest land remaining forest land, Organic soils	CO_2		42				
LULUCF	4.A.2 Land converted to forest land	CO_2	12	11	26	26	20	45
LULUCF	4.B.1 Cropland remaining cropland, Living biomass	CO_2		24	18		31	27
LULUCF	4.B.1 Cropland remaining cropland, Mineral soils	CO_2	13	22	10	11	14	3
LULUCF	4.B.1 Cropland remaining cropland, Organic soils	CO_2	5	6	32	6	6	23
LULUCF	4.B.2 Forest land converted to cropland	CO_2			37			36
LULUCF	4.B.2 Other land uses converted to cropland	CO_2						44
LULUCF	4(II) Cropland on organic soils	CO_2						
LULUCF	4.C.1 Grassland remaining grassland, Living biomass	CO_2						
LULUCF	4.C.1 Grassland remaining grassland, Organic soils	CO_2	9	7	13	9	7	5
LULUCF	4.C.2 Forest land converted to grassland	CO_2						
LULUCF	4.C.2 Other land uses converted to grassland	CO_2		43	39			38
LULUCF	4(II) Grassland on organic soils	CO_2						
LULUCF	4.D.1.1 Peat extraction remaining peat extraction	CO_2						
LULUCF	4.D.1.2 Flooded land remaining flooded land	CO_2						
LULUCF	4.D.2. Land converted to wetlands	CO_2						
LULUCF	4.E.2 Forest land converted to settlements	CO_2						
LULUCF	4.E.2 Other land uses converted to settlements	CO_2	29	34		18	21	40
LULUCF	4.G Harvested wood products	CO_2						43
LULUCF	4(II) Cropland on organic soils	CH_4				25	29	
LULUCF	4(II) Grassland on organic soils	CH_4		40			25	41
LULUCF	4(II) A. Forest land, organic soils	CH_4						
LULUCF	4(II) Land converted to wetlands	CH_4						
LULUCF	4(II) Peatland	CH_4						
LULUCF	4(V) Biomass Burning	CH_4						
LULUCF	4(III) Mineralization/immobilization, Forest land	N_2O						
LULUCF	4(III) Mineralization/immobilization, Cropland	N_2O						
LULUCF	4(III) Mineralization/immobilization, Grassland	N_2O						
LULUCF	4(III) Mineralization/immobilization, Land converted to Settlements	N_2O						
LULUCF	4(V) Biomass burning	N_2O						
LULUCF	4(II) Drainage and rewetting, Forest soils	N_2O						
LULUCF	4(II) Peat extraction remaining peat extraction	N_2O						
Waste	5.E Accidental fires	CO_2						
Waste	5.A Solid waste disposal	CH_4	11	29	19	8	13	4
Waste	5.B.1 Composting	CH_4					28	25
Waste	5.B.2. Anaerobic digestion at biogas facilities	CH_4		30	22		30	24
Waste	5.C.1 Incineration of corpses	CH_4						

IPCC Source Categories (LULUCF included)		GHG	Key categories with number according to ranking in analysis					
			Level Approach 1 1990	**Level Approach 1 2021**	**Trend Approach 1 1990-2021**	**Level Approach 2 1990**	**Level Approach 2 2021**	**Trend Approach 2 1990-2021**
Waste	5.C.2 Incineration of carcasses	CH_4						
Waste	5.D.1 Domestic wastewater	CH_4						
Waste	5.E Accidental fires	CH_4						
Waste	5.B.1 Composting	N_2O						33
Waste	5.C.1 Incineration of corpses	N_2O						
Waste	5.C.2 Incineration of carcasses	N_2O						
Waste	5.D.1 Domestic wastewater	N_2O		44			35	
Waste	5.D.2 Industrial wastewater	N_2O	37		35			29

Table A1-3 Summary of KCA for Denmark, number of key source categories in each of the KCA.

	Level Approach 1 1990	Level Approach 1 2021	Trend Approach 1 1990-2021	Level Approach 2 1990	Level Approach 2 2021	Trend Approach 2 1990-2021
Excluding LULUCF	29	33	28	22	25	36
Including LULUCF	38	46	39	29	36	48

Table A1-4 KCA for Denmark, level assessment, base year excl. LULUCF, approach 1. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Table A1-5 KCA for Denmark, level assessment base year incl. LULUCF, approach 1. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Table A1-6 KCA for Denmark, level assessment 2021 excl. LULUCF, approach 1. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Table A1-7 KCA for Denmark, level assessment 2021 incl. LULUCF, approach 1. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Table A1-8 KCA for Denmark, trend assessment 1990-2021 excl. LULUCF, approach 1. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Table A1-9 KCA for Denmark, trend assessment 1990-2021 incl. LULUCF, approach 1. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Table A1-10 KCA for Denmark, level assessment base year excl. LULUCF, approach 2. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Table A1-11 KCA for Denmark, level assessment base year incl. LULUCF, approach 2. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Table A1-12 KCA for Denmark, level assessment 2021 excl. LULUCF, approach 2. This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Table A1-13 KCA for Denmark, level assessment 2021 incl. LULUCF, approach 2.

This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Table A1-14 KCA for Denmark, trend assessment 1990-2021 excl. LULUCF, approach 2.
This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Table A1-15 KCA for Denmark, trend assessment 1990-2021 incl. LULUCF, approach 2.
This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Annex 2 - Assessment of uncertainty

Description of methodology used for identifying uncertainties

For the inventory of Denmark, the uncertainties are estimated using Approach 1 of the 2006 IPCC Guidelines.

More information and the results are provided in Chapter 1.7.

The underlying table, corresponding to Table 3.3 of volume 1 of the 2006 IPCC Guidelines, is very large and not suitable for incorporation in a text document. The table in Excel format can be found at
https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/greenhouse-gases/supporting-documentation/

Annex 3 - Other detailed methodological descriptions for individual source or sink categories (where relevant)

Annex 3A – Stationary Combustion

Annex 3B – Transport and other mobile sources

Annex 3C – Industrial processes and product use

Annex 3D – Agriculture

Annex 3E – LULUCF

Annex 3F – Waste

Annex 3A - Stationary combustion

Annex 3A-1:	Correspondence list between SNAP and CRF source categories
Annex 3A-2:	Fuel rate
Annex 3A-3:	Default Lower Calorific Value (LCV) of fuels and fuel correspondence list
Annex 3A-4:	Emission factors
Annex 3A-5:	Large point sources
Annex 3A-6:	Adjustment of CO_2 emission
Annex 3A-7:	Uncertainty estimates
Annex 3A-8:	Emission inventory 2021 based on SNAP sectors
Annex 3A-9:	EU ETS data

Annex 3A-1 Correspondence list between SNAP and CRF source categories

Table 3A-1.1 Correspondence list between SNAP and CRF source categories for stationary combustion.

	snap_name	CRF id	CRF name
010100	Public power	1A1a	Public electricity and heat production
010101	Combustion plants >= 300 MW (boilers)	1A1a	Public electricity and heat production
010102	Combustion plants >= 50 and < 300 MW (boilers)	1A1a	Public electricity and heat production
010103	Combustion plants < 50 MW (boilers)	1A1a	Public electricity and heat production
010104	Gas turbines	1A1a	Public electricity and heat production
010105	Stationary engines	1A1a	Public electricity and heat production
010200	District heating plants	1A1a	Public electricity and heat production
010201	Combustion plants >= 300 MW (boilers)	1A1a	Public electricity and heat production
010202	Combustion plants >= 50 and < 300 MW (boilers)	1A1a	Public electricity and heat production
010203	Combustion plants < 50 MW (boilers)	1A1a	Public electricity and heat production
010204	Gas turbines	1A1a	Public electricity and heat production
010205	Stationary engines	1A1a	Public electricity and heat production
010300	Petroleum refining plants	1A1b	Petroleum refining
010301	Combustion plants >= 300 MW (boilers)	1A1b	Petroleum refining
010302	Combustion plants >= 50 and < 300 MW (boilers)	1A1b	Petroleum refining
010303	Combustion plants < 50 MW (boilers)	1A1b	Petroleum refining
010304	Gas turbines	1A1b	Petroleum refining
010305	Stationary engines	1A1b	Petroleum refining
010306	Process furnaces	1A1b	Petroleum refining
010400	Solid fuel transformation plants	1A1c	Oil and gas extraction
010401	Combustion plants >= 300 MW (boilers)	1A1c	Oil and gas extraction
010402	Combustion plants >= 50 and < 300 MW (boilers)	1A1c	Oil and gas extraction
010403	Combustion plants < 50 MW (boilers)	1A1c	Oil and gas extraction
010404	Gas turbines	1A1c	Oil and gas extraction
010405	Stationary engines	1A1c	Oil and gas extraction
010406	Coke oven furnaces	1A1c	Oil and gas extraction
010407	Other (coal gasification, liquefaction)	1A1c	Oil and gas extraction
010500	Coal mining, oil / gas extraction, pipeline compressors	1A1c	Oil and gas extraction
010501	Combustion plants >= 300 MW (boilers)	1A1c	Oil and gas extraction
010502	Combustion plants >= 50 and < 300 MW (boilers)	1A1c	Oil and gas extraction
010503	Combustion plants < 50 MW (boilers)	1A1c	Oil and gas extraction
010504	Gas turbines	1A1c	Oil and gas extraction
010505	Stationary engines	1A1c	Oil and gas extraction
010506	Pipeline compressors	1A3e i	Pipeline transport
020100	Commercial and institutional plants	1A4a i	Commercial/institutional: Stationary
020101	Combustion plants >= 300 MW (boilers)	1A4a i	Commercial/institutional: Stationary
020102	Combustion plants >= 50 and < 300 MW (boilers)	1A4a i	Commercial/institutional: Stationary
020103	Combustion plants < 50 MW (boilers)	1A4a i	Commercial/institutional: Stationary
020104	Stationary gas turbines	1A4a i	Commercial/institutional: Stationary
020105	Stationary engines	1A4a i	Commercial/institutional: Stationary
020106	Other stationary equipments	1A4a i	Commercial/institutional: Stationary
020200	Residential plants	1A4b i	Residential: Stationary
020201	Combustion plants >= 50 MW (boilers)	1A4b i	Residential: Stationary
020202	Combustion plants < 50 MW (boilers)	1A4b i	Residential: Stationary
020203	Gas turbines	1A4b i	Residential: Stationary
020204	Stationary engines	1A4b i	Residential: Stationary
020205	Other equipments (stoves, fireplaces, cooking)	1A4b i	Residential: Stationary
020300	Plants in agriculture, forestry and aquaculture	1A4c i	Agriculture/Forestry/Fishing: Stationary
020301	Combustion plants >= 50 MW (boilers)	1A4c i	Agriculture/Forestry/Fishing: Stationary
020302	Combustion plants < 50 MW (boilers)	1A4c i	Agriculture/Forestry/Fishing: Stationary
020303	Stationary gas turbines	1A4c i	Agriculture/Forestry/Fishing: Stationary
020304	Stationary engines	1A4c i	Agriculture/Forestry/Fishing: Stationary
020305	Other stationary equipments	1A4c i	Agriculture/Forestry/Fishing: Stationary
030100	Comb. in boilers, gas turbines and stationary	1A2g viii	Other manufacturing industry
030101	Combustion plants >= 300 MW (boilers)	1A2g viii	Other manufacturing industry
030102	Combustion plants >= 50 and < 300 MW (boilers)	1A2g viii	Other manufacturing industry
030103	Combustion plants < 50 MW (boilers)	1A2g viii	Other manufacturing industry
030104	Gas turbines	1A2g viii	Other manufacturing industry

	snap_name	CRF id	CRF name
030105	Stationary engines	1A2g viii	Other manufacturing industry
030106	Other stationary equipments	1A2g viii	Other manufacturing industry
030200	Process furnaces without contact (a)	1A2g viii	Other manufacturing industry
030203	Blast furnace cowpers	1A2a	Iron and steel
030204	Plaster furnaces	1A2g viii	Other manufacturing industry
030205	Other furnaces	1A2g viii	Other manufacturing industry
030400	Iron and Steel	1A2a	Iron and steel
030401	Combustion plants >= 300 MW (boilers)	1A2a	Iron and steel
030402	Combustion plants >= 50 and < 300 MW (boilers)	1A2a	Iron and steel
030403	Combustion plants < 50 MW (boilers)	1A2a	Iron and steel
030404	Gas turbines	1A2a	Iron and steel
030405	Stationary engines	1A2a	Iron and steel
030406	Other stationary equipments	1A2a	Iron and steel
030500	Non-Ferrous Metals	1A2b	Non-ferrous metals
030501	Combustion plants >= 300 MW (boilers)	1A2b	Non-ferrous metals
030502	Combustion plants >= 50 and < 300 MW (boilers)	1A2b	Non-ferrous metals
030503	Combustion plants < 50 MW (boilers)	1A2b	Non-ferrous metals
030504	Gas turbines	1A2b	Non-ferrous metals
030505	Stationary engines	1A2b	Non-ferrous metals
030506	Other stationary equipments	1A2b	Non-ferrous metals
030600	Chemical and Petrochemical	1A2c	Chemicals
030601	Combustion plants >= 300 MW (boilers)	1A2c	Chemicals
030602	Combustion plants >= 50 and < 300 MW (boilers)	1A2c	Chemicals
030603	Combustion plants < 50 MW (boilers)	1A2c	Chemicals
030604	Gas turbines	1A2c	Chemicals
030605	Stationary engines	1A2c	Chemicals
030606	Other stationary equipments	1A2c	Chemicals
030700	Non-Metallic Minerals	1A2f	Non-metallic minerals
030701	Mineral wool	1A2f	Non-metallic minerals
030702	Glass	1A2f	Non-metallic minerals
030703	Tile	1A2f	Non-metallic minerals
030704	Gas turbines	1A2f	Non-metallic minerals
030705	Stationary engines	1A2f	Non-metallic minerals
030706	Other non-metallic minerals	1A2f	Non-metallic minerals
030800	Mining and Quarrying	1A2g viii	Other manufacturing industry
030801	Combustion plants >= 300 MW (boilers)	1A2g viii	Other manufacturing industry
030802	Combustion plants >= 50 and < 300 MW (boilers)	1A2g viii	Other manufacturing industry
030803	Combustion plants < 50 MW (boilers)	1A2g viii	Other manufacturing industry
030804	Gas turbines	1A2g viii	Other manufacturing industry
030805	Stationary engines	1A2g viii	Other manufacturing industry
030806	Other stationary equipments	1A2g viii	Other manufacturing industry
030900	Food and Tobacco	1A2e	Food processing, beverages and tobacco
030901	Combustion plants >= 300 MW (boilers)	1A2e	Food processing, beverages and tobacco
030902	Combustion plants >= 50 and < 300 MW (boilers)	1A2e	Food processing, beverages and tobacco
030903	Combustion plants < 50 MW (boilers)	1A2e	Food processing, beverages and tobacco
030904	Gas turbines	1A2e	Food processing, beverages and tobacco
030905	Stationary engines	1A2e	Food processing, beverages and tobacco
030906	Other stationary equipments	1A2e	Food processing, beverages and tobacco
031000	Textile and Leather	1A2g viii	Other manufacturing industry
031001	Combustion plants >= 300 MW (boilers)	1A2g viii	Other manufacturing industry
031002	Combustion plants >= 50 and < 300 MW (boilers)	1A2g viii	Other manufacturing industry
031003	Combustion plants < 50 MW (boilers)	1A2g viii	Other manufacturing industry
031004	Gas turbines	1A2g viii	Other manufacturing industry
031005	Stationary engines	1A2g viii	Other manufacturing industry
031006	Other stationary equipments	1A2g viii	Other manufacturing industry
031100	Paper, Pulp and Print	1A2d	Pulp, Paper and Print
031101	Combustion plants >= 300 MW (boilers)	1A2d	Pulp, Paper and Print
031102	Combustion plants >= 50 and < 300 MW (boilers)	1A2d	Pulp, Paper and Print
031103	Combustion plants < 50 MW (boilers)	1A2d	Pulp, Paper and Print
031104	Gas turbines	1A2d	Pulp, Paper and Print
031105	Stationary engines	1A2d	Pulp, Paper and Print
031106	Other stationary equipments	1A2d	Pulp, Paper and Print
031200	Transport Equipment	1A2g viii	Other manufacturing industry

	snap_name	CRF id	CRF name
031201	Combustion plants >= 300 MW (boilers)	1A2g viii	Other manufacturing industry
031202	Combustion plants >= 50 and < 300 MW (boilers)	1A2g viii	Other manufacturing industry
031203	Combustion plants < 50 MW (boilers)	1A2g viii	Other manufacturing industry
031204	Gas turbines	1A2g viii	Other manufacturing industry
031205	Stationary engines	1A2g viii	Other manufacturing industry
031206	Other stationary equipments	1A2g viii	Other manufacturing industry
031300	Machinery	1A2g viii	Other manufacturing industry
031301	Combustion plants >= 300 MW (boilers)	1A2g viii	Other manufacturing industry
031302	Combustion plants >= 50 and < 300 MW (boilers)	1A2g viii	Other manufacturing industry
031303	Combustion plants < 50 MW (boilers)	1A2g viii	Other manufacturing industry
031304	Gas turbines	1A2g viii	Other manufacturing industry
031305	Stationary engines	1A2g viii	Other manufacturing industry
031306	Other stationary equipments	1A2g viii	Other manufacturing industry
031400	Wood and Wood Products	1A2g viii	Other manufacturing industry
031401	Combustion plants >= 300 MW (boilers)	1A2g viii	Other manufacturing industry
031402	Combustion plants >= 50 and < 300 MW (boilers)	1A2g viii	Other manufacturing industry
031403	Combustion plants < 50 MW (boilers)	1A2g viii	Other manufacturing industry
031404	Gas turbines	1A2g viii	Other manufacturing industry
031405	Stationary engines	1A2g viii	Other manufacturing industry
031406	Other stationary equipments	1A2g viii	Other manufacturing industry
031500	Construction	1A2g viii	Other manufacturing industry
031501	Combustion plants >= 300 MW (boilers)	1A2g viii	Other manufacturing industry
031502	Combustion plants >= 50 and < 300 MW (boilers)	1A2g viii	Other manufacturing industry
031503	Combustion plants < 50 MW (boilers)	1A2g viii	Other manufacturing industry
031504	Gas turbines	1A2g viii	Other manufacturing industry
031505	Stationary engines	1A2g viii	Other manufacturing industry
031506	Other stationary equipments	1A2g viii	Other manufacturing industry
031600	Cement production	1A2f	Non-metallic minerals
031601	Combustion plants >= 300 MW (boilers)	1A2f	Non-metallic minerals
031602	Combustion plants >= 50 and < 300 MW (boilers)	1A2f	Non-metallic minerals
031603	Combustion plants < 50 MW (boilers)	1A2f	Non-metallic minerals
031604	Gas turbines	1A2f	Non-metallic minerals
031605	Stationary engines	1A2f	Non-metallic minerals
031606	Other stationary equipments	1A2f	Non-metallic minerals
032000	Non-specified (Industry)	1A2g viii	Other manufacturing industry
032001	Combustion plants >= 300 MW (boilers)	1A2g viii	Other manufacturing industry
032002	Combustion plants >= 50 and < 300 MW (boilers)	1A2g viii	Other manufacturing industry
032003	Combustion plants < 50 MW (boilers)	1A2g viii	Other manufacturing industry
032004	Gas turbines	1A2g viii	Other manufacturing industry
032005	Stationary engines	1A2g viii	Other manufacturing industry
032006	Other stationary equipments	1A2g viii	Other manufacturing industry

Annex 3A-2 Fuel rate

Table 3A-2.1 Fuel consumption rate for stationary combustion plants 1990-2021, PJ.

Sum of Fuel_rate_PJ			Year									
fuel_type	**fuel_id**	**fuel_gr_abbr**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
SOLID	101A	Other solid fossil										
	102A	Coal	253.4	344.3	286.8	300.8	323.4	270.3	371.9	276.3	234.3	196.5
	103A	Fly ash (fossil)										
	106A	BKB	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
	107A	Coke oven coke	1.3	1.4	1.2	1.2	1.2	1.3	1.2	1.3	1.3	1.4
LIQUID	110A	Petroleum coke	4.5	4.4	4.3	5.7	7.5	5.3	5.9	6.0	5.3	6.8
	203A	Residual oil	32.1	37.0	37.3	32.5	46.6	33.3	38.1	26.7	29.5	23.0
	204A	Gas oil	73.4	76.8	67.3	73.1	64.2	64.2	67.9	61.1	57.8	56.8
	206A	Kerosene	5.1	1.0	0.8	0.8	0.7	0.6	0.5	0.4	0.4	0.3
	225A	Orimulsion						19.9	36.8	40.5	32.6	34.2
	303A	LPG	3.0	2.8	2.5	2.6	2.6	2.8	3.1	2.6	2.8	2.5
	308A	Refinery gas	14.2	14.5	14.9	15.4	16.4	20.8	21.4	16.9	15.2	15.7
GAS	301A	Natural gas	76.1	86.1	90.5	102.5	114.6	132.7	156.3	164.5	178.7	187.9
WASTE	114A	Waste	15.5	16.7	17.8	19.4	20.3	22.9	25.0	26.8	26.6	29.1
	115A	Industrial waste										
BIOMASS	111A	Wood	16.7	17.9	18.6	20.1	19.7	19.5	20.7	20.5	19.7	20.3
	117A	Straw	12.5	13.3	13.9	13.4	12.7	13.1	13.5	13.9	13.9	13.7
		Wood pellets	1.6	2.1	2.5	2.1	2.1	2.3	2.7	2.9	3.2	4.0
	215A	Bio oil	0.7	0.7	0.7	0.8	0.2	0.3	0.1	0.0	0.0	0.0
	309A	Biogas	0.8	0.9	0.9	1.1	1.3	1.8	2.0	2.4	2.7	2.7
	310A	Bio gasification gas					0.1	0.0	0.0	0.0	0.0	0.0
	315A	Biomethane										
Total			**511.0**	**620.3**	**560.1**	**591.5**	**633.8**	**611.2**	**767.1**	**662.9**	**624.1**	**595.0**

Sum of Fuel_rate_PJ			Year									
fuel_type	**fuel_id**	**fuel_gr_abbr**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
SOLID	101A	Other solid fossil										0.0
	102A	Coal	164.7	174.3	174.7	239.0	182.5	154.0	232.0	194.1	170.5	167.7
	103A	Fly ash (fossil)										
	106A	BKB	0.0	0.0	0.0	0.0					0.0	0.0
	107A	Coke oven coke	1.2	1.1	1.1	1.0	1.1	1.0	1.0	1.1	1.0	0.8
LIQUID	110A	Petroleum coke	6.8	7.8	7.8	8.0	8.4	8.1	8.5	9.2	6.9	5.9
	203A	Residual oil	18.0	20.2	24.8	27.3	23.5	21.1	25.4	19.3	15.3	14.2
	204A	Gas oil	50.0	52.2	47.1	47.1	44.0	40.0	35.3	30.9	30.4	32.5
	206A	Kerosene	0.2	0.3	0.3	0.3	0.2	0.3	0.2	0.1	0.1	0.1
	225A	Orimulsion	34.1	30.2	23.8	1.9	0.0					
	303A	LPG	2.4	2.1	2.0	2.1	2.1	2.1	2.2	1.9	1.7	1.5
	308A	Refinery gas	15.6	15.8	15.2	16.6	15.9	15.3	16.1	15.9	14.1	15.0
GAS	301A	Natural gas	186.1	193.8	193.6	195.9	195.1	187.4	191.1	171.0	173.0	165.7
WASTE	114A	Waste	29.8	31.3	33.3	35.1	35.3	35.8	37.8	38.9	40.1	38.1
	115A	Industrial waste	0.5	1.4	1.9	1.5	2.0	2.0	0.6	0.9	1.4	1.2
BIOMASS	111A	Wood	22.3	23.7	23.7	29.1	31.1	33.7	36.5	43.8	45.1	45.9
	117A	Straw	12.2	13.7	15.7	16.9	17.9	18.5	18.5	18.8	15.9	17.4
		Wood pellets	5.1	7.1	7.9	9.8	12.8	16.1	15.6	16.5	18.5	20.1
	215A	Bio oil	0.0	0.2	0.1	0.4	0.6	0.8	1.1	1.2	1.8	1.7
	309A	Biogas	2.9	3.0	3.4	3.6	3.7	3.8	3.9	3.9	3.9	4.2
	310A	Bio gasification gas	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3
	315A	Biomethane										
Total			**552.3**	**578.5**	**576.2**	**635.6**	**576.4**	**540.0**	**626.0**	**567.4**	**539.9**	**532.3**

Sum of Fuel_rate_PJ			Year									
fuel_type	**fuel_id**	**fuel_gr_abbr**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
SOLID	101A	Other solid fossil	0.0	0.0	0.0	0.0						
	102A	Coal	163.0	135.5	106.2	135.0	107.0	76.0	88.2	65.8	67.2	37.8
	103A	Fly ash (fossil)		0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.0
	106A	BKB	0.0	0.0	0.0	0.0	0.0		0.0			
	107A	Coke oven coke	0.7	0.7	0.6	0.6	0.6	0.5	0.3	0.3	0.4	0.3
LIQUID	110A	Petroleum coke	5.1	6.5	6.7	6.1	6.6	6.6	7.6	7.9	6.9	7.7
	203A	Residual oil	12.8	7.8	7.2	5.5	4.5	4.2	4.1	4.1	3.2	3.0
	204A	Gas oil	31.8	25.5	21.7	20.0	13.1	13.9	14.0	12.1	13.5	10.4
	206A	Kerosene	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
	225A	Orimulsion										
	303A	LPG	1.6	1.5	1.7	1.6	1.3	1.8	2.1	2.3	2.3	2.3
	308A	Refinery gas	14.3	13.7	14.8	14.8	15.4	16.2	14.4	15.6	15.0	16.1
GAS	301A	Natural gas	185.7	157.3	147.1	139.3	119.3	120.6	122.5	116.5	113.1	105.5
WASTE	114A	Waste	37.2	37.1	36.1	35.9	37.1	37.7	37.8	38.1	37.1	38.4
	115A	Industrial waste	0.9	1.3	1.2	1.6	1.6	2.2	2.6	2.7	3.4	3.1
BIOMASS	111A	Wood	51.3	48.8	48.6	46.4	45.0	50.1	51.6	51.6	52.7	52.3
	117A	Straw	23.3	20.2	18.3	20.3	18.6	19.8	19.7	20.2	17.6	18.0
	122A	Wood pellets	29.9	30.0	33.2	35.0	36.3	36.5	44.3	57.4	55.2	53.3
	215A	Bio oil	2.0	0.8	1.1	0.9	0.7	0.6	0.3	0.2	0.2	0.1
	309A	Biogas	4.3	4.1	4.4	4.6	5.2	5.3	5.9	5.8	6.3	6.9
	310A	Bio gasification gas	0.2	0.3	0.4	0.1	0.4	0.5	0.5	1.0	1.4	1.5
	315A	Biomethane					0.3	1.0	3.1	5.2	7.1	9.4
Total			**564.3**	**491.3**	**449.5**	**467.6**	**413.2**	**393.6**	**419.0**	**407.0**	**402.8**	**366.5**

Sum of Fuel_rate_PJ			Year	
fuel_type	**fuel_id**	**fuel_gr_abbr**	**2020**	**2021**
SOLID	101A	Other solid fossil		
	102A	Coal	33.2	44.3
	103A	Fly ash (fossil)	0.0	0.1
	106A	BKB		
	107A	Coke oven coke	0.3	0.3
LIQUID	110A	Petroleum coke	7.9	6.9
	203A	Residual oil	3.1	2.7
	204A	Gas oil	9.5	11.7
	206A	Kerosene	0.0	0.0
	225A	Orimulsion		
	303A	LPG	2.3	2.7
	308A	Refinery gas	15.3	15.7
GAS	301A	Natural gas	85.3	85.5
WASTE	114A	Waste	38.2	37.8
	115A	Industrial waste	3.4	2.8
BIOMASS	111A	Wood	57.6	63.1
	117A	Straw	18.9	21.6
	122A	Wood pellets	47.2	66.2
	215A	Bio oil	0.1	0.2
	309A	Biogas	6.7	6.5
	310A	Bio gasification gas	1.6	1.7
	315A	Biomethane	13.5	19.6
Total			**344.2**	**389.3**

Table 3A-2.2 Detailed fuel consumption data for stationary combustion plants, 1990-2021, PJ.

This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Table 3A-3.1 Time series for calorific values of fuels (DEA, 2022a).

		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Crude Oil, Average	GJ per tonne	42.40	42.40	42.40	42.70	42.70	42.70	42.70	43.00	43.00	43.00
Crude Oil, Golf	GJ per tonne	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80
Crude Oil, North Sea	GJ per tonne	42.70	42.70	42.70	42.70	42.70	42.70	42.70	43.00	43.00	43.00
Refinery Feedstocks	GJ per tonne	41.60	41.60	41.60	41.60	41.60	41.60	41.60	42.70	42.70	42.70
Refinery Gas	GJ per tonne	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00
LPG	GJ per tonne	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00
Naphtha (LVN)	GJ per tonne	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50
Motor Gasoline	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
Aviation Gasoline	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
JP4	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
Other Kerosene	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
JP1	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
Gas/Diesel Oil	GJ per tonne	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70
Fuel Oil	GJ per tonne	40.40	40.40	40.40	40.40	40.40	40.40	40.70	40.65	40.65	40.65
Orimulsion	GJ per tonne	27.60	27.60	27.60	27.60	27.60	28.13	28.02	27.72	27.84	27.58
Petroleum Coke	GJ per tonne	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40
Waste Oil	GJ per tonne	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90
White Spirit	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
Bitumen	GJ per tonne	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80
Lubricants	GJ per tonne	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90
Natural Gas	GJ per 1000 Nm^3	39.00	39.00	39.00	39.30	39.30	39.30	39.30	39.60	39.90	40.00
Gas Works Gas	GJ per 1000 m^3							17.00	17.00	17.00	17.00
Liquefied Natural Gas	GJ per 1000 m^3										
Electricity Plant Coal	GJ per tonne	25.30	25.40	25.80	25.20	24.50	24.50	24.70	24.96	25.00	25.00
Other Hard Coal	GJ per tonne	26.10	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50
Coke	GJ per tonne	31.80	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30
Brown Coal Briquettes	GJ per tonne	18.30	18.30	18.30	18.30	18.30	18.30	18.30	18.30	18.30	18.30
Straw	GJ per tonne	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50
Wood Chips	GJ per m^3	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
Wood Chips	GJ per tonne	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30
Firewood, Hardwood	GJ per m^3	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40
Firewood, Conifer	GJ per tonne	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60
Wood Pellets	GJ per tonne	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50
Wood Waste	GJ per tonne	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70
Wood Waste	GJ per m^3	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20
Biogas	GJ per 1000 m^3								23.00	23.00	23.00
Wastes	GJ per tonne	8.20	8.20	9.00	9.40	9.40	10.00	10.50	10.50	10.50	10.50
Bioethanol	GJ per tonne	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70
Liquid Biofuels	GJ per tonne	37.60	37.60	37.60	37.60	37.60	37.60	37.60	37.60	37.60	37.60
Bio Oil	GJ per tonne	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20

Continued		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Crude Oil, Average	GJ per tonne	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
Crude Oil, Golf	GJ per tonne	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80
Crude Oil, North Sea	GJ per tonne	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
Refinery Feedstocks	GJ per tonne	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70
Refinery Gas	GJ per tonne	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00
LPG	GJ per tonne	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00
Naphtha (LVN)	GJ per tonne	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50
Motor Gasoline	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
Aviation Gasoline	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
JP4	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
Other Kerosene	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
JP1	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
Gas/Diesel Oil	GJ per tonne	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70
Fuel Oil	GJ per tonne	40.65	40.65	40.65	40.65	40.65	40.65	40.65	40.65	40.65	40.65
Orimulsion	GJ per tonne	27.62	27.64	27.71	27.65	27.65	27.65	27.65	27.65	27.65	27.65
Petroleum Coke	GJ per tonne	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40
Waste Oil	GJ per tonne	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90
White Spirit	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
Bitumen	GJ per tonne	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80
Lubricants	GJ per tonne	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90
Natural Gas	GJ per 1000 Nm^3	40.15	39.99	40.06	39.94	39.77	39.67	39.54	39.59	39.48	39.46
Gas Works Gas	GJ per 1000 m^3	17.01	16.88	17.39	16.88	17.58	17.51	17.20	17.14	15.50	21.29
Liquefied Natural Gas	GJ per 1000 m^3										
Electricity Plant Coal	GJ per tonne	24.80	24.90	25.15	24.73	24.60	24.40	24.80	24.40	24.30	24.60
Other Hard Coal	GJ per tonne	26.50	26.50	26.50	26.50	26.50	26.50	26.50	26.50	25.81	25.13
Coke	GJ per tonne										
Brown Coal Briquettes	GJ per tonne										
Straw	GJ per tonne	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50
Wood Chips	GJ per m^3	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
Wood Chips	GJ per tonne	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30
Firewood, Hardwood	GJ per m^3	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40
Firewood, Conifer	GJ per tonne	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60
Wood Pellets	GJ per tonne	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50
Wood Waste	GJ per tonne	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70
Wood Waste	GJ per m^3	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20
Biogas	GJ per 1000 m^3	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00
Wastes	GJ per tonne	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50
Bioethanol	GJ per tonne	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70
Liquid Biofuels	GJ per tonne	37.60	37.60	37.60	37.60	37.60	37.60	37.60	37.60	37.50	37.50
Bio Oil	GJ per tonne	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20

Continued		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Crude Oil, Average	GJ per tonne	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
Crude Oil, Golf	GJ per tonne	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80	41.80
Crude Oil, North Sea	GJ per tonne	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00	43.00
Refinery Feedstocks	GJ per tonne	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70
Refinery Gas	GJ per tonne	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00
LPG	GJ per tonne	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00	46.00
Naphtha (LVN)	GJ per tonne	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50	44.50
Motor Gasoline	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
Aviation Gasoline	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
JP4	GJ per tonne	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80	43.80
Other Kerosene	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
JP1	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
Gas/Diesel Oil	GJ per tonne	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70	42.70
Fuel Oil	GJ per tonne	40.65	40.65	40.65	40.65	40.65	40.65	40.65	40.65	40.65	40.65
Orimulsion	GJ per tonne	27.65	27.65	27.65	27.65	27.65	27.65	27.65	27.65	27.65	27.65
Petroleum Coke	GJ per tonne	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40	31.40
Waste Oil	GJ per tonne	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90
White Spirit	GJ per tonne	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50	43.50
Bitumen	GJ per tonne	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80	39.80
Lubricants	GJ per tonne	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90	41.90
Natural Gas	GJ per 1000 Nm^3	39.46	39.51	39.55	38.99	39.53	39.64	39.63	39.66	39.59	38.81
Gas Works Gas	GJ per 1000 m^3	21.35	21.37	19.30	19.31	20.20	19.80	20.28	20.80	20.82	20.80
Liquefied Natural Gas	GJ per 1000 m^3						26.50	26.50	26.50	26.50	26.50
Electricity Plant Coal	GJ per tonne	24.44	24.38	24.23	24.49	24.70	24.10	24.29	24.33	24.13	23.89
Other Hard Coal	GJ per tonne	24.44	24.38	24.23	24.49	24.70	24.10	26.10	26.88	26.64	24.17
Coke	GJ per tonne	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30
Brown Coal Briquettes	GJ per tonne	18.30	18.30	18.30	18.30	18.30	18.30	18.30	18.30	18.30	18.30
Straw	GJ per tonne	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50	14.50
Wood Chips	GJ per m^3	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
Wood Chips	GJ per tonne	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30	9.30
Firewood, Hardwood	GJ per m^3	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40	10.40
Firewood, Conifer	GJ per tonne	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60
Wood Pellets	GJ per tonne	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50
Wood Waste	GJ per tonne	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70
Wood Waste	GJ per m^3	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20
Biogas	GJ per 1000 m^3	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00
Wastes	GJ per tonne	10.50	10.50	10.50	10.60	10.60	10.60	10.60	10.60	10.60	10.60
Bioethanol	GJ per tonne	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70
Liquid Biofuels	GJ per tonne	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50
Bio Oil	GJ per tonne	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20	37.20

Continued		2020	2021
Crude Oil, Average	GJ per tonne	43.00	43.00
Crude Oil, Golf	GJ per tonne	41.80	41.80
Crude Oil, North Sea	GJ per tonne	43.00	43.00
Refinery Feedstocks	GJ per tonne	42.70	42.70
Refinery Gas	GJ per tonne	52.00	52.00
LPG	GJ per tonne	46.00	46.00
Naphtha (LVN)	GJ per tonne	44.50	44.50
Motor Gasoline	GJ per tonne	43.80	43.80
Aviation Gasoline	GJ per tonne	43.80	43.80
JP4	GJ per tonne	43.80	43.80
Other Kerosene	GJ per tonne	43.50	43.50
JP1	GJ per tonne	43.50	43.50
Gas/Diesel Oil	GJ per tonne	42.70	42.70
Fuel Oil	GJ per tonne	40.65	40.65
Orimulsion	GJ per tonne	27.65	27.65
Petroleum Coke	GJ per tonne	31.40	31.40
Waste Oil	GJ per tonne	41.90	41.90
White Spirit	GJ per tonne	43.50	43.50
Bitumen	GJ per tonne	39.80	39.80
Lubricants	GJ per tonne	41.90	41.90
Natural Gas	GJ per 1000 Nm^3	36.70	36.62
Gas Works Gas	GJ per 1000 m^3	20.78	20.84
Liquefied Natural Gas	GJ per 1000 m^3	26.50	26.50
Electricity Plant Coal	GJ per tonne	24.09	23.96
Other Hard Coal	GJ per tonne	25.63	25.42
Coke	GJ per tonne	29.30	29.30
Brown Coal Briquettes	GJ per tonne	18.30	18.30
Straw	GJ per tonne	14.50	14.50
Wood Chips	GJ per m^3	2.80	2.80
Wood Chips	GJ per tonne	9.30	9.30
Firewood, Hardwood	GJ per m^3	10.40	10.40
Firewood, Conifer	GJ per tonne	7.60	7.60
Wood Pellets	GJ per tonne	17.50	17.50
Wood Waste	GJ per tonne	14.70	14.70
Wood Waste	GJ per m^3	3.20	3.20
Biogas	GJ per 1000 m^3	23.00	23.00
Wastes	GJ per tonne	10.60	10.60
Bioethanol	GJ per tonne	26.70	26.70
Liquid Biofuels	GJ per tonne	37.50	37.50
Bio Oil	GJ per tonne	37.20	37.20

Table 3A-3.2 Fuel category correspondence list, DEA, DCE and Climate Convention reporting (CRF).

Danish Energy Agency	DCE Emission database	IPCC fuel category
Other Hard Coal	Coal	Solid
Coke	Coke oven coke	Solid
Electricity Plant Coal	Coal	Solid
Brown Coal Briquettes	BKB	Solid
-	Other solid fossil	Solid
-	Fly ash fossil	Solid
Orimulsion	Orimulsion	Liquid
Petroleum Coke	Petroleum coke	Liquid
Fuel Oil	Residual oil	Liquid
Waste Oil	Residual oil	Liquid
Gas/Diesel Oil	Gas oil	Liquid
Other Kerosene	Kerosene	Liquid
LPG	LPG	Liquid
Refinery Gas	Refinery gas	Liquid
Gas Works Gas	Natural gas	Gas
Natural Gas	Natural gas	Gas
Straw	Straw	Biomass
Wood Waste	Wood	Biomass
Wood Pellets	Wood pellets	Biomass
Wood Chips	Wood	Biomass
Firewood	Wood	Biomass
Wastes, Renewable	Municipal wastes	Biomass
Biooil	Liquid biofuels	Biomass
Biogas	Biogas	Biomass
(Wood applied in gas engines)	Biomass gasification gas	Biomass
Bio methane	Biomethane	Biomass
Biogas distributed in the town gas grid	Biogas	Biomass
Wastes, Non-renewable	Fossil waste	Other fuel

Annex 3A-4 Emission factors

Table 3A-4.1 CO_2 emission factors, 2021.

Fuel	Emission factor, kg per GJ		Reference type	IPCC fuel category
	Biomass	Fossil fuel		
Coal	-	93.94 [1)]	Country specific	Solid
Brown coal briquettes	-	97.5	IPCC (2006)	Solid
Coke oven coke	-	107 [3)]	IPCC (2006)	Solid
Other solid fossil fuels [6)]	-	118 [1)]	Country specific	Solid
Fly ash fossil (from coal)	-	93.94	Country specific	Solid
Petroleum coke	-	93 [3)]	Country-specific	Liquid
Residual oil	-	79.15 [1)]	Country-specific	Liquid
Gas oil	-	74.1 [1)]	Country-specific	Liquid
Kerosene	-	71.9	IPCC (2006)	Liquid
Orimulsion	-	80 [2)]	Country-specific	Liquid
LPG	-	64.8	Country-specific	Liquid
Refinery gas	-	56.486	Country-specific	Liquid
Natural gas, offshore gas turbines	-	57.356	Country-specific	Gas
Natural gas, other [7)]	-	55.47	Country-specific	Gas
Waste	59.2 [3)4)]	+ 42.5[1)3)4)]	Country-specific	Biomass and Other fuels
Industrial waste	59.2 [3)4)]	+ 42.5[1)3)4)]	Country-specific	Biomass and Other fuels
Straw	100	-	Country-specific	Biomass
Wood (national average 2021 for fire-wood, wood chips and wood waste)	103.4	-	Country-specific	Biomass
Wood pellets	97.4	-	Country-specific	Biomass
Bio oil	70.8	-	IPCC (2006)	Biomass
Biogas	81.9	-	Country-specific	Biomass
Biomass gasification gas	142.9[5)]	-	Country-specific	Biomass
Biomethane [7)]	54.9	-	Country-specific	Biomass

1) Plant specific data from EU ETS incorporated for individual plants.

2) Not applied in 2021. Orimulsion was applied in Denmark in 1995 – 2004.

3) Plant specific data from EU ETS incorporated for cement industry and sugar, lime and mineral wool production.

4) The emission factor for waste is (42.5+59.2) kg CO_2 per GJ waste. The fuel consumption and the CO_2 emission have been disaggregated to the two IPCC fuel categories Biomass and Other fossil fuels in CRF. The corresponding fossil CO_2 emission factor for Other fuels is 94.4 kg CO_2 per GJ fossil waste and 107.6 kg biomass CO_2 per GJ biomass waste.

5) Includes a high content of CO_2 in the gas.

6) Anodic carbon. Not applied in Denmark in 2014-2021.

7) Gas distributed in the gas grid consist of a mixture of two fuels: Biomethane and (fossil) natural gas. The two fuels are treated as separate fuels in the emission inventories, see also Chapter 3.2.3.

Time series have been estimated for:

- Coal
- Residual oil
- Refinery gas
- Natural gas applied in offshore gas turbines
- Natural gas, other
- Waste, fossil part
- Wood

For all other fuels the same emission factor has been applied for 1990-2021.

Table 3A-4.2 CO_2 emission factors, time series.

Year	Coal, kg per GJ	Residual oil, kg per GJ	Refinery gas, kg per GJ	Natural gas, offshore gas turbines, kg per GJ	Natural gas, other, kg per GJ	Waste, fossil part kg fossil CO_2 per GJ waste	Wood, kg per GJ
1990	94	78.7	57.6	57.469	56.9	37	99.785
1991	94	78.7	57.6	57.469	56.9	37	99.661
1992	94	78.7	57.6	57.469	56.9	37	99.718
1993	94	78.7	57.6	57.469	56.9	37	99.691
1994	94	78.7	57.6	57.469	56.9	37	99.802
1995	94	78.7	57.6	57.469	56.9	37	99.819
1996	94	78.7	57.6	57.469	56.9	37	99.897
1997	94	78.7	57.6	57.469	56.9	37	99.894
1998	94	78.7	57.6	57.469	56.9	37	100.081
1999	94	78.7	57.6	57.469	56.9	37	100.057
2000	94	78.7	57.6	57.469	57.1	37	99.948
2001	94	78.7	57.6	57.469	57.25	37	100.009
2002	94	78.7	57.6	57.469	57.28	37	100.161
2003	94	78.7	57.6	57.469	57.19	37	100.583
2004	94	78.7	57.6	57.469	57.12	37	100.615
2005	94	78.7	57.6	57.469	56.96	37	100.448
2006	94.4	78.6	57.812	57.879	56.78	37	100.490
2007	94.3	78.5	57.848	57.784	56.78	37	100.293
2008	94.0	78.5	57.948	56.959	56.77	37	100.658
2009	93.6	78.9	56.817	57.254	56.69	37	100.955
2010	93.6	79.2	57.134	57.314	56.74	37	101.041
2011	94.73	79.25	57.861	57.379	56.97	37.5	101.299
2012	94.25	79.21	58.108	57.423	57.03	40.0	101.512
2013	93.95	79.28	58.274	57.295	56.79	42.5	101.275
2014	94.17	79.49	57.620	57.381	56.95	42.5	101.481
2015	94.46	79.17	57.508	57.615	57.06	42.5	101.277
2016	94.95	79.29	57.335	57.704	57.01	42.5	101.537
2017	94.37	79.19	57.109	57.628	57.00	42.5	102.088
2018	94.04	79.42	56.144	57.639	56.89	42.5	102.492
2019	94.13	79.32	56.452	57.588	56.54	42.5	102.793
2020	94.20	79.03	56.813	57.456	55.52	42.5	103.116
2021	93.94	79.15	56.486	57.356	55.47	42.5	103.388

Table 3A-4.3 CH_4 emission factors and references, 2021.

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
SOLID	Coal	1A1a	Public electricity and heat production	0101 0102	0.9	IPCC (2006), Tier 3, Table 2-6, Utility Boiler, Pulverised bituminous coal combustion, Wet bottom.
		1A2 a-g	Industry	03	10	IPCC (2006), Tier 1, Table 2-3, Manufacturing industries.
		1A4b i	Residential	0202	300	IPCC (2006), Tier 1, Table 2.5, Residential, Bituminous coal.
		1A4c i	Agriculture/ Forestry	0203	10	IPCC (2006), Tier 1, Table 2-4, Commercial, coal.[1)]
	BKB	1A4b i	Residential	0202	300	IPCC (2006), Tier 1, Table 2-5, Residential, brown coal briquettes
	Coke oven coke	1A2 a-g	Industry	03	10	IPCC (2006), Tier 1, Table 2-4, Commercial, coke oven coke.
		1A4b i	Residential	0202	300	IPCC (2006), Tier 1, Table 2-5, Residential, coke oven coke.
	Anodic carbon	1A2 a-g	Industry	03	10	IPCC (2006), Tier 1, Table 2-3, Manufacturing industries.
	Fossil fly ash	1A1a	Public electricity and heat production	0101	0.9	IPCC (2006), Tier 3, Table 2-6, Utility Boiler, Pulverised bituminous coal combustion, Wet bottom.
LIQUID	Petroleum coke	1A2 a-g	Industry	03	3	IPCC (2006), Tier 1, Table 2-3, Industry, petroleum coke.
		1A4a	Commercial/ Institutional	0201	10	IPCC (2006), Tier 1, Table 2-4, Commercial, Petroleum coke.
		1A4b	Residential	0202	10	IPCC (2006), Tier 1, Table 2-5, Residential / agricultural, Petroleum coke.
		1A4c	Agriculture/ Forestry	0203	10	IPCC (2006), Tier 1, Table 2-5, Residential / agricultural, Petroleum coke.
	Residual oil	1A1a	Public electricity and heat production	010101	0.8	IPCC (2006), Tier 3, Table 2-6, Utility Boiler, Residual fuel oil.
				010102 010103	1.3	Nielsen et al. (2010a)
				010104	3	IPCC (2006), Tier 1, Table 2-2, Energy industries, residual oil.
				010105	4	IPCC (2006), Tier 3, Table 2-6, Utility, Large diesel engines
				010203	0.8	IPCC (2006), Tier 3, Table 2-6, Utility Boiler, Residual fuel oil.
		1A1b	Petroleum refining	010306	3	IPCC (2006), Tier 1, Table 2-2, Energy industries, residual fuel oil.
		1A2 a-g	Industry	03	1.3	Nielsen et al. (2010a)
				Engines	4	IPCC (2006), Tier 3, Table 2-6, Utility, Large diesel engines
		1A4a	Commercial/ Institutional	0201	1.4	IPCC (2006), Tier 3, Table 2-10, Commercial, residual fuel oil boilers.
		1A4b	Residential	0202	1.4	IPCC (2006), Tier 3, Table 2-9, Residential, residual fuel oil.
		1A4c	Agriculture/ Forestry	0203	1.4	IPCC (2006), Tier 3, Table 2-10, Commercial, residual fuel oil boilers.[1)].
	Gas oil	1A1a	Public electricity and heat production	010101 010102 010103	0.9	IPCC (2006), Tier 3, Table 2-6, Utility, gas oil, boilers.
				010104	3	IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil.
				010105	24	Nielsen et al. (2010a)
				010202 010203	0.9	IPCC (2006), Tier 3, Table 2-6, Utility, gas oil, boilers.
		1A1b	Petroleum refining	010306	3	IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil.
		1A1c	Oil and gas extraction	010500	0.9	IPCC (2006), Tier 3, Table 2-6, Utility, gas oil, boilers.
		1A2 a-g	Industry	03	0.2	IPCC (2006), Tier 3, Table 2-7, Industry, gas oil, boilers.
				Turbines	3	IPCC (2006), Tier 1, Table 2-3, Industry, gas oil.
				Engines	24	Nielsen et al. (2010a)

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
		1A4a	Commercial/ Institutional	0201	0.7	IPCC (2006), Tier 3, Table 2-10, Commercial, gas oil.
				020105	24	Nielsen et al. (2010a)
		1A4b i	Residential	0202	0.7	IPCC (2006), Tier 3, Table 2.9, Residential, gas oil.
				020204	24	Nielsen et al. (2010a)
		1A4c	Agriculture/ Forestry	0203	0.7	IPCC (2006), Tier 3, Table 2-10, Commercial, gas oil[1)].
				020304	24	Nielsen et al. (2010a)
	Kerosene	1A2 a-g	Industry	03	3	IPCC (2006), Tier 1, Table 2-3, Industry, other kerosene.
		1A4a	Commercial/ Institutional	0201	10	IPCC (2006), Tier 1, Table 2-4, Commercial, other kerosene.
		1A4b i	Residential	0202	10	IPCC (2006), Tier 1, Table 2-5, Residential/agricultural, other kerosene.
		1A4c i	Agriculture/ Forestry	0203	10	IPCC (2006), Tier 1, Table 2-5, Residential/agricultural, other kerosene.
	LPG	1A1a	Public electricity and heat production	0101 0102	1	IPCC (2006), Tier 1, Table 2-2, Energy Industries, LPG.
		1A1b	Petroleum refining	0103	1	IPCC (2006), Tier 1, Table 2-2, Energy Industries, LPG.
		1A2 a-g	Industry	03	1	IPCC (2006), Tier 1, Table 2-3, Industry, LPG
		1A4a	Commercial/ Institutional	0201	5	IPCC (2006), Tier 1, Table 2-4, Commercial, LPG.
		1A4b i	Residential	0202	5	IPCC (2006), Tier 1, Table 2-5, Residential / agricultural, LPG.
		1A4c i	Agriculture/ Forestry	0203	5	IPCC (2006), Tier 1, Table 2-5, Residential / agricultural, LPG.
	Refinery gas	1A1b	Petroleum refining	010304	1.7	Assumed equal to natural gas fuelled gas turbines. Nielsen et al. (2010a)
				010306	1	IPCC (2006), Tier 1, Table 2-2, refinery gas.
GAS	Natural gas	1A1a	Public electricity and heat production	010101 010102 010103	1	IPCC (2006), Tier 3, Table 2-6, Utility, natural gas, boilers.
				010104	1.7	Nielsen et al. (2010a)
				010105	481	Nielsen et al. (2010a)
				010202 010203	1	IPCC (2006), Tier 3, Table 2-6, Utility, natural gas, boilers.
		1A1b	Petroleum refining	010306	1	Assumed equal to industrial boilers.
		1A1c	Oil and gas extraction	010503	1	Assumed equal to industrial boilers.
				010504	1.7	Nielsen et al. (2010a)
		1A2 a-g	Industry	Other	1	IPCC (2006), Tier 3, Table 2-7, Industry, natural gas boilers.
				Gas turbines	1.7	Nielsen et al. (2010a)
				Engines	481	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201	1	IPCC (2006), Tier 3, Table 2-10, Commercial, natural gas boilers.
				020105	481	Nielsen et al. (2010a)
		1A4b i	Residential	0202	37.5	Schweitzer, 2020
				020204	481	Nielsen et al. (2010a)
		1A4c i	Agriculture/ Forestry	0203	1	IPCC (2006), Tier 3, Table 2-10, Commercial, natural gas boilers[1)].
				020304	481	Nielsen et al. (2010a)
WASTE	Waste	1A1a	Public electricity and heat production	0101 0102	0.34	Nielsen et al. (2010a)
		1A2 a-g	Industry	03	30	IPCC (2006), Tier 1, Table 2-3, Industry, municipal wastes.
		1A4a	Commercial/ Institutional	0201	30	IPCC (2006), Tier 1, Table 2-3, Industry, municipal wastes [2)].
	Industrial waste	1A2f	Industry	0316	30	IPCC (2006), Tier 1, Table 2-3, Industry, industrial wastes.
BIOMASS	Wood	1A1a	Public electricity and heat production	0101	3.1	Nielsen et al. (2010a)

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
				0102	11	IPCC (2006), Tier 3, Table 2-6, Utility boilers, wood
		1A2 a-g	Industry	03	11	IPCC (2006), Tier 3, Table 2-7, Industry, wood, boilers.
		1A4a	Commercial/ Institutional	0201	11	IPCC (2006), Tier 3, Table 2-10, Commercial, wood.
		1A4b i	Residential	0202	93.6	DCE estimate based on technology distribution, Nielsen et al. (2021) 3)
		1A4c i	Agriculture/ Forestry	0203	11	IPCC (2006), Tier 3, Table 2-10, Commercial, wood.1).
	Straw	1A1a	Public electricity and heat production	0101	0.47	Nielsen et al. (2010a)
				0102	30	IPCC (2006), Tier 1, Table 2-2, Energy industries, other primary solid biomass
		1A4b i	Residential	0202	300	IPCC (2006), Tier 1, Table 2-5, Residential, other primary solid biomass.
		1A4c i	Agriculture/ Forestry	020300	300	IPCC (2006), Tier 1, Table 2-5, Agriculture, other primary solid biomass.
				020302	30	IPCC (2006), Tier 1, Table 2-2, Energy industries, other primary solid biomass (large agricultural plants considered equal to this plant category)
	Wood pellets	1A1a	Public electricity and heat production	0101	3.1	Nielsen et al. (2010a)
				0102	3	Paulrud et al. (2005)
		1A2 a-g	Industry	03	3	Paulrud et al. (2005)
		1A4a	Commercial/ Institutional	0201	3	Paulrud et al. (2005)
		1A4b i	Residential	0202	3	Paulrud et al. (2005)
		1A4c i	Agriculture/ Forestry	0203	3	Paulrud et al. (2005)
	Bio oil	1A1a	Public electricity and heat production	010102	3	IPCC (2006), Tier 1, Table 2-2, Energy industries, biodiesels.
				010105	24	Nielsen et al. (2010a) assumed same emission factor as for gas oil fuelled engines.
				0102	3	IPCC (2006), Tier 1, Table 2-2, Energy industries, biodiesels.
		1A2 a-g	Industry	03	3	IPCC (2006), Tier 1, Table 2-3, Industry, biodiesels.
				030902	0.2	-
		1A4b i	Residential	0202	10	IPCC (2006), Tier 1, Table 2-5, Residential, biodiesels.
	Biogas	1A1a	Public electricity and heat production	0101	1	IPCC (2006), Tier 1, Table 2-2, Energy industries, other biogas.
				010105	434	Nielsen et al. (2010a)
				0102	1	IPCC (2006), Tier 1, Table 2-2, Energy industries, other biogas.
		1A2 a-g	Industry	03	1	IPCC (2006), Tier 1, Table 2-3, Industry, other biogas.
				Engines	434	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201	5	IPCC (2006), Tier 1, Table 2-4, Commercial, other biogas.
				020105	434	Nielsen et al. (2010a)
		1A4b	Residential	0202	1	Assumed equal to natural gas.
		1A4c i	Agriculture/ Forestry	0203	5	IPCC (2006), Tier 1, Table 2-5, Agriculture, other biogas.
				020304	434	Nielsen et al. (2010a)
	Bio gasification gas	1A1a	Public electricity and heat production	010101	1	Assumed equal to biogas.
				010105	13	Nielsen et al. (2010a)
		1A4a	Commercial/Institutional	020105	13	Nielsen et al. (2010a)
	Biomethane	1A1a	Public electricity and heat production	0101 0102	1	Assumed equal to natural gas.
				Turbines	1.7	Assumed equal to natural gas.
				Engines	481	Assumed equal to natural gas.

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
		1A1b	Petroleum refining	0103	1	Assumed equal to natural gas.
		1A2 a-g	Industry	03	1	Assumed equal to natural gas.
				Tur-bines	1.7	Assumed equal to natural gas.
				Engines	481	Assumed equal to natural gas.
		1A4a	Commercial/ Institu-tional	0201	1	Assumed equal to natural gas.
				Engines	481	Assumed equal to natural gas.
		1A4b	Residential	0202	37.5	Assumed equal to natural gas.
				Engines	481	Assumed equal to natural gas.
		1A4c	Agriculture/ Forestry	0203	1	Assumed equal to natural gas.
				Engines	481	Assumed equal to natural gas.

1) Assumed same emission factors as for commercial plants. Plant capacity and technology are similar for Danish plants.

2) Assumed same emission factor as for industrial plants. Plant capacity and technology is similar to industrial plants rather than to residential plants.

3) Aggregated emission factor based on the technology distribution in the sector (Nielsen et al., 2021) and technology specific emission factors that refer to Paulrud et al. (2005), Johansson et al. (2004) and Olsson & Kjällstrand (2005). The emission factor is within the IPCC (2006) interval for residential wood combustion (100-900 g per GJ).

In general, the same CH_4 emission factors have been applied for 1990-2021. However, time series have been estimated for both natural gas fuelled engines and biogas fuelled engines, residential wood combustion, natural gas fuelled gas turbines[1] and waste incineration plants.

[1] A minor emission source.

Table 3A-4.4 CH_4 emission factors, time series.

Year	Natural gas fuelled engines Emission factor, g per GJ	Biogas fuelled engines Emission factor, g per GJ	Residential wood combustion, g per GJ	Waste incineration g per GJ	Natural gas fuelled gas turbines, g per GJ
1990	266	239	327	0.59	1.5
1991	309	251	321	0.59	1.5
1992	359	264	314	0.59	1.5
1993	562	276	308	0.59	1.5
1994	623	289	302	0.59	1.5
1995	632	301	296	0.59	1.5
1996	616	305	289	0.59	1.5
1997	551	310	283	0.59	1.5
1998	542	314	276	0.59	1.5
1999	541	318	270	0.59	1.5
2000	537	323	263	0.59	1.5
2001	522	342	256	0.59	1.5
2002	508	360	248	0.59	1.6
2003	494	379	240	0.59	1.6
2004	479	397	227	0.51	1.7
2005	465	416	215	0.42	1.7
2006	473	434	206	0.34	1.7
2007	481	434	197	0.34	1.7
2008	481	434	188	0.34	1.7
2009	481	434	178	0.34	1.7
2010	481	434	167	0.34	1.7
2011	481	434	160	0.34	1.7
2012	481	434	152	0.34	1.7
2013	481	434	145	0.34	1.7
2014	481	434	138	0.34	1.7
2015	481	434	131	0.34	1.7
2016	481	434	124	0.34	1.7
2017	481	434	117	0.34	1.7
2018	481	434	111	0.34	1.7
2019	481	434	105	0.34	1.7
2020	481	434	99	0.34	1.7
2021	481	434	94	0.34	1.7

Table 3A-4.5 N_2O emission factors and references, 2021.

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
SOLID	Coal	1A1a	Public electricity and heat production	0101	0.8	Henriksen (2005)
				0102	1.4	IPCC (2006), Tier 3, Table 2.6, Utility source, pulverised bituminous coal, wet bottom boiler.
		1A2 a-g	Industry	03	1.5	IPCC (2006), Tier 1, Table 2-3, Manufacturing industries, coal
		1A4b i	Residential	0202	1.5	IPCC (2006), Tier 1, Table 2-5, Residential, coal
		1A4c i	Agriculture/ Forestry	0203	1.5	IPCC (2006), Tier 1, Table 2-4, Commercial, coal[1)]
	BKB	1A4b i	Residential	0202	1.5	IPCC (2006), Tier 1, Table 2-5, Residential, brown coal briquettes
	Coke oven coke	1A2 a-g	Industry	03	1.5	IPCC (2006), Tier 1, Table 2-3, Industry, coke oven coke
			Industry – mineral wool	030701	71	Emission factor based on plant specific data for the mineral wool industry, 2021
		1A4b i	Residential	020200	1.5	IPCC (2006), Tier 1, Table 2-5, Residential, coke oven coke
	Anodic carbon	1A2 a-g	Industry	03	1.5	IPCC (2006), Tier 1, Table 2-3, manufacturing industries, other bituminous coal
	Fossil fly ash	1A1a	Public electricity and heat production	0101	0.8	Assumed equal to coal.
LIQUID	Petroleum coke	1A2 a-g	Industry – other	03	0.6	IPCC (2006), Tier 1, Table 2-3, Industry, petroleum coke
				031600	1.5	-
		1A4a	Commercial/ Institutional	0201	0.6	IPCC (2006), Tier 1, Table 2-4, Commercial, petroleum coke
		1A4b i	Residential	0202	0.6	IPCC (2006), Tier 1, Table 2-5, Residential, petroleum coke
		1A4c i	Agriculture/ Forestry	0203	0.6	IPCC (2006), Tier 1, Table 2-5, Residential/Agricultural, petroleum coke
	Residual oil	1A1a	Public electricity and heat production	010101	0.3	IPCC (2006), Tier 3, Table 2-6, Utility, residual fuel oil
				010102 010103	5	Nielsen et al. (2010a)
				010104 010105	0.6	IPCC (2006), Tier 1, Table 2-2, Energy industries, residual fuel oil
				010203	0.3	IPCC (2006), Tier 3, Table 2-6, Utility, residual fuel oil
		1A1b	Petroleum refining	010306	0.6	IPCC (2006), Tier 1, Table 2-2, Energy industries, residual fuel oil
		1A2 a-g	Industry	03	5	Nielsen et al. (2010a)
				Engines	0.6	IPCC (2006), Tier 1, Table 2-3, manufacturing industries and construction, residual fuel oil.
		1A4a	Commercial/ Institutional	0201	0.3	IPCC (2006), Tier 3, Table 2-10, Commercial, fuel oil boilers
		1A4b i	Residential	0202	0.6	IPCC (2006), Tier 1, Table 2-5, Residential, residual fuel oil
		1A4c i	Agriculture/ Forestry	0203	0.3	IPCC (2006), Tier 3, Table 2-10, Commercial, fuel oil boilers[1)]
	Gas oil	1A1a	Public electricity and heat production	010101 010102 010103	0.4	IPCC (2006), Tier 3, Table 2-6, Utility, gas oil boilers
				010104	0.6	IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil
				010105	2.1	Nielsen et al. (2010a)

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
				0102	0.4	IPCC (2006), Tier 3, Table 2-6, Utility, gas oil boilers
		1A1b	Petroleum refining	010306	0.6	IPCC (2006), Tier 1, Table 2-2, Energy industries, gas oil
		1A1c	Oil and gas extraction	010500	0.4	IPCC (2006), Tier 3, Table 2-6, Utility, gas oil boilers
		1A2 a-g	Industry	03	0.4	IPCC (2006), Tier 3, Table 2-7, Industry, gas oil boilers
				Tur-bines	0.6	IPCC (2006), Tier 1, Table 2-3, Industry, gas oil
				Engines	2.1	Nielsen et al. (2010a)
			Industry – mineral wool	030701	71	Emission factor based on plant specific data for the mineral wool industry, 2021
		1A4a	Commercial/ Institutional	0201	0.4	IPCC (2006), Tier 3, Table 2-10, Commercial, gas oil boilers
				Engines	2.1	Nielsen et al. (2010a)
		1A4b i	Residential	0202	0.6	IPCC (2006), Tier 1, Table 2-5, Residential, gas oil
				Engines	2.1	Nielsen et al. (2010a)
		1A4c	Agriculture/ Forestry	0203	0.4	IPCC (2006), Tier 3, Table 2-10, Commercial, gas oil boilers[1)]
				Engines	2.1	Nielsen et al. (2010a)
	Kerosene	1A2 a-g	Industry	03	0.6	IPCC (2006), Tier 1, Table 2-3, Industry, other kerosene
		1A4a	Commercial/ Institutional	0201	0.6	IPCC (2006), Tier 1, Table 2-4, Commercial, other kerosene
		1A4b i	Residential	0202	0.6	IPCC (2006), Tier 1, Table 2-5, Residential, other kerosene
		1A4c i	Agriculture/ Forestry	0203	0.6	IPCC (2006), Tier 1, Table 2-4, Commercial, other kerosene [1)]
	LPG	1A1a	Public electricity and heat production	0101 0102	0.1	IPCC (2006), Tier 1, Table 2-2, Energy industries, LPG
		1A1b	Petroleum refining	010306	0.1	IPCC (2006), Tier 1, Table 2-2, Energy industries, LPG
		1A2 a-g	Industry	03	0.1	IPCC (2006), Tier 1, Table 2-3, Industry, LPG
		1A4a	Commercial/ Institutional	0201	0.1	IPCC (2006), Tier 1, Table 2-4, Commercial, LPG
		1A4b i	Residential	0202	0.1	IPCC (2006), Tier 1, Table 2-5, Residential, LPG
		1A4c i	Agriculture/ Forestry	0203	0.1	IPCC (2006), Tier 1, Table 2-5, Residential/Agricultural, LPG
	Refinery gas	1A1b	Petroleum refining	010304	1	Assumed equal to natural gas fuelled turbines. Based on Nielsen et al. (2010a).
				010306	0.1	IPCC (2006), Tier 1, Table 2-2, Energy industries, refinery gas
GAS	Natural gas	1A1a	Public electricity and heat production	010101 010102 010103	1	IPCC (2006), Tier 3, Table 2-6, Natural gas, Utility, boiler
				010104	1	Nielsen et al. (2010a)
				010105	0.58	Nielsen et al. (2010a)
				0102	1	IPCC (2006), Tier 3, Table 2-6, Natural gas, Utility, boiler
		1A1b	Petroleum refining	010306	1	IPCC (2006), Tier 3, Table 2-6, Natural gas, Utility, boiler
		1A1c	Oil and gas extraction	010504	1	Nielsen et al. (2010a)
		1A2 a-g	Industry	03	1	IPCC (2006), Tier 3, Table 2-7, Industry, natural gas boilers

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
				Gas turbines	1	Nielsen et al. (2010a)
				Engines	0.58	Nielsen et al. (2010a)
			Industry – mineral wool	030701	71	Emission factor based on plant specific data for the mineral wool industry, 2021
		1A4a	Commercial/ Institutional	020100 020103	1	IPCC (2006), Tier 3, Table 2-10, Commercial, natural gas boilers
				Engines	0.58	Nielsen et al. (2010a)
		1A4b i	Residential	0202	1	IPCC (2006), Tier 3, Table 2-9, Residential, natural gas boilers
				Engines	0.58	Nielsen et al. (2010a)
		1A4c i	Agriculture/ Forestry	0203	1	IPCC (2006), Tier 3, Table 2-10, Commercial, natural gas boilers [1)]
				Engines	0.58	Nielsen et al. (2010a)
WASTE	Waste	1A1a	Public electricity and heat production	0101 0102	1.2	Nielsen et al. (2010a)
		1A2 a-g	Industry	03	4	IPCC (2006), Tier 1, Table 2-3, Industry, wastes
		1A4a	Commercial/ Institutional	0201	4	IPCC (2006), Tier 1, Table 2-4, Commercial, municipal wastes
	Industrial waste	1A2 a-g	Industry	03	4	IPCC (2006), Tier 1, Table 2-3, Industry, industrial wastes
BIO-MASS	Wood	1A1a	Public electricity and heat production	0101	0.8	Nielsen et al. (2010a)
				0102	4	IPCC (2006), Tier 1, Table 2-2, Energy industries, wood
		1A2 a-g	Industry	03	7	IPCC (2006), Table 2-7 Industrial source emission factors, wood / wood waste boilers
		1A4a	Commercial/ Institutional	0201	4	IPCC (2006), Tier 1, Table 2-4, Commercial, wood
		1A4b i	Residential	0202	4	IPCC (2006), Tier 1, Table 2-5, Residential, wood
		1A4c i	Agriculture/ Forestry	0203	4	IPCC (2006), Tier 1, Table 2-5, Agriculture, wood
	Straw	1A1a	Public electricity and heat production	0101	1.1	Nielsen et al. (2010a)
				0102	4	IPCC (2006), Tier 1, Table 2-2, Energy industries, other primary solid biomass
		1A4b i	Residential	0202	4	IPCC (2006), Tier 1, Table 2-5, Residential, other primary solid biomass
		1A4c i	Agriculture/ Forestry	0203	4	IPCC (2006), Tier 1, Table 2-5, Agriculture, other primary solid biomass
	Wood pellets	1A1a	Public electricity and heat production	0101	0.8	Nielsen et al. (2010a)
				0102	4	IPCC (2006), Tier 1, Table 2-2, Energy industries, wood
		1A2 a-g	Industry	03	4	IPCC (2006), Tier 1, Table 2-3, Industry, wood
		1A4a	Commercial/ Institutional	0201	4	IPCC (2006), Tier 1, Table 2-4, Commercial, wood
		1A4b i	Residential	0202	4	IPCC (2006), Tier 1, Table 2-5, Residential, wood
	Bio oil	1A1a	Public electricity and heat production	0101 0102	0.6	IPCC (2006), Tier 3, Table 2-2, Utility, biodiesels
				Engines	2.1	Assumed equal to gas oil. Based on Nielsen et al. (2010a)
		1A2 a-g	Industry	03	0.4	Assumed equal to gas oil.

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
		1A4b i	Residential	0202	0.6	IPCC (2006), Tier 1, Table 2-5, Residential, biodiesels
	Biogas	1A1a	Public electricity and heat production	0101 0102	0.1	IPCC (2006), Tier 1, Table 2-2, Energy industries, other biogas
				Engines	1.6	Nielsen et al. (2010a)
		1A2 a-g	Industry	03	0.1	IPCC (2006), Tier 1, Table 2-3, Industry, other biogas
				Engines	1.6	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201	0.1	IPCC (2006), Tier 1, Table 2,4, Commercial, other biogas
				Engines	1.6	Nielsen et al. (2010a)
		1A4b	Residential	0202	1	Assumed equal to natural gas.
		1A4c i	Agriculture/ Forestry	0203	0.1	IPCC (2006), Tier 1, Table 2-5, Agriculture, other biogas
				Engines	1.6	Nielsen et al. (2010a)
	Bio gasification gas	1A1a	Public electricity and heat production	010101	0.1	Assumed equal to biogas.
				010105	2.7	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	020105	2.7	Nielsen et al. (2010a)
	Biomethane	1A1a	Public electricity and heat production	0101 or 0102	1	Assumed equal to natural gas.
				Engines	0.58	Assumed equal to natural gas.
		1A1b	Petroleum refining	0103	1	Assumed equal to natural gas.
		1A2 a-g	Industry	03	1	Assumed equal to natural gas.
				Engines	0.58	Assumed equal to natural gas.
		1A4a	Commercial/ Institutional	0201	1	Assumed equal to natural gas.
				Engines	0.58	Assumed equal to natural gas.
		1A4b	Residential	0202	1	Assumed equal to natural gas.
				Engines	0.58	Assumed equal to natural gas.
		1A4c	Agriculture/ Forestry	0203	1	Assumed equal to natural gas.
				Engines	0.58	Assumed equal to natural gas.

1) In Denmark, plants in Agriculture/Forestry are similar to Commercial plants.

Time series have been estimated for natural gas fuelled gas turbines and refinery gas fuelled turbines. All other emission factors have been applied unchanged for 1990-2021.

Table 3A-4.6 N_2O emission factors, time series.

Year	Natural gas fuelled gas turbines. Emission factor, g per GJ	Refinery gas fuelled gas turbines. Emission factor, g per GJ
1990	2.2	2.2
1991	2.2	2.2
1992	2.2	2.2
1993	2.2	2.2
1994	2.2	2.2
1995	2.2	2.2
1996	2.2	2.2
1997	2.2	2.2
1998	2.2	2.2
1999	2.2	2.2
2000	2.2	2.2
2001	2.0	2.0
2002	1.9	1.9
2003	1.7	1.7
2004	1.5	1.5
2005	1.4	1.4
2006	1.2	1.2
2007	1.0	1.0
2008	1.0	1.0
2009	1.0	1.0
2010	1.0	1.0
2011	1.0	1.0
2012	1.0	1.0
2013	1.0	1.0
2014	1.0	1.0
2015	1.0	1.0
2016	1.0	1.0
2017	1.0	1.0
2018	1.0	1.0
2019	1.0	1.0
2020	1.0	1.0
2021	1.0	1.0

Table 3A-4.15 Technology specific CH_4 emission factors for residential wood combustion.

Technology	Emission factor, g per GJ	Reference
Stoves (-1989)	430	Methane emissions from residential biomass combustion, Paulrud et al. (2005) (SMED report, Sweden)
Stoves (1990-2007)	215	Assumed ½ the emission factor for stoves (-1989).
Stoves (2008-2014)	125	Estimated based on the emission factor for stoves (1990-2007) and the emission factors for NMVOC.
Stoves (2015-2016)	125	Same as stoves (2008-2014)
Stoves (2017-)	125	Same as stoves (2008-2014)
Eco labelled stoves / new advanced stoves (-2014)	2	Low emissions from wood burning in an ecolabelled residential boiler. Olsson & Kjällstrand (2005).
Eco labelled stoves / new advanced stoves (2015-2016)	2	Same as advanced/ecolabelled stoves
Eco labelled stoves / new advanced stoves (2017-)	2	Same as advanced/ecolabelled stoves
Open fireplaces and similar	430	Assumed equal to stoves (-1989).
Masonry heat accumulating stoves and similar	215	Assumed equal to stoves (-1989).
Boilers with accumulation tank (-1979)	211	Methane emissions from residential biomass combustion, Paulrud et al 2005 (SMED report, Sweden)
Boilers without accumulation tank (-1979)	256	Methane emissions from residential biomass combustion, Paulrud et al 2005 (SMED report, Sweden)
Boilers with accumulation tank (1980-)	50	Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Johansson et al. (2004)
Boilers without accumulation tank (1980-)	50	Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Johansson et al. (2004)

Annex 3A-5 Large point sources

Table 3A-5.1 Large point sources, 2021 (stationary combustion).

Large point sources
Aalborg Portland
AarhusKarlshamn Denmark A/S
AffaldPlus+, Naestved Forbraendingsanlaeg
Affaldplus+, Slagelse Forbr. and DONG Slagelse KVV
Affaldscenter aarhus - Forbraendsanlaegget
Affaldsforbraendingsanlaeg I/S REFA
Amagerforbraending
Amagervaerket
Ardagh Glass Holmegaard A/S
Asnaesvaerket
Avedoerevaerket
AVV Forbraendingsanlaeg
Bofa I/S
Cheminova
Dalum Kraftvarmevaerk
Danisco Grindsted Dupont
DanSteel
DTU
Duferco Danish Steel
Esbjergvaerket
Faxe Kalk
Fjernvarme Fyn, Centrum Varmecentral
Frederikshavn Affaldskraftvarmevaerk
Fynsvaerket
H.C.Oerstedsvaerket
Haldor Topsoee
Hammel Fjernvarmeselskab
Herningvaerket
Hilleroed Kraftvarmevaerk
Horsens Kraftvarmevaerk
I/S Kara Affaldsforbraendingsanlaeg
I/S Kraftvarmevaerk Thisted
I/S Nordforbraending
I/S Reno Nord
I/S Reno Syd
I/S Vestforbraending
Koege Kraftvarmevaerk
Kolding Forbraendingsanlaeg TAS
Kommunekemi
Kyndbyvaerket
L90 Affaldsforbraending
LECA Danmark
Maabjergvaerket
Maricogen
Nordic Sugar Nakskov
Nordic Sugar Nykoebing
Nordjyllandsvaerket
Nybro Gasbehandlingsanlaeg
Odense Kraftvarmevaerk
Oestkraft
Randersvaerket Verdo
Rensningsanlaegget Lynetten
Rockwool A/S Doense
Rockwool A/S Vamdrup
Saint-Gobain Isover A/S
Shell Raffinaderi
Silkeborg Kraftvarmevaerk

Continued
Skaerbaekvaerket
Soenderborg Kraftvarmevaerk
Statoil Raffinaderi
Studstrupvaerket
Svanemoellevaerket
Svendborg Kraftvarmevaerk
Viborg Kraftvarme
Vordingborg Kraftvarme

Table 3A-5.2 Large point sources, aggregated fuel consumption in 2021.

nfr_id_EA	fuel_id	fuel_gr_abbr	Fuel, TJ
1A1a	102A	Coal	39071
	103A	Fossil fly ash	97
	111A	Wood	31248
	114A	Waste	36855
	117A	Straw	5827
	122A	Wood Pellets	45056
	203A	Residual oil	730
	204A	Gas oil	499
	215A	Bio oil	1
	301A	Natural gas	6293
	303A	LPG	1
	309A	Biogas	7
	315A	Biomethane	1752
1A1a Total			167437
1A1b	203A	Residual oil	140
	204A	Gas oil	16
	301A	Natural gas	654
	303A	LPG	0
	308A	Refinery gas	15714
	315A	Biomethane	182
1A1b Total			16706
1A1c	204A	Gas oil	0
	301A	Natural gas	91
	315A	Biomethane	0
1A1c Total			91
1A2a	204A	Gas oil	3
	301A	Natural gas	1360
	303A	LPG	2
	315A	Biomethane	379
1A2a Total			1743
1A2c	204A	Gas oil	0
	301A	Natural gas	838
	303A	LPG	1
	315A	Biomethane	233
1A2c Total			1073
1A2e	102A	Coal	372
	107A	Coke oven coke	102
	111A	Wood	719
	203A	Residual oil	1717
	204A	Gas oil	529
	215A	Bio oil	103
	301A	Natural gas	246
	303A	LPG	45
	309A	Biogas	73
	315A	Biomethane	68
1A2e Total			3975
1A2f	102A	Coal	3851
	107A	Coke oven coke	220
	110A	Petroleum coke	6473
	111A	Wood	1061
	114A	Waste	8
	115A	Industrial waste	2829
	203A	Residual oil	64
	204A	Gas oil	112
	215A	Bio oil	0
	301A	Natural gas	1394
	303A	LPG	242
	315A	Biomethane	388
1A2f Total			16643
1A4a i	111A	Wod	203
	114A	Waste	0
	309A	Biogas	0
1A4a i Total			203
Grand Total			207869

Annex 3A-6 Adjustment of CO_2 emission

Table 3A-6.1 Adjustment of CO_2 emission (DEA, 2022a).

		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Actual Degree Days	Degree days	2857	3284	3022	3434	3148	3297	3837	3236	3217	3056
Normal Degree Days	Degree days	3379	3380	3359	3365	3366	3378	3395	3389	3375	3339
Net electricity import	PJ	25.4	-7.1	13.5	4.3	-17.4	-2.9	-55.4	-26.1	-15.6	-8.3
Actual CO_2 emission	1 000 000 tonnes	38.6	48.2	42.3	44.6	48.1	44.9	57.9	48.1	44.1	40.9
Adjusted CO_2 emission	1 000 000 tonnes	44.9	46.6	45.2	45.6	44.3	44.2	44.9	42.1	40.5	39.0
Continued		**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Actual Degree Days	Degree days	2902	3279	3011	3150	3113	3068	2908	2807	2853	3061
Normal Degree Days	Degree days	3304	3289	3273	3271	3261	3224	3188	3136	3120	3127
Net electricity import	PJ	2.4	-2.1	-7.5	-30.8	-10.3	4.9	-25.0	-3.4	5.2	1.2
Actual CO_2 emission	1 000 000 tonnes	36.9	38.5	38.0	42.8	36.8	33.1	40.8	35.4	32.5	31.7
Adjusted CO_2 emission	1 000 000 tonnes	37.6	38.1	36.4	36.0	34.6	34.2	35.2	34.6	33.7	32.0
Continued		**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Actual Degree Days	Degree days	3742	2970	3234	3207	2664	2921	2998	2970	2900	2847
Normal Degree Days	Degree days	3171	3156	3166	3155	3131	3112	3070	3057	3041	3030
Net electricity import	PJ	-4.1	4.7	18.8	3.9	10.3	21.3	18.2	16.4	18.8	20.9
Actual CO2 emission	1 000 000 tonnes	32.1	27.4	23.8	25.8	21.5	18.9	20.2	17.7	17.5	14.2
Adjusted CO2 emission	1 000 000 tonnes	31.2	28.4	28.0	26.4	23.3	22.5	23.3	20.4	20.5	17.4
Continued		**2020**	**2021**								
Actual Degree Days	Degree days	2715	3098								
Normal Degree Days	Degree days	3021	3012								
Net electricity import	PJ	24.8	17.5								
Actual CO2 emission	1 000 000 tonnes	12.5	13.5								
Adjusted CO2 emission	1 000 000 tonnes	15.9	15.7								

Annex 3A-7 Uncertainty estimates

Table 3A-7.1 Uncertainty estimation, approach 1, GHG
This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Table 3A-7.2 Uncertainty estimation, approach 1, CO_2
This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Table 3A-7.3 Uncertainty estimation, approach 1, CH_4
This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Table 3A-7.4 Uncertainty estimation, approach 1, N_2O
This table is available at: https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Annex 3A-8 Emission inventory 2021 based on SNAP sectors

Table 3A-8.1 Emission inventory 2021 based on SNAP sectors.

CRF	SNAP	CO_2, kt	CH_4, t	N_2O, t
1A1a	010100	0.0	0.0	0.0
	010101	3804.2	153.7	63.5
	010102	924.8	72.3	47.8
	010103	434.6	11.2	16.9
	010104	383.9	64.4	25.3
	010105	235.7	3956.0	12.7
	010200	0.0	0.0	0.0
	010201	0.0	0.0	0.0
	010202	47.0	1.0	1.0
	010203	446.7	367.6	97.5
	010205	0.0	0.0	0.0
1A1a Total		6277.0	4626.2	264.7
1A1b	010304	114.2	3.3	1.9
	010306	823.9	15.1	2.3
1A1b Total		938.1	18.4	4.2
1A2	030104	0.0	0.0	0.0
	030105	0.0	0.0	0.0
	030106	2.7	0.1	0.1
	030400	19.5	0.4	0.3
	030402	75.7	1.7	1.7
	030500	0.0	0.0	0.0
	030600	173.6	3.8	3.7
	030602	23.8	0.5	0.5
	030603	0.0	0.0	0.0
	030604	22.8	0.9	0.5
	030605	0.0	41.0	0.2
	030700	211.2	5.4	4.1
	030701	62.3	3.1	78.6
	030702	33.1	0.8	0.8
	030703	22.0	2.3	0.4
	030705	0.2	1.7	0.0
	030706	98.2	8.9	1.5
	030800	133.7	4.2	3.6
	030900	643.4	21.3	13.9
	030902	118.2	11.5	9.2
	030903	120.3	4.0	5.8
	030904	12.7	0.5	0.3
	030905	12.1	472.7	1.4
	031000	9.4	0.4	0.4
	031005	0.0	0.0	0.0
	031100	58.6	3.8	3.0
	031102	0.0	0.0	0.0
	031103	0.0	0.9	0.6
	031104	0.0	0.0	0.0
	031200	10.4	0.3	0.3
	031205	0.0	0.0	0.0
	031300	140.7	3.2	3.2
	031305	0.0	0.0	0.0
	031400	11.3	9.5	7.9
	031403	0.0	2.2	1.4
	031405	0.3	3.5	0.0
	031500	25.7	0.5	0.4
	031600	1038.2	144.0	32.9
	031604	0.0	0.0	0.0
	031605	0.0	0.0	0.0
	032000	26.3	14.8	3.4
	032002	0.0	0.0	0.0
	032004	0.0	0.0	0.0
	032005	0.1	9.6	0.0
1A2 Total		3106.4	777.5	180.1
1A1c_ii	010500	15.4	0.2	0.1
	010503	5.0	0.1	0.1
	010504	873.1	25.9	15.2
	010505	0.0	0.0	0.0
1A1c_ii Total		893.5	26.2	15.4
1A4a_i	020100	575.6	21.5	17.8
	020103	2.0	2.5	0.9
	020105	3.2	361.9	1.3
1A4a_i Total		580.8	385.9	19.9

Continued				
1A4b_i	020200	1385.0	3260.5	163.4
	020202	2.3	2.0	0.1
	020204	4.7	52.0	0.1
1A4b_i Total		1392.0	3314.5	163.5
1A4c_i	020300	286.8	628.1	11.9
	020302	0.0	0.0	0.0
	020303	0.0	0.0	0.0
	020304	12.5	352.5	1.0
	020305	0.0	0.0	0.0
1A4c_i Total		299.3	980.6	12.9
Grand Total		13487.1	10129.2	660.7

Annex 3A-9 EU ETS data for coal

EU ETS data are available for the years 2006-2019. Corresponding values for lower calorific value (LCV) and implied emission factor (IEF) for CO_2 for 2006-2009 are shown in Figure 3A-9.1. The IEF factors include the oxidation factors.

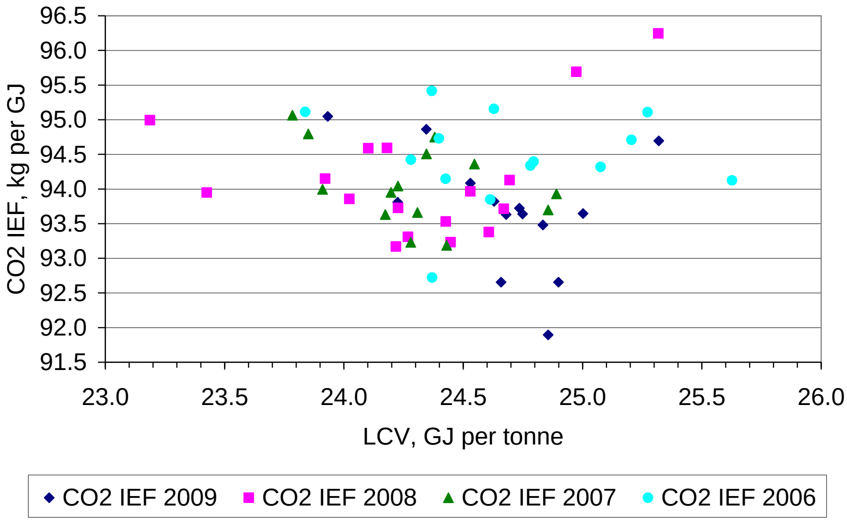

Figure 3A-9.1 EU ETS data for LCV and CO_2 IEF (including oxidation factor) for coal. Data for the years 2006-2009.

Annex 3B - Transport and other mobile sources

Annex 1: Fleet data 1985-2021 for road transport (No. vehicles)

Annex 2: Mileage data 1985-2021 for road transport (km)

Annex 3: EU directive emission limits for road transportation vehicles

Annex 4: Basis fuel consumption and emission factors (g pr km) for conventional vehicles and PHEV (gasoline), fuel consumption factors for electric, PHEV (el) and hydrogen vehicles

Annex 6: Deterioration factors in 2021

Annex 7: Final fuel consumption factors (MJ/km) and emission factors (g/km) for conventional vehicles and PHEV (gasoline), fuel consumption factors for electric, PHEV (el) and hydrogen vehicles in 2021, for urban/rural/highway and weighted traffic

Annex 8: Fuel consumption (GJ) and emissions (tonnes) per vehicle category and as totals

Annex 9: Model consumption:Fuel sales derived fuel and emission adjustment factors

Annex 10-1: Correspondence table between actual aircraft type codes and representative aircraft types

Annex 10-2: LTO no. and average LTO fuel consumption and emission factors per representative aircraft type for domestic and international flights (Copenhagen and other airports)

Annex 10-3: No. of flights between Danish airports and airports in Greenland and Faroe Islands

Annex 10-4: Total distance flown (NM) and average cruise fuel consumption and emission factors per representative aircraft type for cruise flying

Annex 10-5: LTO times-in-modes (s) for the Danish airports

Annex 10-6: APU Engine mode specific fuel flows (kg/h), emission rates (kg/h or g/kg) and times-in-modes per aircraft type

Annex 11-1: Stock numbers per machine type for non road mobile machinery 1985-2021, grouped into sector, fuel type, engine type and engine size class

Annex 11-2: Engine size in kW (weighted by number) per machine type for non road mobile machinery 1985-2021, grouped into sector, fuel type, engine type and engine size class

Annex 11-3: Engine load factor (weighted by total engine kWh output) per machine type for non road mobile machinery 1985-2021, grouped into sector, fuel type, engine type and engine size class

Annex 11-4: Annual working hours (weighted by number) per machine type for non road mobile machinery 1985-2021, grouped into sector, fuel type, engine type and engine size class

Annex 11-5: Total annual working hours (1000 hours) per machine type for non road mobile machinery 1985-2021, grouped into sector, fuel type, engine type and engine size class

Annex 11-6: Total MWh per machine type for non road mobile machinery 1985-2021, grouped into sector, fuel type, engine type and engine size class

Annex 11-7: Stock data for recreational craft 1985-2021

Annex 11-10: Stage V Emission Standards for Nonroad Engines

Annex 12-1: Annual traffic data (no. of round trips) per route for Danish ferries 1990-2021

Annex 12-2: Annual traffic data (no. of round trips) per route per ferry for Danish ferries 1990-2021

Annex 12-3: Round trip shares per route per ferry for Danish ferries 1990-2021

Annex 12-4: Sailing time (single trip) per route per ferry for Danish ferries 1990-2021

Annex 12-5: Engine load factor (% MCR) per route per ferry for Danish ferries 1990-2021

Annex 12-6: Ferry service, ferry name, engine type, engine year, fuel type, main engine MCR (kW), aux. engine (kW), engine load factors (%), Number of round trips, Sailing time (mins), MWh produced, fuel consumption (tons and GJ), specific fuel consumption (g/kWh), SO2, NOx, NMVOC, CH4, VOC, CO, CO2, N2O, NH3, TSP, PM10, PM2.5 and BC emission factors for 2021 (g/kWh, g/GJ, g/kg fuel).

Annex 12-7: Hours at sea, engine load (%), MWh produced, fuel consumption (PJ), specific fuel consumption (g/kWh), SO2, NOx, NMVOC, CH4, VOC, CO, CO2, N2O, NH3, TSP, PM10, PM2.5 and BC emission factors (g/kWh, g/GJ, g/kg fuel) for Danish fishing vessels 1985-2021 distributed into overall length classes.

Annex 13-1: Specific fuel consumption, NOx, CO, VOC, NMVOC and CH4 emission factors (g pr kWh) per engine year for marine engines

Annex 13-2: Fuel consumption (PJ and tonnes), S-%, SO2 , NOx, NMVOC, CH4, CO, CO2, N2O, TSP, PM10, PM2.5 and BC emission factors (g/kg fuel and g/GJ) per fuel type for national sea transport, international sea transport and fisheries

Annex 13-3: Engine load adjustment functions for sfc, NOx, VOC, CO, N2O and TSP emission factors for marine engines

Annex 14-1: Fuel sales figures from DEA, and further processed fuel consumption data suited for the Danish inventory

Annex 14-2: Fuel sulphur legislation limits, fuel sulphur content and lower heating values used in the Danish inventory

Annex 15-1: Emission factors for 1990 in CollectER format

Annex 15-2: Emission factors for 2021 in CollectER format

Annex 15-3: Emissions for 1990 in CollectER format

Annex 15-4: Emissions for 2021 in CollectER format

Annex 15-5: Non-exhaust emission factors, activity data and total non-exhaust emissions of TSP, PM1, PM2.5, BC and heavy metals in 2021

Annex 16-1: Fuel consumption 1985-2021 in CRF format

Annex 16-2: Emissions 1985-2021 in CRF format

Annex 16-3: Fuel consumption 1985-2021 in NFR format

Annex 16-4: Emissions 1985-2021 in NFR format

Annex 17-1: Uncertainty estimates for greenhouse gases

Annex 17-2: Uncertainty estimates for emission components reported to the LRTAP Convention

All annexes are available at:
https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Annex 3C - Industrial processes and product use

Annex 3C-25: CO_2 emissions from consumption of lubricants, kt

Annex 3C-26: Use of paraffin wax candles, kt

Annex 3C-27: Emissions from the use of paraffin wax candles

Annex 3C-28: Activity data for solvent use, kt

Annex 3C-29: CO_2 emission factors for solvent use

Annex 3C-30: CO_2 emissions from solvent use

Annex 3C-31: Activity data for road paving with asphalt, kt

Annex 3C-32: Emissions from road paving with asphalt, t

Annex 3C-33: Activity data for asphalt roofing, kt

Annex 3C-34: Emissions from asphalt roofing, t

Annex 3C-35: Activity data for urea used in catalysts, kt

Annex 3C-36: Emissions from urea used in catalysts, kt

Annex 3C-37: Consumption of F-gasses in other electronic industry, t

Annex 3C-38: Emissions from other electronic industry, kt CO_2 equivalents

Annex 3C-39: Consumption of cream in Denmark, t

Annex 3C-40: Emissions from the use of canned whipped cream, kt

Annex 3C-41: Activity data for other product uses, kt

Annex 3C-42: Emissions from other product uses, kt

All annexes are available at:

https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Please note that data found via this link are updated annually. This means that data in the annexes always matches the newest version of the NIR report.

Annex 3D - Agriculture

Table 3D-1 Changes in housing type 1990 – 2021. https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation (most recently submitted values).

Table 3D-2 Number of animals allocated on subcategories for 1990-2021, 1 000 head. https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation (most recently submitted values).

Table 3D-3 (a-d) NH_3 emission factors for housing units, 2021.

a) **Cattle**

		Urine	Slurry	Solid manure	Deep litter manure
		TAN	TAN	Total N	Total N
Housing type		pct. loss of TAN ex animal		pct. loss of N ex animal	
Tethered	urine and solid manure	6	-	5	-
	slurry manure	-	6	-	-
Loose-housing with beds	solid floor	-	20	-	-
	slatted floor	-	13.5	-	-
	slatted floor and scrape		13.5		
	drained floor	-	10.4	-	-
	solid floor with tilt	-	10.4	-	-
Deep litter	All	-	-	-	6
	solid floor	-	-	-	6
	slatted floor	-	13.5	-	6
	slatted floor and scrape	-	12	-	6
	solid floor and scrape	-	20	-	6
Boxes	sloping bedded floor	-	16	-	-
	slatted floor	-	16	-	-

Continued…

b) **Swine**

			Urine TAN	Slurry TAN	Solid manure Total N	Deep litter Total N
	Housing type	Floor or manure type	Pct. loss of TAN ex animal		pct. loss of N ex animal	
Sows	Individual, mating and gestation	Partly slatted floor	-	13	-	-
		Full slatted floor	-	19	-	-
		Solid floor	21	-	16	-
	Group, mating and gestation	Deep litter	-	-	-	15
		Deep litter + slatted floor	-	16	-	15
		Deep litter + solid floor	-	19	-	15
		Partly slatted floor	-	16	-	-
	Organic production	Deep litter	-	16	-	15
	Farrowing crate	Full slatted floor	-	26	-	-
		Partly slatted floor	-	13	-	-
	Farrowing pen	Solid floor	20	-	15	-
		Partly slatted floor	-	22	15	-
Weaners		Full slatted floor	-	24	-	-
		Drained + partly slatted floor	-	21	-	-
		Deep litter (to-climate housings)	-	10	-	15
		Solid floor	37	-	25	-
		Deep litter	-	-	-	15
	Organic production	Deep litter	-	15	-	15
Fattening pigs		Partly slatted floor (50-75 % solid)	-	13	-	-
		Partly slatted floor (25-49% solid)	-	17	-	-
		Drained + partly slatted floor	-	21	-	-
		Full slatted floor	-	24	-	-
		Solid floor	27	-	18	-
		Deep litter, divided	-	18	-	15
		Deep litter	-	-	-	15
	Organic production	Partly slatted floor	-	38	-	-

c) **Poultry**

			Solid manure Total N	Deep litter Total N
	Housing type	Floor or manure type	pct. loss of N ex animal	
Hens and pullets	Free-range, organic and barn	Deep pit	40	25
		Deep litter	-	28
		Manure belt	10	25
	Battery	Deep pit	12	-
		Manure belt	10	-
Broilers	Conventional	Deep litter	-	10
	Organic and barn	Deep litter	-	13
Turkeys, ducks and geese		Deep litter	-	20

Continued…

d) **Other**

	Slurry TAN	Deep litter Total N
	Pct. loss of TAN ex animal	pct. loss of N ex animal
Fur animals	30-67	40
Horses, sheep and goats	-	15

Table 3D-4 NH_3 emission factors for storage units, 2021.

			Urine	Slurry	Solid manure	Deep litter	Pct. of solid manure stored in heap on field
Cattle		Total N	2.2	2	4	1	35
		TAN	2.2	3.4	-	-	-
Pigs	Sows	Total N	2.2	2.1	19	6.5	50
		TAN	2.2	2.7	-	-	-
	Weaners	Total N	2.2	2.1	19	9.8	-
		TAN	2.2	2.7	-	-	-
	Fattening pigs	Total N	2.2	2.1	19	9.8	75
		TAN	2.2	2.7	-	-	-
Poultry	Hens and pullets	Total N	-	2	7.5	4.8	95
	Broilers	Total N	-	-	11.5	6.8	85
	Turkeys, ducks, and geese	Total N	-	-	-	6.8, 8(Tur-keys)	-
Ostric		Total N				4.8	
Fur animals		Total N	0	1.9	-	8	-
		TAN	0	2.7	-	-	-
Sheep and goats		Total N	-	-	-	3	-
Horses		Total N	-	-	-	3	-

Table 3D-5 EF for poultry for CH_4 from enteric fermentation, kg CH_4 per 100 or 1000 heads

	Number of heads	CH_4 EF
Hens	100	1.061
Pullets (consumption), 112 days	100	0.285
Pullets (hatching), 119 days	100	0.303
Broilers:		
30 days	1 000	0.011
32 days	1 000	0.012
35 days	1 000	0.013
40 days	1 000	0.015
45 days	1 000	0.017
56 days	1 000	0.021
81 days (organic)	1 000	0.075
Other poultry		
Turkeys, male	100	0.014
Turkeys, hen	100	0.007
Ducks	100	0.003
Geese	100	0.005
Pheasant, chicken	1 000	0.003
Pheasant, hen	100	0.472
Ostrich, chicken	1	0.001
Ostrich, hen	1	0.660

Table 3D-6 Parameters for winter feeding plans.

		Feeding code*	% dm*	% Crude protein*	% Raw fat*	% Raw ashes*	% Carbo-hydrates*	FU/kg dm*	kg dm/day**	MJ/day	GE_{FU}
Heifers:	Straw	781	85.0	4.0	1.9	4.5	89.6	0.2	33.4	571.8	
	Maize silage	593	31.0	8.7	2.2	4.2	84.9	0.9	57.5	1 009.0	
	Toasted soya	155	87.5	49.1	3.2	7.4	40.3	1.4	8.1	161.7	
	Total	-	-	-	-	-	-	-	99.0	1 742.4	25.8
Suckling cows:	Straw	781	85.0	4.0	1.9	4.5	89.6	0.2	1.6	119.1	
Period 1 (2 mth)	Toasted soya	155	87.5	49.1	3.2	7.4	40.3	1.4	3.4	49.6	
	Barley	201	85.0	11.2	2.9	2.2	83.7	1.1	1.8	29.2	
Period 2 (4 mth)	Straw	781	85.0	4.0	1.9	4.5	89.6	0.2	3.2	238.2	
	Toasted soya	155	87.5	49.1	3.2	7.4	40.3	1.4	3.0	29.1	
	Barley	202	85.0	11.2	2.9	2.2	83.7	1.1	3.2	52.0	
	Total	-	-	-	-	-	-	-	15.2	517.1	34.0
Horses:	Straw	781	85.0	4.0	1.9	4.5	89.6	0.2	4.0	58.2	
	Hay	665	85.0	12.1	2.6	7.7	77.6	0.6	3.0	44.0	
	Oat	202	86.0	12.1	5.7	2.7	79.5	0.9	2.5	40.1	
	Supplemental		86.4	15.4	4.3	6.6	73.7	1.0	1.0	15.5	
	Total	-	-	-	-	-	-	-	-	157.7	29.8
Sheep and Goats:	Straw	781	85.0	4.0	1.9	4.5	89.6	0.2	1.0	14.6	
	Toasted soya	155	87.5	49.1	3.2	7.4	40.3	1.4	0.1	1.8	
	Barley	202	85.0	11.2	2.9	2.2	83.7	1.1	0.4	6.2	
	Grass pills (dried)	707	92.0	17.0	3.1	11.0	68.9	0.6	1.0	15.7	
	Total	-	-	-	-	-	-	-	-	38.2	30.0
Summer grazing											
Grazing	Clover grass, 2 weeks old	422	18.0	22.0	4.1	9.4	64.5	1.0	1.0	18.8	
	Total	-	-	-	-	-	-	-	1.0	18.8	18.8
Swine:	Full feeding										
	Sows	-	87.1	16.1	5.2	5.5	73.2	1.2	-	64.2	17.5
	Weaners	-	87.4	18.8	5.7	5.5	70.0	1.3	-	2.1	16.5
	Fattening pigs	-	86.9	17.0	4.7	5.1	73.3	1.2	-	9.6	17.3

* Møller et al. (2000)

** SEGES

Table 3D-7 Energy factors used for GE.

	MJ per kg dm
$E_{Crude\ protein}$	24.237
$E_{Raw\ fat}$	34.116
$E_{Carbonhydrates}$	17.3

Table 3D-8 Feed intake 1990-2021, Dairy cattle; kg DM per cow per year, Others; FU per animal per year. https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation (most recently submitted values)

Table 3D-9 Grazing animals 1990 – 2021, number of days on grass per year. https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation (most recently submitted values)

Table 3D-10 Gross energy per kg DM for dairy cattle, 1990-2021, MJ per kg DM. https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation (most recently submitted values)

Table 3D-11 Average gross energy intake (GE) 1990 – 2021, MJ per head per day. https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation (most recently submitted values)

Table 3D-12 Implied Emission Factor of CH4 from enteric fermentation, 1990 – 2021. https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation (most recently submitted values)

Table 3D-13 Emission of CH_4 from enteric fermentation, 1990 – 2021. https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation (most recently submitted values)

Table 3D-14 VS daily excretion 1990 – 2021, kg DM per head per day. https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation (most recently submitted values)

Table 3D-15 National manure management system and MCF vs. IPCC manure management system and MCF https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Table 3D-16 MCF for liquid manure, 1990 – 2021 https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation (most recently submitted values)

Table 3D-17 Implied Emission Factor of CH4 from manure management, 1990 – 2021, https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation (most recently submitted values)

Table 3D-18 Emission of CH_4 from manure management, 1990 – 2021. https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation (most recently submitted values)

Table 3D-19 Area of agricultural land, 1990 – 2021, ha. https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation (most recently submitted values)

Table 3D-20 Above-ground residue dry matter $AG_{DM(T)}$ 1990-2021, kg DM per ha. https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation (most recently submitted values)

Nitrogen leaching and Run-off

Calculations of nitrogen lost by leaching from groundwater are based on two models described in Børgesen and Grant (2003) (in Danish). The model SKEP/DAISY is a dynamic model, N-LES is an empirical model and SKEP is an up scaling model. The SKEP/DAISY calculations were done for 10 scenarios (the years 1984, 1989 and 1995-2002) and the N-LES calculations were done for an 11-year period (1990-2000). Both calculations were up-scaled nationwide. The key parameters for the models were land use, nitrogen from synthetic fertilizer and manure, application practice for manure and NH_3 evaporation at application of manure (SKEP/DAISY only). The calculations were normalised to an average climate. A schematic overview of the models is seen below.

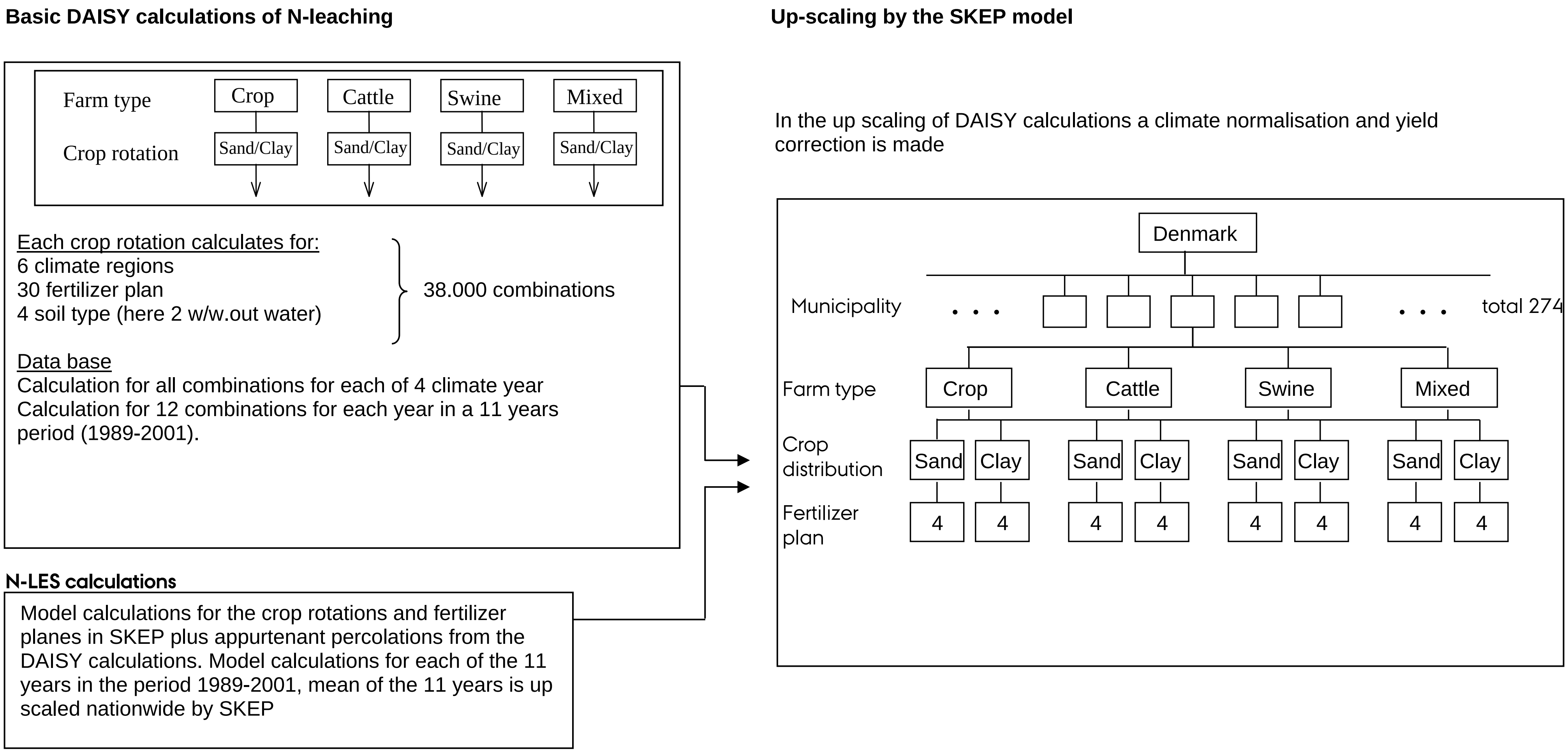

Figure 3D-1 Model calculation of nitrogen leaching from groundwater nationwide by SKEP/DAISY and N-LES.

Table 3D-21 QA/QC procedure, stage I – III.

Stage I: Check of input data	**Variable**	**Reference**
Livestock production	- number of animal	DSt
	- slaughter data	
Normative figures	- N-excretion	DCA
	- use of straw	
	- amount of manure	
	- feed intake	
	- milk yield	
Housing types	- distribution	DAA + SEGES
Grazing days		SEGES
Crops	- land use	DSt
	- crop yield	
	- crop production	
Synthetic fertiliser	- N-content	DAA
	- fertiliser types	
N-leaching	- amount of nitrogen leached	DCE
Atmospheric deposition	- all NH_3 emission sources	DCE – NH_3 inventory
Sewage sludge and industrial waste	- Amount of sludge applied to soils	EPA + DAA
Manure management	- manure delivered to biogas plants	DEA
Stage II: Check of IDA data – overall	**Variable**	**Comments**
Recalculation	- CO_2–eqv. total emission	- compared with latest submission
	- CH_4, N_2O, NMVOC	
	- emission from field burning	
Time series	- CO_2–eqv. total emission	- trends
	- CH_4, N_2O, NMVOC	- jumps and dips
	- emission from field burning	
Stage III: Check of IDA data – specific	Variable	Comments
CH_4	- enteric fermentation	- IEF (jumps and dips)
		- Ym (dairy cattle + heifer)
		- GE
CH_4	- manure management	- IEF (jumps and dips)
		- VS
		- biogas
N_2O	- manure management	- trends (jumps and dips)
		- IEF
		- biogas
N_2O	- synthetic fertiliser	- trends (jumps and dips)
		- IEF
N_2O	- animal waste applied to soil	- trends (jumps and dips)
		- IEF
N_2O	- N-fixing crops	- trends (jumps and dips)
		- IEF
N_2O	- crop residue	- trends (jumps and dips)
		- IEF
N_2O	- pasture, range and paddock	- trends (jumps and dips)
		- IEF
N_2O	- atmospheric deposition	- trends (jumps and dips)
		- IEF
N_2O	- N-leaching and run-off	- trends (jumps and dips)
		- IEF
N_2O	- sewage sludge + industrial waste	- trends (jumps and dips)
		- IEF
NMVOC	- crops	- trends (jumps and dips)
	- manure management	
NOx	- livestock	
	- crops	
All compounds from field burning		- trends (jumps and dips)

Chapter 3D-1 Biogas treatment of manure

Introduction

A significant and growing part of the Danish animal slurry is being used for production of biogas. The production uses anaerobic digestion of animal manure in combination with other biodegradable products, e.g. agricultural waste and slaughterhouse waste. Biogas treatment is important to include in the inventory, because the anaerobic digested slurry produces lower CH_4 emission from storage and from applied slurry on cultivated soils.

CH_4 emission from manure management depends, among other variables, on the CH_4 conversion factor (MCF), which depends on the actual temperature and storage conditions. The IPCC 2019 Refinement Tier 2 approach recommends a MCF between 6-31 % dependent on time for storage for slurry in cool climate (average annual temperature ≤10 °C). Based on study activities in 2015-2016 a national MCF has been estimated for raw untreated slurry and for anaerobic digested slurry, from cattle and swine slurry respectively. Focus has been on cattle and swine slurry, which cover >95 % of the total CH_4 emission from manure management.

The result of the national MCF estimated will first be presented. Following is an overview of the biogas production in Denmark and the estimation of the amount of treated slurry. Finally a more detailed description and documentation of the estimation of the national MCF is provided.

National estimated MCF for cattle- and swine slurry

The national estimates of MCF are based on temperature dependent degradation functions, which take into account the different temperature conditions inside the barns and during outdoor storage. The storage time and the related CH_4 emission inside the barns, outdoor storage and storage of anaerobic digested biomass is also taken into account. The approach use temperature dependent functions adapted to Danish conditions.

The national estimated MCF for untreated swine- and cattle slurry is higher than the IPCC 2019 Refinement default for 6 Month storage for cool climate (≤10 °C). The national study shows a fast turnover of VS especially for the swine slurry inside the barns caused by the relatively high temperatures (Møller, 2013), which leading to a high emission of methane per kg of VS.

Table 3D-22 shows the trend 1990 – 2021 for the national estimated MCF for cattle and swine slurry both digested and not digested. The national estimated MCF for not digested slurry for cattle is changing slightly over time, from 14.21 in 1990 to 14.36 in 2021. The MCF for not digested slurry for swine is reduced from 19.48 in 1990 to 17.75 in 2021. The changes in MCF over time is mainly caused by change in the distribution of housing system, which influences the average HRT (Hydraulic Retention Time).

Table 3D-22 Estimated methane conversion factor (MCF) for digested and not digested cattle and swine slurry from 1990 to 2021, %.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Cattle										
MCF for digested cattle slurry	6.47	6.42	7.33	7.24	7.37	7.60	7.34	7.28	7.24	7.14
MCF for not digested cattle slurry	14.21	14.07	14.91	14.75	14.77	14.80	14.60	14.51	14.47	14.36
Swine										
MCF for digested swine slurry	12.07	11.90	11.61	10.71	10.75	10.66	10.20	10.21	10.14	10.20
MCF for not digested swine slurry	19.48	19.36	19.13	18.38	18.29	18.05	17.78	17.75	17.71	17.75

Estimation of slurry treated in biogas plants in Denmark

In Denmark, the biogas plants are divided in five facility types; wastewater, industrial, landfills, large-scale plants (centralised multi farms) and farm-level plants. Large-scale biogas plants are larger facilities, where slurry is received from several farms and farm-level plants are characterised by receiving manure from one or a few farms. For 2021, the Energy Statistics estimated the total energy production based on biogas to 26 195 TJ (DEA, 2022a), and out of this, the manure based biogas plants account for 91 % produced at approximately 30 large-scale plants and 60 farm-level plants. The Energy Statistic provides data annually and thus data from all years 1990-2021 is available.

Table 3D-23 Biogas production, 2021 (DEA, 2022a).

Facility type	Biogas production, TJ	%
Wastewater treatment	1269	5
Industrial	1072	4
Large-scale and farm-scale*	23854	91
Total	26195	100

*Include Landfill, which only accounts for approximately 139 TJ (less than 1 % of total biogas production).

The livestock production mainly takes place in the western parts of Denmark in Jutland and consequently the majority of manure based biogas plants are located here.

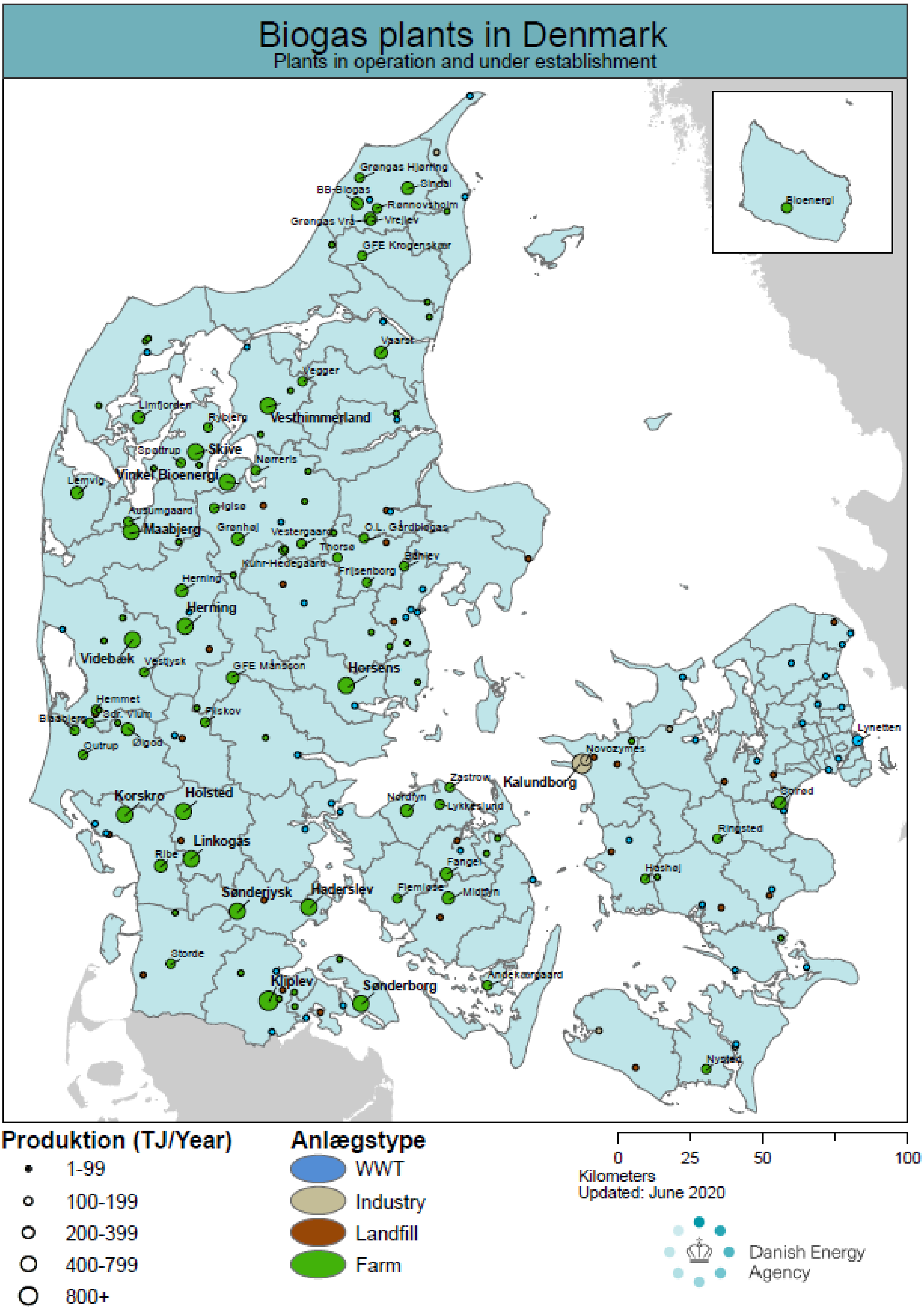

Figure 3D-2 Biogas producers in Denmark (DEA, 2020). WWT – waste water treatment.

For year 2015-2021, data for the actual amount and different types of biomass delivered to the biogas plants is available. Data is collected by the Danish Energy Agency (DEA, 2022b), based on reporting from each biogas plant and covers data from all the biggest biogas plants. In the following, these data are referenced as the BIB-register; Biomass Input to Biogas production. The BIB register does not fully cover all biogas plants, but the most important biogas producers, and thus it covers 80-90 % of the total biogas production.

Data regarding the amount of slurry delivered to biogas plants is available for the years 2001, 2003, 2015-2021. Data for year 2001 and 2003 is based on a single investigation provided by the DEA – the Danish Energy Agency, while the data for year 2015-2021 is based on the BIB – register. For the intervening years, 1990-2000, 2002 and 2004-2014, the data for amount of slurry delivered to the biogas production is based on an interpolation, by using the relation between the amount of slurry delivered and the total energy production produced at the biogas plants. The total energy production from biogas plants for all years is based on the Energy Statistics (DEA, 2022a).

In 1990, the biogas production at the large-scale, farm-level and industrial biogas plants is 266 TJ, which correspond to slurry input of 220 kt, increasing to 24 787 TJ and 9 575 kt slurry in 2021.

In 2021, around 25 % of total amount of slurry is delivered to biogas production, 34 % of the total amount of cattle slurry and 17 % for swine slurry.

Table 3D-24 Biogas production, 1990-2021.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Biogas production, TJ[1]										
Total	752	1 758	2 912	3 830	4 337	6 285	13 333	16 482	21 152	26 195
Biogas plants*	266	746	1 442	2 375	3 184	5 199	12 244	15 278	19 937	24 787
Slurry delivered to biogas plants, kt[2]										
Cattle, swine and mixed	220	617	1 192	1 838	2 115	2 884	5 741	7 073	8 303	9 575
Percent of total produced slurry	1	2	4	6	6	8	15	19	21	25

* Large-scale, farm-level and industrial.
[1]DEA, (2022a).
[2]DEA, (2022b).

The anaerobic digestion process is complicated and sensitive to several factors, such as different biomass types and different combination of biomass input, nutrients concentration, species and concentration of bacteria, operational conditions for each biogas plants, etc. Uses of current data from the BIB register will to some extend take these variations from biogas plant to biogas plant into account, because the data is based on existing production.

Calculation method for the national MCF

MCF is estimated by using the Tier 2 equation for estimating CH_4 emission factor from manure management from IPCC 2019:

$$MCF_{not\ digested} = \left(\frac{E_{barns} + E_{storage,not\ digested}}{VS_{barns}}\right) / (0.67 \cdot B_0) \qquad \text{(Eq. 3D-1)}$$

Where:

$MCF_{not\ digested}$ = methane conversion factor for not digested slurry, %
E_{barns} = emission of CH_4 from barns, kg CH_4, see Equation 3D-3

$E_{storage, not digested}$ = emission of CH_4 from storage of not digested slurry, kg CH_4, see Equation 3D-4
VS_{barns} = amount of volatile solids, kg VS, based on VS excreted, see Table 3D-26
B_0 = maximum methane producing capacity, m^3 CH_4 per VS
0.67 = conversion factor, CH_4 per m^3 CH_4

$$\mathrm{MCF}_{digested} = \left(\frac{E_{barns}+E_{storage,digested}}{VS_{barns}}\right)/(0.67 \cdot B_0) \quad \text{(Eq. 3D-2)}$$

Where:
$MCF_{digested}$ = methane conversion factor for digested slurry, %
E_{barns} = emission of CH_4 from barns, kg CH_4, see Equation 3D-3
$E_{storage, digested}$ = emission of CH_4 from storage of not digested slurry, kg CH_4, see Equation 3D-4
VS_{barns} = amount of volatile solids, kg VS, based on VS excreted, see Table 3D-26
B_0 = maximum methane producing capacity, m^3 CH_4 per VS
0.67 = conversion factor, CH_4 per m^3 CH_4

Estimation of methane emission from raw cattle and swine slurry and anaerobic digested animal manure

The CH_4 emission from liquid cattle and swine manure is based on CH_4 emission from barns, from outdoor stored raw cattle and swine slurry, from anaerobic digesters and from anaerobically digested biomass/primarily animal manure.

Emission of CH_4 from barns

$$\mathrm{E}_{barns} = \mathrm{VS}_{barns} \cdot \mathrm{EF}_{barns} \cdot \mathrm{HRT}/365 \quad \text{(Eq. 3D-3)}$$

Where:
E_{barns} = emission of CH_4 from barns, kg CH_4
VS_{barns} = amount of volatile solids, kg VS, based on VS excreted, see Table 3D-26
EF_{barns} = emission factor for CH_4, based on measurements see Table 3D-25
HRT = Hydraulic Retention Time, days, see Table 3D-26

Emission of CH_4 from storage of not digested slurry

CH_4 emission from storage of slurry is estimated as VS multiplied by EF where VS is divided in VS degradable (VSd) and VS non-degradable[1] (VSnd).

$$\mathrm{E}_{Storage,not\ digested} = \mathrm{VSd}_{storage,not\ digested} \cdot \mathrm{EFd}_{storage,not\ digested} + \mathrm{VSnd}_{storage,not\ digested} \cdot \mathrm{EFnd}_{storage,not\ digested} \quad \text{(Eq. 3D-4)}$$

Where:
$E_{storage, not digested}$ = emission of CH_4 from storage of not digested slurry, kg CH_4
$VSd_{storage, not digested}$ = amount of degradable volatile solids in the slurry not digested, see Table 3D-26
$EFd_{storage, not digested}$ = emission factor for CH_4 for degradable VS, see Table 3D-25

[1] Non-degradable could also be refed to as low-degradable because a small decomposition is possible.

$VSnd_{storage, not digested}$	= amount of non-degradable volatile solids in the slurry not digested, see Table 3D-26
$EFnd_{storage, not digested}$	= emission factor for CH_4 for degradable VS, see Table 3D-25

Emission of CH_4 from storage of digested slurry

$$E_{Storage,digested} = VS_{storage,digested} \cdot EF_{storage,digested} \quad \text{(Eq. 3D-5)}$$

Where:

$E_{storage, digested}$	= emission of CH_4 from storage of digested slurry, kg CH_4
$VS_{storage, digested}$	= amount of volatile solids in the slurry digested, see Table 3D-26
$EF_{storage, digested}$	= emission factor for CH_4 for VS, see Table 3D-25

Table 3D-25 Estimated emission factors.

Cattle	
EF_{barns}, g CH_4 per kg VS per year	182.99
$EFd_{storage, not digested}$, g CH_4 per kg VSd per year	36.89
$EFnd_{storage, not digested}$, g CH_4 per kg VSnd per year	0.37
$EF_{storage, digested}$, g CH_4 per kg VS per year	1.64
Swine	
EF_{barns}, g CH_4 per kg VS per year	572.97
$EFd_{storage, not digested}$, g CH_4 per kg VSd per year	60.37
$EFnd_{storage, not digested}$, g CH_4 per kg VSnd per year	0.60
$EF_{storage, digested}$, g CH_4 per kg VS per year	1.64

Table 3D-26a-c shows the estimated CH_4 emission from liquid cattle and swine slurry for the years 1990-2021. Table 3D-26a-c shows the total amount of liquid VS excreted by cattle and swine, the average HRT, the estimated g CH_4 per kg VS and the total emission of CH_4 from that category.

For cattle slurry, the total emission in barns in 1990 has been estimated to 10.50 kt CH_4 increasing to 13.50 kt CH_4 in 2021. The increase in this emission is due to change in housing systems where the slurry is kept in the housings longer and more slurry. In addition to this, an emission from outdoor storage estimated to 13.87 kt CH_4 in 1990 and decreased to 10.83 kt CH_4 in 2021. To this comes a small amount from digested manure (Table 3D-26c).

For swine slurry, the total emission inside the barns in 1990 has been estimated to 19.01 kt CH_4 in 1990 increasing to 27.32 kt CH_4 in 2021, due to a growing swine production until 2011. To this comes an emission from outdoor storage. This has been estimated to 13.13 kt CH_4 in 1990 and an increase to 20.43 kt CH_4 in 2021. The increase in this emission is due to increase in the share of degradable volatile solids in the slurry. In addition, a small amount is realised from the digested manure (Table 3D-26c).

Table 3D-26a Emission estimates for cattle slurry inside the barns and not digested stored liquid manure.

Cattle	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Barns										
Slurry, tonnes VS per year	1 140 939	1 044 346	1 014 726	1 160 046	1 204 501	1 281 868	1 342 416	1 329 862	1 330 589	1 344 073
EF, g CH_4 per kg VS per year	182.99	182.99	182.99	182.99	182.99	182.99	182.99	182.99	182.99	182.99
Average HRT, days	18.36	18.48	21.47	21.25	21.17	21.21	20.70	20.44	20.33	20.03
EF, g CH_4 per kg VS per year	9.20	9.27	10.77	10.65	10.61	10.63	10.38	10.25	10.19	10.04
Emission, kt CH_4 per year	10.50	9.68	10.92	12.36	12.79	13.63	13.93	13.63	13.56	13.50
Storage, not digested										
Slurry, not digested, tonnes VSd ab barn	368 401	329 843	309 006	343 933	356 772	374 674	347 515	320 954	302 548	287 741
Slurry, not digested, tonnes VSnd ab barn	756 412	677 298	635 681	707 435	733 809	770 645	714 561	659 840	621 960	591 411
EF, g CH_4 per kg VSd per year	36.89	36.89	36.89	36.89	36.89	36.89	36.89	36.89	36.89	36.89
EF, g CH_4 per kg VSnd per year	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Emission, kt CH_4 per year	13.87	12.42	11.63	12.95	13.43	14.11	13.08	12.08	11.39	10.83

Table 3D-26b Emission estimates for swine slurry inside the barns and not digested stored liquid manure.

Swine	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Barns										
Slurry, tonnes VS per year	548 932	718 704	816 232	944 522	952 318	930 705	952 406	910 269	1 032 704	972 397
EF, g CH_4 per kg VS per year	572.97	572.97	572.97	572.97	572.97	572.97	572.97	572.97	572.97	572.97
Average HRT, days	22.06	21.77	21.23	19.41	19.21	18.63	17.98	17.91	17.80	17.90
EF, g CH_4 per kg VS per year	34.63	34.17	33.32	30.47	30.15	29.25	28.22	28.11	27.94	28.09
Emission, kt CH_4 per year	19.01	24.56	27.20	28.78	28.72	27.22	26.88	25.59	28.85	27.32
Storage, not digested										
Slurry, not digested, tonnes VSd ab barn	214 808	279 784	316 103	370 874	373 093	361 279	353 734	328 277	369 385	334 506
Slurry, not digested, tonnes VSnd ab barn	266 396	345 628	387 740	444 367	445 895	428 620	416 232	385 933	433 675	393 207
EF, g CH_4 per kg VSd per year	60.37	60.37	60.37	60.37	60.37	60.37	60.37	60.37	60.37	60.37
EF, g CH_4 per kg VSnd per year	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Emission, kt CH_4 per year	13.13	17.10	19.32	22.66	22.79	22.07	21.61	20.05	22.56	20.43

Table 3D-26c Emission estimates for digested biomass.

Digested biomass	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
VSd, tonnes	8 551	23 942	46 279	77 773	109 374	186 923	328 671	422 714	495 469	573 892
EF, g CH_4 per kg VS per year	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64
Emission, kt CH_4 per year	0.01	0.04	0.08	0.13	0.18	0.31	0.54	0.69	0.81	0.94

Documentation for estimation of the national MCF

CH_4 formation in manure is mainly formed by microorganisms that produce methane as a metabolic by-product in anoxic conditions. They are classified as archaea, a domain distinct from bacteria. The metabolism is temperature dependent, and actual temperatures are therefore the main driver for the methanogenesis.

The overall methodology for estimating the CH_4 emission from liquid animal manure and anaerobically digested biomass is based on the available amount of volatile substance (VS) in the biomass and the temperature dependent CH_4 formation functions (Van't-Hoof/Arrhenius equation) (Sommer et al., 2004). The model by Sommer et al. (2004) uses a 2-pooled concept for estimating the CH_4 emission from degradable VS (VSd) and from non-degradable[2] VS (VSnd). The emission from VSnd has been set to 1 % of VS (Sommer et al., 2001, 2004). During storage inside the barns, in outdoor storages and in the anaerobic digesters VS is degraded. To take into account a "decreasing" emission due to depletion of the VS in the manure in up to 8-9 months a degradation model has been developed.

For the purpose of documenting the emission estimate in the inventories the following tasks have been performed:

- a thorough literature search
- estimation of temperature functions for animal manure stored
  - inside the barns for swine and cattle barns
  - outdoor storage for untreated liquid manure
  - anaerobically digested manure
- estimation of storage time, HRT (Hydraulic Retention Time) in the barns (Kai et al., 2015)
- temperature dependent CH_4 formation from 20 samples of different types of liquid swine manure and 11 samples of different type of liquid dairy cattle manure (Petersen et al., 2016)
- developing a model to estimate the storage time in outdoor liquid manure stores
- compilation of data from BIB. The BIB include information on suppliers, amount and types of manure and other biomass used in the Danish anaerobic digesters
- developing an emission model based on time steps of 10 days.

Parameters for Arrhenius function

For the CH_4 calculation, a model based on VS quantity and degradability and temperature was used (Sommer et al., 2004). The parameters for Arrhenius function is based on Petersen et al. (2016), Elsgaard et al. (2016) and Maldaner et al. (2018). Equation 11.18 shows the calculation of CH_4 emission form slurry F(T), VSd and $VSnd$ are the proportions of degradable and "non-degradable" VS. The $\ln A$ is the pre-exponential factor (≈ methane production potential) and Ea the activation energy of methanogenesis, while R is the universal gas constant and T is the absolute temperature.

$$F(T) = \left(VS_d * b_1 * \exp\left(lnA - E_a * \left(\frac{1}{RT}\right)\right) + VS_{nd} * b_2 * \exp(lnA - E_a * \left(\frac{1}{RT}\right))\right) \cdot 24 \qquad \text{(Eq. 11.18)}$$

Where:

[2] Non-degradable could also be refed to as low-degradable because a small decomposition is possible.

F(T) = the methane production rate, g CH_4 per day
VSd = the proportions of degradable volatile solids, kg
VSnd = the proportions of non-degradable volatile solids, kg
b1 and b2 = scaling factors, 1 for VSd and 0.01 for VSnd (dimension-less)
lnA = the pre-exponential factor (≈ methane production potential), g CH_4 per kg VS_d per h or g CH_4 per kg VS per h (digestate)
Ea = the activation energy of methanogenesis, J per mol
R = the gas constant, 8.314 J per mol per K
T = temperature, K
24 = conversion from hour to day

Ea: An activation energy, Ea, of 81 kJ per mol was recently proposed by Elsgaard et al. (2016) which represented the temperature response of a cattle slurry, a swine slurry, fresh digestate and stored digestate (no significant differences).

Ln*A*: The parameter ln*A* reflects a potential for CH_4 production that is influenced by the chemical and biological characteristics of the slurry, which in Petersen et al. (2016) is derived for 20 samples of swine slurry and 11 samples cattle slurry. In average the observed ln*A* was 31.3 and 31.2 g CH_4 kg-1 VS h-1 for pig and cattle slurry, respectively.

VS – volitale solid: The amount of excreted dry matter is taken from the Danish Normative System for animal manure (data included in IDA). The share of VS of dry matter is set as a default to 80 % as used in the agricultural inventories.

VSd and VSnd: In the model for estimating the CH_4 emission a 2-pooled model is used, dividing the VS in VSd and VSnd (Tong et al., 1990, Sommer et al., 2004). The share of VSd and VSnd has for the purpose of the inventories been estimated by Petersen et al. (2016) for swine (sow, weaners and fattening pigs) and cattle slurry (mainly dairy cattle slurry). The manure samples were taken in barns in full production and can thus be seen as normal farming practise. Petersen et al. (2016) estimated the average age of the swine slurry to 13-15 days and the cattle slurry to around 20-30 days. The slurry samples can therefore be seen as quite fresh manure with only little degradation.

Petersen et al. (2016) sampled 20 swine slurry samples and 11 dairy cattle slurry samples and estimated the VSd. For swine manure they found an average VSd of 51 % (95 % Confidence Interval: 44 – 57 %) and for slurry for dairy cattle a VSd of 33 % (95 % Confidence Interval: 29 – 37 %).

Møller and Moset (2015) has measured dry matter and VS in digested manure from eight biogas plants. They found an average dry matter in the digested manure of 4.88 % were VS of dry matter in average were 3.32 %. Møller (2016) has measured the B0-value of the digestate from the continuous biogas plants to 13.8 m3 CH4 per kg VS indicating that the major part of the digestate is non-degradeable. Based on the model, which take storage time and temperature into account, the emission factor for $VS_{digested}$ were estimated to 1.76 g CH_4 per kg VS per year

In Table 3D-27 is shown the used parameters.

Table 3D-27 CH_4 emission estimate parameters. Petersen et al. (2016) combined with Elsgaard et al. (2016) and Maldaner et al. (2018).

	Ea, kJ per mol	Ln(A), g CH_4 per kg VS per hour	VSd, %	VSnd, %
Liquid cattle manure	81	31.2	33	67
Liquid swine manure	81	31.3	51	49
Digestate	81	27.9	100[a]	0

[a]For digestate, the model parameter is set to 100 mimicking that all VS is degradable.

Degradation function

Based on literature data and unpublished research data it was estimated that the C loss from manure stores constitutes roughly of 20 % CH_4-C and 80 % CO_2-C (Dinuccion et al., 2008). In the emission estimate a conservative figure of 25 % is used. Beside this Patni and Jui (1987) found 10-25 % losses of dry matter during storage of dairy cattle slurry supporting that a high share of loss of VS is taken place as CO_2 as this is not lost as CH_4. For effluent from digested animal manure, Wang et al. (2016) found very low CH_4/CO_2 ratios at around 3-4 % (unpublished data received from Yue Wang). For the digestate, an estimate for CH_4-C/CO_2-C fraction of 10 % is used (Dong, 2013, Pers. Comm.).

The CH_4-degradation model was built in an excel spreadsheet with a time step of 10 days.

Danish animal housing systems and Hydraulic Retention Time (HRT)

The most common housing systems for swine in Denmark are partly plug-systems with slatted floors and a depth of the slurry channels of 40-60 cm. The storage capacity inside the barns in these systems is around 40 days. After 40 days the farmers pull the plugs and the slurry under the slats are flushed to the outdoor storage tanks. During the production cycle of weaners and fattening pigs it is normally only needed to flush once during the production, and once after the pigs have been moved and the barn is washed and cleaned. In these systems the average storage time is therefore app. 40 days/2 = 20 days. The average storage time is named the Hydraulic Retention Time (HRT).

For the purpose of the Danish inventories, Kai et al. (2015) have investigated/measured the storage capacity in swine and cattle barns and estimated the HRT for all barn types mentioned in the Danish Normative System for animal manure.

Animal housing systems change over time. To take into account changes in the HRT inside the barns over time since 1990, the shares of the different barn types have been multiplied with the HRT for each barn type and summed for swine and cattle slurry to get the average HRT for swine and cattle slurry (Table 3D.29). The HRT for liquid cattle manure has increased since 1990. This is mainly because in the 1990's there was a high share of tied-up dairy cattle with liquid handling and frequent removal of the slurry. These were later replaced by cubicles combined with slats. In recent years cubicles with scrapers are becoming more common so a decrease in the HRT for cattle is expected in the future. The most common housing system for swine has until recently been fully slatted floors. A ban on fully slatted floors forced the farmers to build partly slatted floors/drained floors. This has reduced the storage capacity below the slats and thus reduced the average HRT for swine slurry.

Table 3D-28 Average Hydraulic Retention Time (HRT) in cattle and swine barns from 1990 to 2021.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Cattle	18.36	18.48	21.47	21.25	21.17	21.21	20.70	20.44	20.33	20.03
Swine	22.06	21.77	21.23	19.41	19.21	18.63	17.98	17.91	17.80	17.90

In the emission estimate, it is assumed that all manure regardless of whether it is used for anaerobic digestion or not is having the same HRT. The data collected by Kai et al. (2015) do not prove that farms delivering manure to anaerobic digestion are empting their slurry channels more frequently than farmers who are not.

Temperatures

Based on average air temperature for the period 2001-2010 (Wang, 2012), measured temperatures and literature data temperature functions have been developed.

Insulated swine barns

Only few measured slurry temperatures inside the barns can be found in the literature. Some measurements have been made by SEGES (Holm, 2015). Besides this, Petersen et al. (2016) have measured slurry temperatures in 27 different swine barns in November and December 2014 in connection with the CH_4 emission parameterisation. Holm (2015, Pers. Comm.) has made 48 measurements in barns with fattening pigs at different times of the year and found an average slurry temperature of 18.6 °C (16.0-21.8 °C) with a standard deviation of 1.29. The highest temperatures were measured in summer. When the average outdoor temperature was 16-17 °C the slurry temperature tended to be around 19 °C. In winter when the average outdoor temperature was around 2-5 °C the slurry temperature was 17-18 °C (Figure 3D-5). The dots represent different combinations of slurry height and temperatures. Petersen et al. (2016) found an average temperature of 18.7 °C in their measurements in November and December. In the inventories are used the average data of 18.6 °C from SEGES throughout as the data are not sufficient qualified to distinguish between winter and summer. Figure 3D-3 shows the measured data by SEGES.

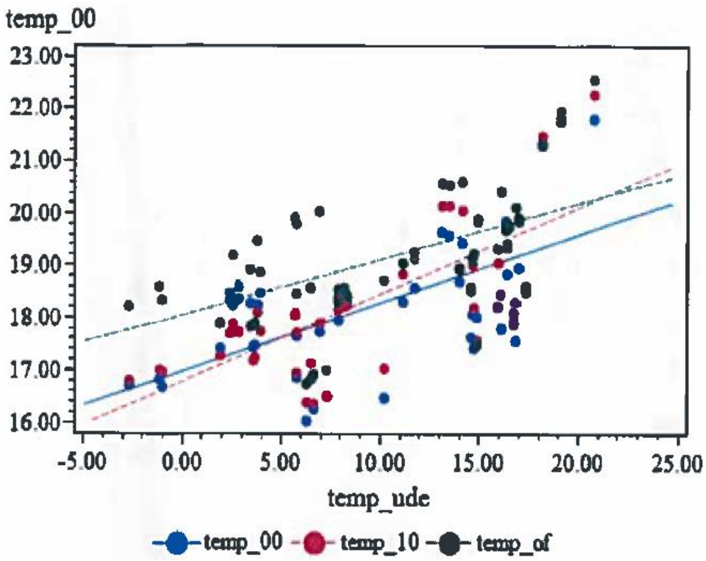

Figure 3D-3 Measured slurry temperature in fattening pig slurry channel in different times during the production cycle. The different colours indicate different slurry heights in the slurry channel (Holm, 2015).

Open cattle barns

Most cattle barns in Denmark are naturally ventilated. Inside the barns the air temperature is generally 5-6 °C higher than the outdoor temperature. The manure temperature inside the slurry channels do not follow the air temperature closely (Andersen and Grønkjær, 2020). In 2017 and 2018, temperature measurements were carried out in one cattle barn in the Southern Denmark and one in the Northern Denmark with logging 2-5 times per day. As Denmark is quite small, these data were combined and converted to a sine-wave representing whole Denmark (Figure 3D-4).

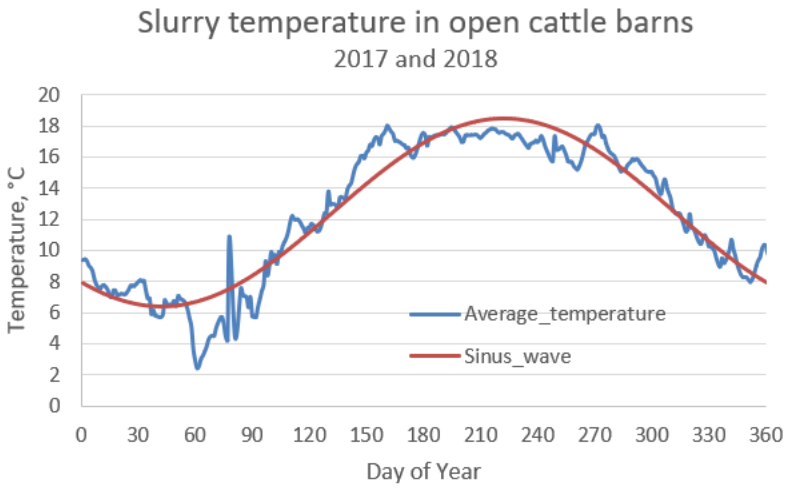

Figure 3D-4 Average daily measured slurry temperature in two cattle barns in 2017 and 2018 (Andersen and Grønkjær, 2020).

Table 3D-29 shows given the parameters for the Sine-function, which estimates the daily average air temperatures.

Table 3D-29 Parameters for the Sine-function (y=a+ b sin (2πx/d+c)) for air temperature. R^2 = 0.92

Parameter	Value	Std Error	t-value	95% confidence limits	
a	12.45	0.087	142.64	12.28	12.62
b	6.04	0.098	61.55	5.84	6.23
c	3.97	0.046	86.73	3.89	4.07
d	360.08	4.209	85.55	351.80	368.35

Outdoor storage temperatures

The temperature in outdoor slurry tanks is expected to follow the outdoor temperature to a great extent. As with indoor storage only few data can be found in the literature. The temperature is a function of the loading with slurry, the actual amount stored and the solar radiation. If data from other climatic conditions is used they therefore have to be converted to Danish conditions. E.g. Park et al. (2006) found a linear relation between air temperature and slurry temperature in Canada with the following model parameters: Slurry_temperature = Air_temperature * 0.879 + 4.24 (Figure 3D-5). However, the locations used for this study is far more southern than Denmark and are thus not suited for Danish conditions, especially not during summer where a higher solar radiation is occurring. Hansen et al. (2006) measured the slurry temperatures in slurry tanks throughout a year on three farms receiving digestate from anaerobic digesters. They found also a linear relation similar to Park et al. (2006) with the parameters Slurry_temperature = Air_temperature * 0.75 + 6.23 (Figure 3D-5). The measurements by Hansen et al. (2006) cannot be seen as representative for raw liquid manure as the digestate as a starting point is having a higher temperature than raw slurry due to the exothermic process in the anaerobic digesters. The model by Hansen et al. (2006) is used for anaerobic digested manure as this is likely a normal temperature profile for digestate returned to the farms for continued storage.

For raw slurry, a linear model has been constructed with data from Husted (1994) and Rodhe et al. (2009, 2012, 2015) with the following parameters Slurry_temperature = Air_temperature * 0.5011 + 5.1886 (r^2 = 0.75).

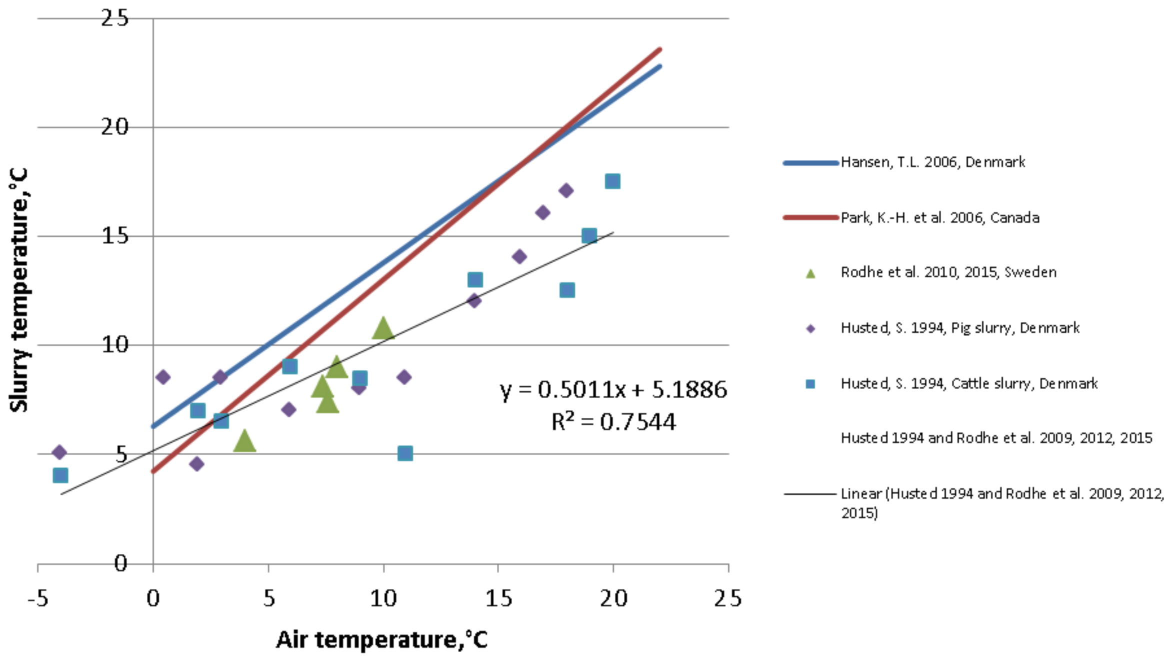

Figure 3D-5 Measured and modelled slurry temperatures in outdoor storage tanks.

Manure storage and application to fields

The Ministry of Environment and Food of Denmark regulate the storage time and the secondary field application of raw biomass and digested biomass. The general rule is that manure is only allowed to be applied to crops, which have a nitrogen norm and is harvested the same calendar year. Only crops with an official nitrogen norm are allowed to be fertilised.

It means that autumn application is not allowed as these crops are not harvested within the calendar year. The storage manure capacity is therefore 8-10 months including eventually storage capacity inside the barns.

Field application of manure is not allowed before February 1st and not on frozen or snow covered areas. Because of difficulties for driving in the fields the optimum application time is March and April, plus some application to grass cuttings during summer. In cooperation with the Danish Agricultural Advisory Centre (SEGES), a general storage profile for animal manure storages has been developed, Figure 3D-6. The figure shows that the maximum storage is in February and the minimum in end April. Slurry is generally stored in four meter deep concrete tanks where two meters are above ground and two meters below ground. As it is not possible to empty the tanks completely (crust cover) it is assumed that 10 % of the annual production is the minimum amount stored by end of April.

No reduction in the CH_4 emission due to microbial degradation in the crust cover (IPCC 2006) is implemented in the emission estimate so far.

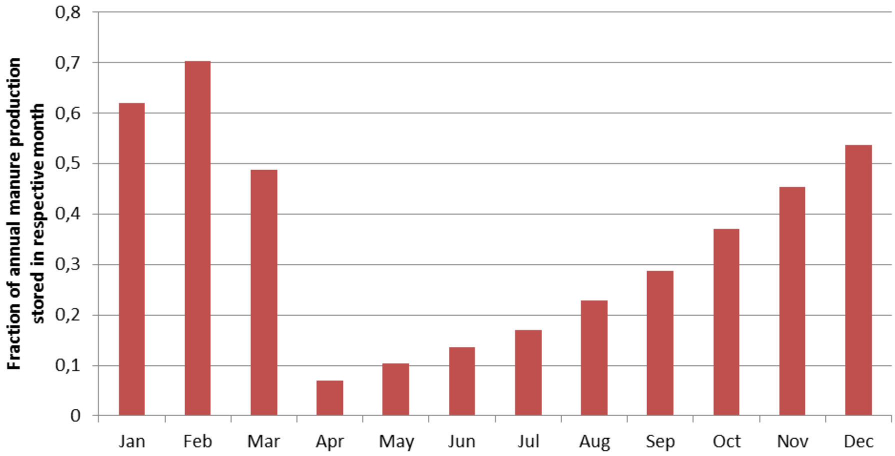

Figure 3D-6 The fraction of animal manure stored during different month of the year. The fraction is the share of the total annual manure production corrected for grazing. Small amounts are applied to grass during summer giving a lower increase in the summer months than in the winter period.

The model

The model estimates methane emission for slurry from cattle and swine. Estimations of CH_4, VSd and VSnd is based on measurements (Petersen et al., 2016). The measurements are not made on the exact time for excretion of the manure and the CH_4 emission is therefore calculated as a constant emission per day, even though some degrading of VS in the barn will take place. The CH_4 emission in barns for swine at 18.6 °C is estimated to 572.97 g CH_4 per kg VS per year, corresponding to 1.57 g CH_4 per kg VS per day. VS from barns are not divided in VSd and VSnd because the measured emission relate to the total amount of VS. The total CH_4 emission from barns is calculated as excreted VS multiplied by 1.54 g CH_4 per kg VS per day and average storage time (HRT) in the barn.

For cattle barns, the temperature varies through the year. The emission factor of 182.99 g CH_4 per kg VS per year given in Table 3D-25 is an average for a year. For cattle total CH_4 emission from barns is also calculated as VS multiplied with average store time (HRT). It is assumed that excretion of VS in barns is constant. The period in which the cattle is on grass gives less manure in the barns, but this is not taken in to account. It is assumed that the effect of grazing is very small because the majority of dairy cattle in Denmark spend most of the time in the barns.

Methane emission from outdoor storage of not digested slurry is estimated in a matrix, where slurry is supplied and taken away with a time step of 10 days. The matrix sums the total methane emission until the decomposition of VS is almost null (around two years). The amount of VS supplied the storage is the total VS excretion from the animals and the straw used for bedding, subtracted VS-loss from barns. Removal of VSd and VSnd from storage is estimated for every time step and a new methane emission is calculated (see Table 3D-25).

For estimation of methane emission from outdoor storage of digested slurry, the amount of digested slurry delivered to the biogas plants based on the BIB register is used. Same model as used for not digested slurry is used for digested slurry, though with a higher temperature in the storage after biogas treatment. The stored digested slurry has a high content of VSnd and the emission of methane is therefore low. Due to the low activity of the decomposition, a lower CH_4:CO_2-ratio (of 0.1) is assumed for digested slurry compared to not digested slurry (Dong, 2013, Pers. Comm.).

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Annex 3E - LULUCF

The full Annex 3E with supporting information can be found here:

https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

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Table 3E.1 Estimation of forest percentage and forest area.

Equation	Description
$X_j = \frac{A_j}{A_{15,j}}$	The forest percentage (X) of the *j*th sample plot (SSU) is estimated as the forested area (*A*) divided by the total area of the 15 m radius sample plot ($A_{15,j}$).
$\bar{X}_Z = \frac{1}{n_Z} \sum_Z X_j R_j$	Average forest percentage ($\bar{X}$) of all inventoried plots (SSU) with forest status *Z* based on aerial photos. R_j is an indicator variable that is 1 for inventoried plots and 0 otherwise. n_Z is the number of inventoried plots identified as forest or OWL from the air photos.
$\bar{\bar{X}} = \frac{1}{n}\left(\sum_{j=1}^{n} X_j R_j + N_{21}\bar{X}_1 + N_{22}\bar{X}_2 \right)$	Overall average forest percentage ($\bar{\bar{X}}$). *n* is the total number of inventoried and non-inventoried sample plots. N_{21} and N_{22} is the number of non-inventoried sample plots with forest and OWL, respectively.
$A_{Forest} = \bar{\bar{X}} \cdot A_{Total}$	Total forest area. A_{Total} is the total land area, $\bar{\bar{X}}$ is the estimated forest percentage and A_{Forest} is the total forest area.

Table 3E.2 Estimation of forest area with a specific characteristic.

Equation	Description
$\bar{X}_k = \frac{\sum_{j=1}^{n} R_{jk} A_j}{\sum_{j=1}^{n} A_j}$	Proportion of the forest area with a given characteristic ($\bar{X}_k$). R_{jk} is an indicator variable which is 1 if the the forest area on the *j*'th sample plots has the *k*'th characteristic and 0 otherwise. A_j is the sample plot area and *n* is the total number of inventoried sample plots with forest cover.
$A_k = \bar{X}_k \cdot A_{Forest}$	Total area with a given characteristic (A_k). $\bar{X}_k$ is the estimated proportion of the forest area with the *k*'th characteristic and A_{Forest} is the total forest area.

Table 3E.3 Estimation of diameter-height equations.

Equation	Description
$h_{ij} = 13 + (\bar{h}_j - 13) \cdot \exp\left(\alpha_1 \cdot \left(1 - \frac{\bar{d}_j}{d_{ij}} \right) + \alpha_2 \cdot \left(\frac{1}{\bar{d}_j} - \frac{1}{d_{ij}} \right) \right)$	Site specific dh-regression for calculating height of trees not measured for height. h_{ij} and d_{ij} is the height and diameter of the i'th tree on the j'th sample plot. $\bar{h}_j$ and $\bar{d}_j$ are the average height and diameter of trees measured for height on the *j*th sample plot. α_1 and α_2 are species and growth-region specific parameters
$h_{ij} = 13 + \beta_1 \cdot \exp(-\frac{\beta_2}{d_{ij}})$	General dh-regression for calculating height of trees not measured for height. h_{ij} and d_{ij} is the height and diameter of the i'th tree on the j'th sample plot. β_1 and β_2 are species and growth-region specific parameters

Table 3E.4 Estimation of quadratic mean diameter.

Equation	Description
$g_{ij} = \frac{\pi}{4} d_{ij}^2$	Basal area (*g*) of the *i*th tree on the *j*th plot is calculated from the diameter at breast height (*d*) (1.3 m above ground) assuming a circular stem form.
$G_j = \sum_{i=1}^{m} \frac{1}{A_{c,ij}} g_{ij}$	Basal area per hectare (*G*) the jth sample plot is calculated as the scaled sum of individual tree basal areas. Basal area (*g*) of the *i*th tree on the *j*th sample plot is scaled according to the plot area ($A_{c,ij}$) of the *c*'th concentric circle (c=3,5; 10; 15 m).
$N_j = \sum_{i=1}^{m} \frac{1}{A_{c,ij}}$	Stem number per hectare (*N*) the *j*th sample plot is calculated as the scaled number of individual trees. The *i*th tree on the *j*th sample plot is scaled according to the plot area ($A_{c,ij}$) of the *c*'th concentric circle (c=3,5; 10; 15 m).
$D_{g,j} = \sqrt{\frac{4}{\pi} \frac{G_j}{N_J}}$	The mean squared diameter is calculated from the calculated basal area and stem number for each plot.

Table 3E.5 Estimation of biomass and carbon of trees.

Equation	Description
$v_{ij} = F(d_{ij}, h_{ij}, D_{g,j})$	The volume (*v*) of the *i*'th tree on the *j*th sample plots is calculated using the existing volume functions (*F*) using the tree diameter and height and the quadratic mean diameter.
$B_{ij} = V_{ij} \cdot Density_{ij}$	Biomass (*B*) of the *i*th tree on the *j*th sample plot is estimated as the total volume (V_{Tot}) times the species-specific density.
$E_{ij} = F(d_{ij}, h_{ij})$	Expansion factor model for beech and Norway spruce
$v_{tot,ij} = B_{ij} \cdot E_{ij}$	The total above and below ground volume (v_{tot}) of the ith tree on the jth sample plot. B_{ij} is the calculated aboveground biomass of the tree and *E* is the expansion factor.
$C_{ij} = B_{ij} \cdot 0.5$	Carbon of the *i*th tree on the *j*th sample plot is calculated as the biomass (*B*) times 0.5.

Table 3E.6 Estimation of total biomass and carbon pools.

Equation	Description
$V_{cj} = \frac{1}{A_{cj}} \sum_{i=1}^{m} R_{c,i} v_{ij}$	Volume, biomass or carbon per hectare (*V*) of the *c*th concentric circle on the *j*th sample plot (*c*=3,5; 10; 15 m). R_c is an indicator variable that is 1 if the *i*th tree is measured on the *c*th circle and 0 otherwise. $A_{c,ij}$ is the area of the *j*th sample plot and *c*th concentric circle; *m* is the number of trees on the *jth* sample plot.
$\overline{V}_c = \frac{\sum_{j=1}^{n} A_{cj} V_{cj}}{\sum_{j=1}^{n} A_{cj}}$	The average area weighted volume, biomass or carbon per hectare ($\overline{V}$) of the *c*th concentric circle. $A_{c,ij}$ is the area of the *j*th sample plot and *c*th concentric circle; *n* is the number of sample plots.
$\overline{\overline{V}} = \overline{V}_{3,5} + \overline{V}_{10} + \overline{V}_{15}$	The overall average volume, biomass or carbon per hectare ($\overline{\overline{V}}$) is estimated as the sum of the average volume, biomass or carbon per hectare ($\overline{V}_c$) for the three concentric circles (*c*=3.5, 10 and 15)
$V = \overline{\overline{V}} \cdot A_{Skov}$	Total volume, biomass or carbon *V* is the overall average volume, biomass or carbon per hectare ($\overline{\overline{V}}$) times the forest area A_{Forest}.

Table 3E.7 Estimation of biomass and carbon with a given characteristic.

Equation	Description
$V_{cj,k} = \frac{1}{A_{cj}} \sum_{i=1}^{m} R_{c,ij} R_{k,ij} v_{ij}$	Volume, biomass or carbon per hectare (*V*) with the *k*th characteristic of the *c*th concentric circle on the *j*th sample plot (c=3,5; 10; 15 m). R_c is an indicator variable that is 1 if the *i*th tree is measured on the *c*th circle and 0 otherwise. R_k is an indicator variable that is 1 if the tree has *k*th characteristic and 0 otherwise. $A_{c,ij}$ is the area of the *j*th sample plot and *c*th concentric circle; *m* is the number of trees on the *j*th sample plot.
$\overline{V}_{c,k} = \frac{\sum_{j=1}^{n} A_{cj} V_{cj,k}}{\sum_{j=1}^{n} A_{cj}}$	The average area weighted volume, biomass or carbon per hectare ($\overline{V}$) with the *k*th characteristic of the cth concentric circle. $A_{c,ij}$ is the area of the *j*th sample plot and *c*th concentric circle; *m* is the number of trees on the *j*th sample plot.
$\overline{\overline{V}}_k = \overline{V}_{3,5,k} + \overline{V}_{10,k} + \overline{V}_{15,k}$	The overall average volume, biomass or carbon per hectare with the *k*th characteristic ($\overline{\overline{V}}$) is estimated as the sum of the average volume, biomass or carbon per hectare ($\overline{V}_{c,k}$) for the three concentric circles (*c*=3.5, 10 and 15)
$V_k = \overline{\overline{V}}_k \cdot A_{Forest}$	Total volume, biomass or carbon with the k^{th} characteristic (V_k) is the overall average volume, biomass or carbon per hectare ($\overline{\overline{V}}_k$) times the forest area A_{Forest}.

Table 3E.8 Estimation of biomass and carbon content of dead wood.

Equation	Description
$v_{s,ij} = F\left(d_{s,ij}, h_{s,ij}, D_{g,j}\right)$	The volume (v_s) of the *i*th standing, dead tree on the *j*th sample plots is calculated using the existing volume functions (*F*) using the tree diameter and height and the squared mean diameter.
$v_{l,ij} = \frac{\pi}{4} d_{l,ij}^2 \cdot l_{l,ij}$	Volume of lying dead trees (v_l) is calculated as the length (*l*) and the ith tree on the jth sample plot times the cross sectional area. The cross sectional area is calculated from the mid-diameter (d_l) of the dead wood.
$B_{s,ij} = v_{s,ij} \cdot D_{ij} \cdot r_{k,ij}$ $B_{l,ij} = v_{l,ij} \cdot D_{ij} \cdot r_{k,ij}$	Biomass of the *i*th standing (B_s) or lying (B_l) tree on the jth sample plot is calculated as the volume (v_s or v_l) times the species specific density (*D*) and a the *k*th reduction factor according to the structural decay of the wood observed in the field.
$B_{s,tot,ij} = B_{s,ij} \cdot E_{ij}$	The total above and below ground volume ($B_{s,tot}$) of the *i*th standing, dead tree on the *j*th sample plot. v_s is the calculated biomass of the tree and *E* is the expansion factor.
$K_{s,ij} = B_{s,ij} \cdot 0.5$ $K_{l,ij} = B_{l,ij} \cdot 0.5$	Carbon in standing or lying dead wood (C_s or C_l) is calculated as the biomass (B_s or B_l) times 0.5.

Table 3E.9 Estimation of total biomass and carbon pools of dead wood.

Equation	Description
$V_{D,cj} = \frac{1}{A_{cj}} \sum_{i=1}^{m} R_c v_{s,ij} + R_c v_{l,ij}$	Deadwood volume, biomass or carbon pools per hectare (V_D) for the *c*th circle and the *j*th sample plot. v_s and v_l is the volume of standing and lying deadwood respectively. R_c is an indicator variable that is 1 if the tree is measured in the *c*th circle and 0 otherwise. A_C is the sample plot area of the *c*th circle. *m* is the number of trees within the *j*th sample plot.
$\overline{V}_{D,c} = \frac{\sum_{j=1}^{n} A_{cj} V_{cj}}{\sum_{j=1}^{n} A_{cj}}$	The average area weighted deadwood volume, biomass or carbon per hectare ($\overline{V}_D$) of the cth concentric circle. $A_{c,ij}$ is the area of the jth sample plot and cth concentric circle; *n* is the number of sample plots.
$\overline{\overline{V}}_D = \overline{V}_{D,3,5} + \overline{V}_{D,10} + \overline{V}_{D,15}$	The overall average deadwood volume, biomass or carbon per hectare ($\overline{\overline{V}}_D$) is estimated as the sum of the average volume, biomass or carbon per hectare ($\overline{V}_{D,c}$) for the three concentric circles (c=3.5, 10 and 15)
$V_D = \overline{\overline{V}}_D \cdot A_{Forest}$	Total deadwood volume, biomass or carbon V_D is the overall average deadwood volume, biomass or carbon per hectare ($\overline{\overline{V}}_D$) times the forest area A_{Forest}.

Table 3E.10 Estimation of forest floor carbon.

Equation	Description
$C_{floor,s,j} = Depth_j \cdot A_j \cdot B_s \cdot F_{s,j}$	Forest floor carbon ($C_{floor,s,j}$) of the *s*th species, on the *j*th plot with an area of *A*. B_s is the species specific forest floor density and *F* is the fraction of species *s*.
$C_{floor,j} = \sum_{s=1}^{k} C_{floor,s,j}$	Total forest floor carbon on the jth plot.
$C_{floor} = \frac{\sum_{j=1}^{n} C_{floor,j}}{\sum_{j=1}^{n} A_j} \cdot A_{Forest}$	Total forest floor carbon is estimated as the area weighted average forest floor carbon content times the total forest area.

Table 3E.11 Crops grown in 2021 distributed on regions, in ha. https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation (Statistics Denmark, 2023).

Table 3E.12 Crop yield in 2021 distributed on regions, in Hkg crop yield per ha. https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation (Statistics Denmark, 2023).

Table 3E.13 Area input to C-TOOL in 2021 in hectares. https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Table 3E.14 Average annual temperatures for Denmark, 1977-2021, °C https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation (Danish Meteorological Institute, 2023).

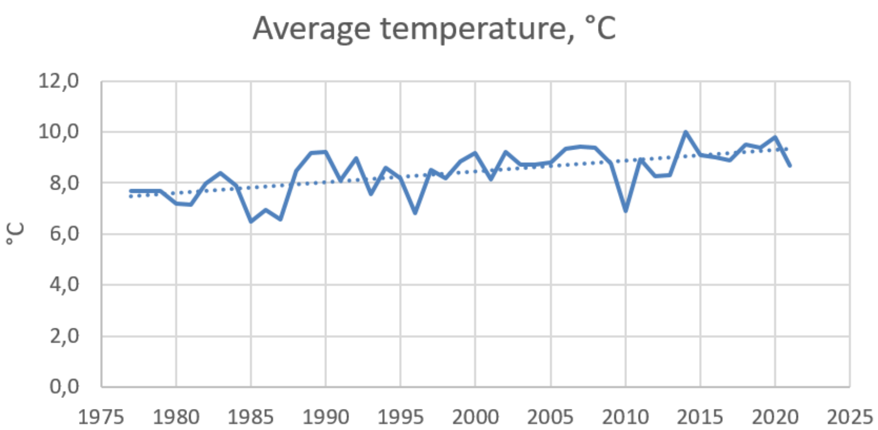

Figure 3E.1 Average annual temperatures for Denmark, 1977-2021, °C. (The Danish Meteorological Institute, 2023).

Hedgerows

Since the beginning of the early 1930s, governmental subsidiaries have been given to increase the area with hedgerows to reduce soil erosion. In the 1950-

60's, 6-9 million single rowed confers, mainly white spruce (*Picea glauca*), were planted annually. From around 1965, the annual rate decreased sharply to almost zero. Instead new hedges were made of broadleaved trees/plants but only around 2-3 million trees annually. This can be converted to annually financial support given to approximately 400-800 km of hedgerow. From 2014, only minor subsidized areas have been erected. Currently there is a small annual governmental subsidy available for approximately 100 ha per year.

The new updated LiDAR model for hedges and biotopes not qualifying for forest is based on LiDAR measurements in 2006 and 2014/15. Information on the exact location of subsidized hedge planting and some of the removal is available from 2007 and onwards. In the period from 2006 to 2014/15 is the area with removed hedges estimated from what is missing in the 2014/15 LiDAR measurements compared to 2006.

Future updates with this technology will be available because the Danish Government has decided to make new LiDAR measurements in a five years rotation for the whole country starting 2019.

30-year transition period and effect on eventual on under- or overestimation of the C source/sink in the period up to 1990

The Danish inventory has implemented an annual Land Use Matrix from 1990 and onwards using a 30 years transition period for estimating emissions from Land Use Change (LUC). This is different from the 20 years transition period as mentioned in the 2006 IPCC Guidelines, however the default of 20 years, is not appropriate for mineral soils under the cold temperate conditions in Denmark.

The choice of transition period has mainly two effects on the inventory.

The first issue is a distribution of the reported hectares and emissions between "Land remaining in the same Land category" and the subcategory "Land converted to." For all emission estimates except for the carbon stock in soils is used either a distribution of the known carbon stock as in forest or the instant oxidation approach is used. For all living and dead biomass Denmark is using instant oxidation, except for hedges where an area based Tier 3 carbon stock model is developed. Thus, the emission/sink from living and dead biomass has no impact on the emission estimate for the base year. An eventual over- or underestimation of the emission will therefore only occur from mineral soils in transition as the period until the new equilibrium is reached is extended.

The main historical LUC in Denmark is conversion from:

- Cropland (CL) to Settlement (SE) with an indicative loss of carbon stock/ha and a lower yearly C storage in the living biomass.
  CL to Forest land (FL) with an indicative increase in the carbon stock/ha and a higher yearly C storage in the living biomass.

Figure 3E.2 shows the apparent Land Use Change from 1960 to 2021 (Statistics Denmark 1896, 1919, 1952, 1990). As can be seen the area with FL has increased substantially as well as the SE area. The total area with CL is more or less constant but the GL has decreased substantially. Approximately half of the 900 000 ha GL in 1888 were heathland. Of this only 70 000 ha is left today. The remaining heathland has been turned into agricultural soils. According to our forest statistics from 1954 (Vivian Kvist Johannesen, pers. com) about 55 % of the afforestation since 1954 has taken place on former CL and 32 % on land we would have considered as GL. The afforestation on CL has mainly taken place on the fertile land around the cities and the afforestation on GL was mainly on the sandy heathland, planted with Norwegian spruce.

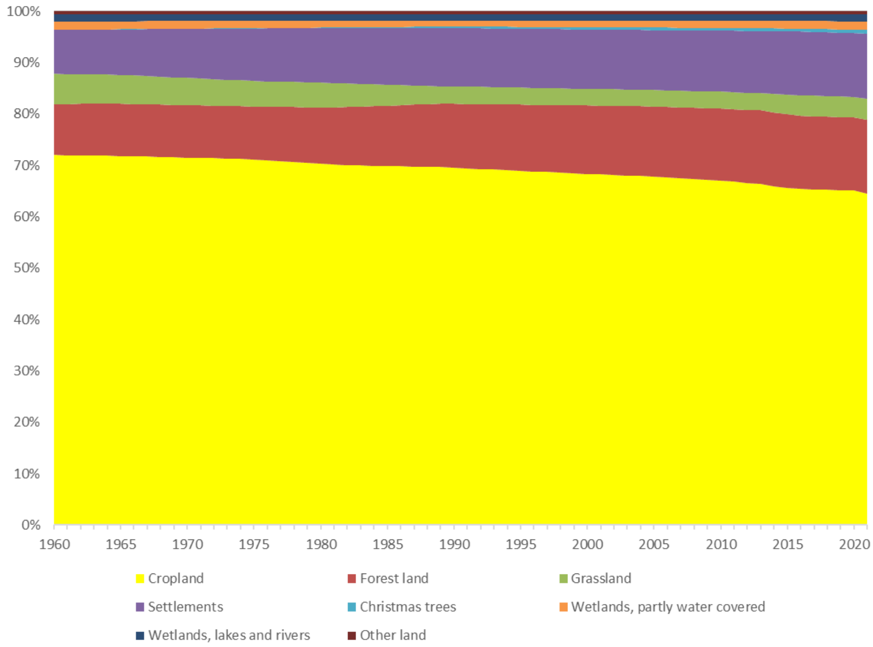

Figure 3E.2 Land Use Change 1960-2021.

Very few data is available on the carbon stock in the different soil types and it is therefore very difficult to estimate Danish default reference carbon stocks. The earliest representative data we have on agricultural land is from the beginning of the 1960'ies from our agricultural research stations (Lamm, 1971). Forty-nine of these soil samples can be considered as mineral. They had an average C stock (0-100 cm) of 103.3 tonnes C/ha (SE ±33.8). The sandy soils showed both low and high values, depending on its podsolization. In Danish soil sampling grid from 1986 (approximately 500 samples), the weighted average C stock was 120.8 tonnes C/ha indicating a build-up in the period from the 1960's to the 1980's. This coincided with the increased fertilization in agriculture leading to higher yields.

Long-term agricultural experiments at Rothhamsted in the United Kingdom has shown that >95 % of the Soil Organic Matter (SOM) has a half-life (t½) of more than 49 years (Jenkinson and Rayner, 1977), Table 1. Both the Roth-C model used in England and C-TOOL (Petersen et al., 2002) is based on the long-term experiments. All models are using prediction of the age of the soil carbon. Basically, the models are operating with fast pools (crop residue), medium reacting pools and slow acting pools. The fast pools are normally considered as crop residues or litter and the slow reacting pools is of minor interest for inventory purposes because of t½ >> 100 years. Hence, the medium pools is the single most important factor for the reporting obligation within the time frame of the inventories submitted to UNFCCC. According to the data presented in Table 3E.15 from Rothamstedt (Jenkinson and Rayner 1977) and Denmark (Petersen et al., 2002) the medium pool accounts for approximately 45 % of the total C stock. New unpublished data in Denmark has estimated that on sandy soils (former heathland) the medium pool is even lower (Taghizadeh-Toosi, 2015).

Table 3E.15 Modelled half-lives and pool sizes in Rothamstedt. (Jenkinson & Rayner, 1977).

	t½, yr	t per ha (0-23 cm)	Fraction
Decomposable Plant Material, DPM	0.165	0.01	0.0004
Resistant Plant Material, RPM	2.31	0.47	0.0194
Soil Biomass	1.69	0.28	0.0115
Physically stabilized Organic Matter POM	49.5	11.3	0.4658
Chemically Stabilized Organic Matter, COM	1980	12.2	0.5029
Total		24.3	1.0000

The Danish inventory is using C-TOOL to estimate the C turnover in agricultural soils. As the major Land Use Conversion is from agricultural land to Settlements, this model may be able to predict loss from agricultural soils when land is transferred to Settlements. When looking on the large Danish conversion from unfertile sandy heathland to fertile CL and the afforestation on this land it is currently a difficult task to come with any conclusive figures on the loss and gain from mineral soils combined with LUC.

Technical documentation for C-TOOL

C-TOOL is a simple tool for simulation of soil carbon turnover. The technical documentation for C-TOOL with parameterization is provided and documented by Taghizadeh-Toosi et al. (201) and Taghizadeh-Toosi (2015).

Table 3E.16 Land use matrix 1959-2021.
https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

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Annex 3F - Waste

Annex 3F-1 Emissions from the waste sector.

Table 3F-1.1 Emissions for the waste sector, kt CO_2 equivalents.

Annex 3F-2 Solid Waste Disposal on Land

Table 3F-2.1 All nationally produced waste categorised after handling method.

Table 3F-2.2 Annual amounts of deposited waste, total organic degradable matter, amounts of annual degraded organic matter, deposited methane potential, gross methane emission, recovered methane collected for biogas production, oxidised methane in the top layer, the resulting net emission and implied emission factors for the Danish solid waste disposal sites.

Table 3F-2.3 Annual amounts of deposited waste allocated between individual waste types, kt.

Annex 3F-3 Biological Treatment of Solid Waste

Table 3F-3.1 Activity data for composting, kt.

Table 3F-3.2 National emissions from composting.

Table 3F-3.3 Activity data and methane emissions from anaerobic digestion at manure-based biogas plants.

Annex 3F-4 Incineration and open burning of waste

Table 3F-4.1 Greenhouse gas emissions from Incineration and open burning of waste.

Table 3F-4.2 Activity data for human cremation.

Table 3F-4.3 Activity data for animal cremation.

Annex 3F-5 Wastewater treatment and discharge

Table 3F-5.1 Produced, recovered and emitted CH_4 from wastewater treatment.

Table 3F-5.2 N_2O emissions from wastewater.

Table 3F-5.3 The contribution from industrial wastewater to the influent TOW at Danish wastewater treatment plants, population number, measured BOD and COD data and resulting COD/BOD ratio.

Table 3F-5.4 Nitrogen content in the influent and effluent wastewater, t.

Annex 3F-6 Other

Table 3F-6.1 Greenhouse gasses from accidental fires.

Table 3F-6.2 Occurrence of accidental fires.

Table 3F-6.3 Full scale equivalent accidental building fires.

Table 3F-6.4 Emission factors for accidental building fires.

Table 3F-6.5 Average building floor space.

Table 3F-6.6 Number of nationally registered vehicles and full scale equivalent vehicle fires.

Table 3F-6.7 Average weight vehicles, kg.

Table 3F-6.8 Activity data for accidental vehicle fires, t.

See:
https://envs.au.dk/en/faglige-omraader/luftforurening-udledninger-og-effekter/udledning-af-luftforurening/greenhouse-gases/supporting-documentation

Please note that data found via this link are updated annually. This means that data in the annexes always matches the newest version of the NIR report.

Annex 4 - Information on the energy statistics

This description of the Danish energy statistics has been prepared by DCE in cooperation with the Danish Energy Agency (DEA) as background information to the Danish National Inventory Report (NIR).

The Danish energy statistics system

DEA is responsible for the Danish energy balance. Main contributors to the energy statistics outside DEA are Statistics Denmark and Danish Energy Association (before Association of Danish Energy Companies). The statistics are performed using an integrated statistical system building on an Access database and Excel spreadsheets.

The DEA follows the recommendations of the International Energy Agency as well as Eurostat.

The national energy statistics is updated annually and all revisions are immediately included in the published statistics, which can be found on the DEA homepage[1]. It is an easy task to check for breaks in a series because the statistics is 100 % time-series oriented.

The national energy statistics does not include Greenland and the Faroe Islands.

For historical reasons, DEA receive monthly information from the Danish oil companies regarding Danish deliveries of oil products to Greenland and Faroe Islands. However, the monthly (MOS) and annual (AOS) reporting of oil statistics to Eurostat and IEA exclude Greenland and Faroe Islands. For all other energy products, the Danish figures are also excluding Greenland and Faroe Islands.

Reporting to the Danish Energy Agency

The Danish Energy Agency receives monthly statistics for the following fuel groups:

- Crude oil and oil products
  - Monthly data from 46 oil companies, the main purpose is monitoring oil stocks according to the oil preparedness system
- Natural gas
  - Fuel/flare from platforms in the North Sea
  - Natural gas balance from the regulator Energinet.dk (National monopoly)
- Coal and coke
  - Power plants (94 %)
  - Industry companies (4 %)
  - Coal and coke traders (2 %)
- Electricity
  - Monthly reporting by e-mail from the regulator Energinet.dk (National monopoly)
  - The statistics covers:

[1] https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/annual-and-monthly-statistics

        - Production by type of producer
        - Own use of electricity
        - Import and export by country
        - Domestic supply (consumption + distribution loss)
- Town gas (quarterly) from two town gas producers
- The large central power plants also report monthly consumption of biomass

Annual data includes renewable energy including waste. The DEA conducts a biannual survey on wood pellets and wood fuel. Statistics Denmark conducts biannual surveys on the energy consumption in the service and industrial sectors. Statistics Denmark prepares annual surveys on forest (wood fuel) & straw.

Other annual data sources include:

- DEA
    - Survey on production of electricity and heat and fuels used
    - Survey on end use of oil
    - Survey on end use of natural gas
    - Survey on end use of coal and coke
- DCE, Aarhus University
    - Energy consumption for domestic air transport
- Danish Energy Association (Association of Danish Energy companies)
    - Survey on electricity consumption
- Ministry of Taxation
    - Border trade
- Centre for Biomass Technology
    - Annual estimates of final consumption of straw and wood chips

Annual revisions

In general, DEA follows the same procedures as in the Danish national account. This means that normally only figures for the last two years are revised.

Aggregating the energy statistics on SNAP level

The sectors used in the official energy statistics have been mapped to SNAP categories, used in the Danish emission database. DCE aggregates the official energy statistics to SNAP level based on a source correspondence table.

In cooperation between DEA and DCE, a fuel correspondence table has been developed mapping the fuels used by the DEA in the official energy statistics with the fuel codes used in the Danish national emission database. The fuel correspondence table between fuel categories used by the DEA, DCE and IPCC is presented in Annex 3A-3.

The mapping between the energy statistics and the SNAP and fuel codes used by DCE can be seen in the table below.

Table 3A-9.1 Correspondence between the Danish national energy statistics and the SNAP nomenclature (only stationary combustion part shown).

Unit: TJ	End-use		Transformation	
	SNAP	Fuel	SNAP	Fuel
Energy Sector				
Extraction and Gasification				
- Extraction				
- - Natural Gas	010504	301A		
- Gasification				
- - Biogas, Landfill				
- - Biogas, Other				
- - Electricity				
Refineries				
- Used for Refining				
- - Crude Oil				
- - Refinery Feedstocks				
- - Electricity				
- - District Heating				
- Own Use				
- - Refinery Gas	010306	308A		
- - LPG	010306	303A		
- - Gas-/Diesel Oil	010306	204A		
- - Fuel Oil	010306	203A		
- Net Production				
- - Refinery Gas				
- - LPG				
- - Naphtha (LVN)				
- - Aviation Gasoline				
- - Motor Gasoline				
- - JP4				
- - Other Kerosene				
- - JP1				
- - Gas-/Diesel Oil				
- - Fuel Oil				
- - Petroleum Coke				
- - White Spirit				
- - Lubricants				
- - Bitumen				
- - Biodiesel				
Distribution				
- Electricity Used in Distribution				
- - Electricity Distribution				
- - District Heating Distribution				
- - Gas Distribution				
Transformation Sector				
Large-scale Power Units				
- Fuels Used for Power Production				
- - Gas-/Diesel Oil			010100	204A
- - Fuel Oil			010100	203A
- - Electricity Plant Coal			010100	102A
- - Straw			010100	117A
- Own Use				
- - Electricity				
- Gross Production				
- - Electricity				
Large-Scale CHP Units				
- Fuels Used for Power Production				
- - Refinery Gas			010300	308A
- - LPG			010100	303A
- - Naphtha (LVN)			010100	210A
- - Gas-/Diesel Oil			010100	204A
- - Fuel Oil			010100	203A
- - Petroleum Coke			010100	110A
- - Orimulsion			010100	225A
- - Natural Gas			010100	301A
- - Electricity Plant Coal			010100	102A
- - Straw			010100	117A
- - Wood Chips			010100	111A
- - Wood Pellets			010100	111A
- - Wood Waste			010100	111A
- - Biogas, Landfill			010100	309A
- - Biogas, Sludge			010100	309A

Continued			
- - Biogas, Others		010100	309A
- - Bio Natural Gas		010100	315A
- - Waste, Non-renewable		010100	114A
- - Wastes, Renewable		010100	114A
- Fuels Used for Heat Production			
- - Refinery Gas		010300	308A
- - LPG		010100	303A
- - Naphtha (LVN)		010100	210A
- - Gas-/Diesel Oil		010100	204A
- - Fuel Oil		010100	203A
- - Petroleum Coke		010100	110A
- - Orimulsion		010100	225A
- - Natural Gas		010100	301A
- - Electricity Plant Coal		010100	102A
- - Straw		010100	117A
- - Wood Chips		010100	111A
- - Wood Pellets		010100	111A
- - Wood Waste		010100	111A
- - Biogas, Landfill		010100	309A
- - Biogas, Sludge		010100	309A
- - Biogas, Other		010100	309A
- - Bio Natural Gas		010100	315A
- - Wastes, Non-renewable		010100	114A
- - Wastes, Renewable		010100	114A
- Own Use			
- - Electricity			
- - District Heating			
- Production			
- - Electricity, Gross			
- - District Heating, Net			
Small-Scale CHP Units			
- Fuels Used for Power Production			
- - Gas-/Diesel Oil		010100	204A
- - Fuel Oil		010100	203A
- - Natural Gas		010100	301A
- - Electricity Plant Coal		010100	102A
- - Straw		010100	117A
- - Wood Chips		010100	111A
- - Wood Pellets		010100	111A
- - Wood Waste		010100	111A
- - Biogas, Landfill		010100	309A
- - Biogas, Sludge		010100	309A
- - Biogas, Other		010100	309A
- - Bio Natural Gas		010100	315A
- - Waste, Non-renewable		010100	114A
- - Wastes, Renewable		010100	114A
- Fuels Used for Heat Production			
- - Gas-/Diesel Oil		010100	204A
- - Fuel Oil		010100	203A
- - Natural Gas		010100	301A
- - Electricity Plant Coal		010100	102A
- - Straw		010100	117A
- - Wood Chips		010100	111A
- - Wood Pellets		010100	111A
- - Wood Waste		010100	111A
- - Biogas, Landfill		010100	309A
- - Biogas, Sludge		010100	309A
- - Biogas, Other		010100	309A
- - Bio Natural Gas		010100	315A
- - Wastes, Non-renewable		010100	114A
- - Wastes, Renewable		010100	114A
- Own Use			
- - Electricity			
- - District Heating			
- Production			
- - Electricity, Gross			
- - District Heating, Net			
Wind Turbines			
- Used for Power Production			
- - Wind Power			
- Gross Production			
- - Electricity			

Continued			
Hydro Power Units			
- Used for Power Production			
- - Hydro Power			
- Gross Production			
- - Electricity			
District Heating Units			
- Fuels Used for Heat Production			
- - Refinery Gas		010300	308A
- - LPG		010200	303A
- - Gas-/Diesel Oil		010200	204A
- - Fuel Oil		010200	203A
- - Waste Oil		010200	203A
- - Petroleum Coke		010200	110A
- - Natural Gas		010200	301A
- - Electricity Plant Coal		010200	102A
- - Coal		010200	102A
- - Solar Energy			
- - Geothermal Energy			
- - Straw		010200	117A
- - Wood Chips		010200	111A
- - Wood Pellets		010200	111A
- - Wood Waste		010200	111A
- - Biogas, Landfill		010200	309A
- - Biogas, Sludge		010200	309A
- - Biogas, Other		010200	309A
- - Bio Natural Gas		010200	315A
- - Wastes, Non-renewable		010200	114A
- - Wastes, Renewable		010200	114A
- - Bio Oil		010200	215A
- - Electricity for Heat Pumps			
- Own Use			
- - District Heating			
- Net Production			
- - District Heating			
Auto producers, Electricity Only			
- Fuels Used for Power Production			
- - Natural Gas		030100	301A
- - Solar Energy			
- - Biogas, Landfill		030100	309A
- - Biogas, Sewage Sludge		030100	309A
- - Biogas, Other		030100	309A
- - Bio Natural Gas		030100	315A
- Gross Production			
- - Electricity			
Auto producers, CHP Units			
- Fuels Used for Power Production			
- - Refinery Gas		010300	308A
- - Gas-/Diesel Oil		030100	204A
- - Fuel Oil		030100	203A
- - Waste Oil		030100	203A
- - Natural Gas		030100	301A
- - Coal		030100	102A
- - Straw		030100	117A
- - Wood Chips		030100	111A
- - Wood Pellets		030100	111A
- - Wood Waste		030100	111A
- - Biogas, Landfill		030100	309A
- - Biogas, Sludge		030100	309A
- - Biogas, Other		030100	309A
- - Bio Natural Gas		030100	315A
- - Bio Oil		030100	215A
- - Wastes, Non-renewable		010100	114A
- - Wastes, Renewable		010100	114A
- Fuels Used for Heat Production		030100	114A
- - Refinery Gas		010300	308A
- - Gas-/Diesel Oil		030100	204A
- - Fuel Oil		030100	203A
- - Waste Oil		030100	203A
- - Natural Gas		030100	301A
- - Coal		030100	102A
- - Wood Chips		030100	111A
- - Wood Waste		030100	111A

Continued				
- - Biogas, Landfill			030100	309A
- - Biogas, Sludge			030100	309A
- - Biogas, Other			030100	309A
- - Bio Natural Gas			030100	315A
- - Wastes, Non-renewable			010100	114A
- - Wastes, Renewable			010100	114A
- Production				
- - Electricity, Gross				
- - District Heating, Net				
Auto producers, Heat Only				
- Fuels Used for Heat Production				
- - Gas-/Diesel Oil			030100	204A
- - Fuel Oil			030100	203A
- - Waste Oil			030100	203A
- - Natural Gas			030100	301A
- - Straw			030100	117A
- - Wood Chips			030100	111A
- - Wood Pellets			030100	111A
- - Wood Waste			030100	111A
- - Biogas, Landfill			030100	309A
- - Biogas, Sludge			030100	309A
- - Biogas, Other			030100	309A
- - Bio Natural Gas			030100	315A
- - Wastes, Non-renewable			010200	114A
- - Wastes, Renewable			010200	114A
- - Heat Pumps				
- Net Production				
- - District Heating				
Gas Works Gas Units	030106	301A		
- Fuels Used for Gas Works Gas				
- - Refinery Gas				
- - LPG				
- - Naphtha (LVN)				
- - Gas-/Diesel Oil				
- - Natural Gas				
- - Hard Coal				
- Production				
- - Gas Works Gas				
- - Coke				
Distribution Losses				
- Distribution Losses etc.				
- - Natural Gas				
- - Electricity				
- - District Heating				
- - Gas Works Gas				
Consumption Sector				
- Non-energy Use				
- - White Spirit				
- - Lubricants				
- - Bitumen				
Transport				
Military Transport				
- Aviation Gasoline	Transport	209A		
- Motor Gasoline	Transport	208A		
- JP4	Transport	207A		
- JP1	Transport	207A		
- Gas-/Diesel Oil	Transport	205A		
Road				
- LPG	Transport	303A		
- Motor Gasoline	Transport	208A		
- Other Kerosene	020200	206A		
- Gas-/Diesel Oil	Transport	205A		
- Fuel Oil	Transport	203A		
- Natural gas	Transport	301A		
- Bio Natural Gas	Transport	315A		
- Bioethanol	Transport	223A		
- Biodiesel	Transport	215A		
Rail				
- Motor Gasoline	Transport	208A		
- Other Kerosene	Transport	206A		
- Gas-/Diesel Oil	Transport	205A		

Continued			
- Electricity			
Domestic Sea Transport			
- LPG	Transport	303A	
- Other Kerosene	Transport	206A	
- Gas-/Diesel Oil	Transport	205A	
- Fuel Oil	Transport	203A	
Domestic Aviation			
- LPG	Transport	303A	
- Aviation Gasoline	Transport	209A	
- Motor Gasoline	Transport	208A	
- Other Kerosene	020100	206A	
- JP1	Transport	207A	
International Aviation			
- Aviation Gasoline	Transport	209A	
- JP1	Transport	207A	
Agriculture and Forestry and Horticulture			
- LPG	Transport	303A	
- Motor Gasoline	Transport	208A	
- Other Kerosene	020300	206A	
- Gas-/Diesel Oil	Transport	205A	
- Fuel Oil	020300	203A	
- Petroleum Coke	020300	110A	
- Natural Gas	020300	301A	
- Coal	020300	102A	
- Brown Coal Briquettes	020300	106A	
- Straw	020300	117A	
- Wood Chips	020300	111A	
- Wood Waste	020300	111A	
- Biogas, Other	020300	309A	
- Bio Natural Gas	020300	315A	
- Heat Pumps			
- Electricity			
- District Heating			
Fishing			
- LPG	Transport	303A	
- Motor Gasoline	Transport	208A	
- Other Kerosene	Transport	206A	
- Gas-/Diesel Oil	Transport	205A	
- Fuel Oil	Transport	203A	
Manufacturing Industry			
- Refinery Gas	030100	308A	
- LPG	Transport	303A	
- Naphtha (LVN)	Transport	210A	
- Motor Gasoline	Transport	208A	
- Other Kerosene	030100	206A	
- Gas-/Diesel Oil	Transport	205A	
- Fuel Oil	030100	203A	
- Waste Oil	030100	203A	
- Petroleum Coke	030100	110A	
- Natural Gas	030100	301A	
- Coal	030100	102A	
- Coke	030100	107A	
- Brown Coal Briquettes	030100	106A	
- Wood Chips	030100	111A	
- Wood Pellets	030100	111A	
- Wood Waste	030100	111A	
- Biogas, Landfill	030100	111A	
- Biogas, Other	030100	309A	
- Bio Natural Gas	030100	315A	
- Wastes, Non-renewable	030100	114A	
- Wastes, Renewable	030100	114A	
- Heat Pumps			
- Electricity			
- District Heating			
- Gas Works Gas	030100	301A	
Construction			
- LPG	031500	303A	
- Motor Gasoline	Transport		
- Other Kerosene	031500	206A	
- Gas-/Diesel Oil	Transport		
- Fuel Oil	031500	203A	
- Natural Gas	031500	301A	

Continued			
- Bio Natural Gas	031500	315A	
- Electricity			
Wholesale			
- LPG	020100	303A	
- Other Kerosene	020100	206A	
- Gas-/Diesel Oil	020100	204A	
- Petroleum Coke	020100	110A	
- Natural Gas	020100	301A	
- Wood Waste	020100	111A	
- Bio Natural Gas	020100	315A	
- Electricity			
- District Heating			
Retail Trade			
- LPG	020100	303A	
- Other Kerosene	020100	206A	
- Gas-/Diesel Oil	020100	204A	
- Fuel Oil	020100	203A	
- Petroleum Coke	020100	110A	
- Natural Gas	020100	301A	
- Electricity			
- District Heating			
Private Service			
- LPG	020100	303A	
- Other Kerosene	020100	206A	
- Gas-/Diesel Oil	020100	204A	
- Fuel Oil	020100	203A	
- Waste Oil	020100	203A	
- Petroleum Coke	020100	110A	
- Natural Gas	020100	301A	
- Wood Chips	020100	111A	
- Wood Waste	020100	111A	
- Biogas, Landfill	020100	309A	
- Biogas, Sludge	020100	309A	
- Biogas, Other	020100	309A	
- Bio Natural Gas	020100	315A	
- Wastes, Non-renewable	020100	114A	
- Wastes, Renewable	020100	114A	
- Electricity			
- District Heating			
- Gas Works Gas	020100	301A	
Public Service			
- LPG	020100	303A	
- Other Kerosene	020100	206A	
- Gas-/Diesel Oil	020100	204A	
- Fuel Oil	020100	203A	
- Petroleum Coke	020100	110A	
- Natural Gas	020100	301A	
- Coal	020100	102A	
- Brown Coal Briquettes	020100	106A	
- Solar Energy			
- Wood Chips	020100	111A	
- Wood Pellets	020100	111A	
- Bio Natural Gas	020100	315A	
- Electricity			
- District Heating			
- Gas Works Gas	020100	301A	
Single Family Houses			
- LPG	020200	303A	
- Motor Gasoline	Transport	208A	
- Other Kerosene	020200	206A	
- Gas-/Diesel Oil	020200	204A	
- Fuel Oil	020200	203A	
- Petroleum Coke	020200	110A	
- Natural Gas	020200	301A	
- Coal	020200	102A	
- Coke	020200	107A	
- Brown Coal Briquettes	020200	106A	
- Solar Energy			
- Straw	020200	117A	
- Firewood	020200	111A	
- Wood Chips	020200	111A	
- Wood Pellets	020200	111A	

Continued			
- Bio Natural Gas	020200	315A	
- Biodiesel	020200	215A	
- Heat Pumps			
- Electricity			
- District Heating			
- Gas Works Gas	020200	301A	
Multi-family Houses			
- LPG	020200	303A	
- Other Kerosene	020200	206A	
- Gas-/Diesel Oil	020200	204A	
- Fuel Oil	020200	203A	
- Petroleum Coke	020200	110A	
- Natural Gas	020200	301A	
- Coal	020200	102A	
- Coke	020200	107A	
- Brown Coal Briquettes	020200	106A	
- Solar Energy			
- Bio Natural Gas	020200	315A	
- Electricity			
- District Heating			
- Gas Works Gas	020200	301A	

Annex 5 - Assessment of completeness and (potential) sources and sinks of greenhouse gas emissions and removals excluded

The Danish greenhouse gas emission inventories for 1990-2021 include all sources identified by the 2006 IPCC Guidelines where methodologies and default emission factors exist. Some very minor sources have not been estimated due to lack of methodology, activity data or emission factors, i.e.:

- Direct and indirect CH_4 emissions from agricultural soils;
- N_2O emissions from accidental fires.

In addition to these sources, Denmark reports emissions from the memo items 'Multilateral operations', 'Long-term Storage of C in Waste Disposal Sites', 'Annual Change in Total Long-term C Storage' and 'Annual Change in Total Long-term C Storage in HWP Waste' as not estimated due to lack of data.

Annex 6 - Comparison of fuel data from Eurostat and CRF

This annex has not been included in the 2023 submission, but will be included in the 2024 submission.

Annex 7 Information on accounting of Kyoto units

Referring to Decision 3/CMP.11 on 'Implications of the implementation of decisions 2/CMP.7 to 4/CMP.7 and 1/CMP.8 on the previous decisions on methodological issues related to the Kyoto Protocol, including those relating to Articles 5, 7 and 8 of the Kyoto Protocol, part I: implications related to accounting and reporting and other related issues' for the preparation of the information required under Articles 7 of the Kyoto Protocol (UNFCCC, 2015), this chapter and chapters 13, 14 and 15 include information and references to the annual supplementary information under the Kyoto Protocol. Decision 3/CMP.11 states that decisions 13/CMP.1, 15/CMP.1, 18/CMP.1 and 19/CMP.1 shall apply mutatis mutandis, except where otherwise specified in decisions 1/CMP.8 and 2/CMP.8 and in decision 3/CMP.11.

Information on transferred or acquired units

In accordance with paragraph 10 of the annex to Decision 15/CMP.1 information on emission reduction units (ERUs), certified emission reductions (CERs), temporary certified emission reductions (tCERs), long-term certified emission reductions (lCERs), assigned amount units (AAUs) and removal units (RMUs) will be reported for the first calendar year in which these units will be transferred or acquired.

Summary of information reported in the SEF tables

The Standard Electronic Format (SEF) report for 2022 CP1 and CP2 has been submitted to the UNFCCC Secretariat electronically and the contents of the reports can also be found in Annex 8.

Discrepancies and notifications

Annex-I parties are inter alia required to submit four reports according to paragraphs 12 to 16 of the annex to decision 15/CMP.1. These reports are:

- Paragraph 12 – List of discrepancies identified by the ITL. List not included as no discrepant transactions occurred in 2022.
- Paragraph 13/14 – List of notifications from the CDM Executive Board regarding lCERs. No CDM notifications occurred in 2022.
- Paragraph 15 – List of non-replacement identified by the ITL. No non-replacements occurred in 2022.
- Paragraph 16 – List of invalid Kyoto units. No invalid units exist as of 31 December 2022.

No actions were taken or changes made to address discrepancies for the period under review.

Publicly accessible information

Information from the SEF available to the public will be included in the Danish SEF report 2022. The report will be available on the Danish Business Authority's website in addition to other public reports (pursuant to paragraphs 44 to 48 of the annex to Decision 13/CMP.l) as well as in the ETS registry:

In English: https://danishbusinessauthority.dk/public-information

In Danish:
https://erhvervsstyrelsen.dk/offentlig-information-og-persondata

Link to reports available from the ETS registry:
https://unionregistry.ec.europa.eu/euregistry/DK/public/reports/publicReports.xhtml

The reports are updated every month.

The reports include information on each account as required in paragraph 45 of the annex to Decision 13/CMP.1. Please note that publishing the contact information (paragraph 45 (d) and (e)) requires the consent of the account holder according to EU legislation. Thus, this information is not publicly available. The Danish Business Authority complies with the requirements stipulated in the European Commission's Union Registry Regulation, No. 389/2013, concerning the publication of confidential information.

Other information that is required to be publicly available can be found on the EUTL website: https://ec.europa.eu/clima/ets/

Information on article 6 projects is not available as Denmark to this date has not approved any Joint Implementation projects in Denmark.

Calculation of the commitment period reserve

The calculation of the Commitment Period Reserve (CPR) for all of the second commitment period wsa based on the assigned amount of 269,377,890 tonnes of CO_2 equivalents (UNFCCC, 2017). Subsequently, the CPR calculated as 90 % of the assigned amount is 242,440,102 tonnes CO_2 equivalent, during the commitment period and has not changed since the Report of the review of the initial report of Denmark published on 9 August 2017 (UNFCCC, 2017). The commitment period reserve has not changed since the previous submission, as 100 % times the most recent inventory times eight would amount to a higher value.

KP-LULUCF accounting

Accounting of KP-LULUCF under the second commitment period of the Kyoto Protocol began with the entering into force of the Doha-Amendment to the Kyoto Protocol. As of the preparation of the 2023 NIR, a review report has not been published after final review under the second commitment period. Table 12.1 below contains data as submitted under the Kyoto Protocol for the purposes of the Doha Amendment.

Table **Error! No text of specified style in document.**.1 Information on accounting for activities under articles 3.3 and 3.4 of the Kyoto Protocol.

Greenhouse gas source and sink activities	Base year	Net emissions/-removals									Accounting Parameters	Accounting Quantity
		2013	2014	2015	2016	2017	2018	2019	2020	Total		
	($kt\ CO_2$ equivalent)											
A. Article 3.3 activities												
A.1. Afforestation and Reforestation		-110.00	-221.21	-287.32	-278.23	-343.14	-484.76	-610.36	-274.99	-2610.01		-2610.01
A.2. Deforestation		70.23	170.68	677.88	563.31	44.74	415.57	213.89	514.67	2670.97		2670.97
B. Article 3.4 activities												
B.1. Forest Management										-21160.24		-23771.31
Net emissions/removals		-3377.03	-3863.94	-3868.09	-3018.92	-2390.93	-1707.32	-1988.59	-945.42	-21160.24		
Forest management reference level (FMRL)											409.00	
Technical corrections to FMRL											-82.62	
Forest management cap											19822.07	-19822.07
B.2. Cropland Management	5544.77	2422.07	3560.94	2450.75	2610.04	2208.34	3302.01	2994.15	2756.71	22305.01		-22053.14
B.3. Grazing Land Management	2371.07	1810.94	1953.75	1992.16	2117.88	2058.79	2186.44	2152.20	2254.65	16526.81		-2441.75

References

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http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:386:0001:0077:EN:PDF

UNFCCC, 2015: Report of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol on its eleventh session, held in Paris from 30 November to 13 December 2015. Available at:
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UNFCCC, 2017: Report on the review of the report to facilitate the calculation of the assigned amount for the second commitment period of the Kyoto Protocol of Denmark. Available at: http://unfccc.int/resource/docs/2017/irr/dnk.pdf

Annex 8 - Additional information to be considered as part of the annual inventory submission and the supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol or other useful reference information

Tables A8.1 to A8.5 below contain the information publicly available in this report.

Table A8.1 Total quantities of Kyoto Protocol units by account type at beginning of reported year.

Account type	Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Party holding accounts	269 377 890	NO	NO	NO	NO	NO
Entity holding accounts	NO	NO	NO	2 485 793	NO	NO
Retirement account	NO	NO	NO	NO	NO	NO
Previous period surplus reserve account	NO					
Article 3.3/3.4 net source cancellation accounts	NO	NO	NO	NO		
Non-compliance cancellation account	NO	NO	NO	NO		
Voluntary cancellation account	NO	NO	NO	295 556	NO	NO
Cancellation account for remaining units after carry-over	NO	NO	NO	NO	NO	NO
Article 3.1 ter and quater ambition increase cancellation account	NO					
Article 3.7 ter cancellation account	NO					
tCER cancellation account for expiry					NO	
lCER cancellation account for expiry						NO
lCER cancellation account for reversal of storage						NO
lCER cancellation account for non-submission of certification report						NO
tCER replacement account for expiry	NO	NO	NO	NO	NO	
lCER replacement account for expiry	NO	NO	NO	NO		
lCER replacement account for reversal of storage	NO	NO	NO	NO		NO
lCER replacement account for non-submission of certification report	NO	NO	NO	NO		NO
Total	269 377 890	NO	NO	2 781 349	NO	NO

Table A8.2a Annual internal transactions.

Transaction type	Additions						Subtractions					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Art6 issuance and conversion												
Party verified projects		NO					NO		NO			
Independently verified projects		NO					NO		NO			
Art3.3 and 3.4 issuance or cancellation												
3.3 Afforestation reforestation			NO				NO	NO	NO	NO		
3.3 Deforestation			NO				NO	NO	NO	NO		
3.4 Forest management			NO				NO	NO	NO	NO		
3.4 Cropland management			NO				NO	NO	NO	NO		
3.4 Grazing land management			NO				NO	NO	NO	NO		
3.4 Revegetation			NO				NO	NO	NO	NO		
3.4 Wetland drainage and rewetting			NO				NO	NO	NO	NO		
Art 12 afforestation and reforestation												
Replacement of expired tCERs							NO	NO	NO	NO	NO	
Replacement of expired lCERs							NO	NO	NO	NO		
Replacement for reversal of storage							NO	NO	NO	NO		NO
Cancellation for reversal of storage												NO
Replacement for non-submission of certification report							NO	NO	NO	NO		NO
Cancellation for non-submission of certification report												NO
Other cancelation												
Voluntary cancellation							NO	NO	NO	NO	NO	NO
Article 3.1 ter and quater ambition increase cancellation							NO					
Subtotal		NO	NO				NO	NO	NO	NO	NO	NO

Table A8.2ab Annual internal transactions.

Transaction type	Retirement					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Retirement	NO	NO	NO	NO	NO	NO
Retirement from PPSR	NO					
Total	NO	NO	NO	NO	NO	NO

Table A8.2b Annual external transactions.

	Additions						Subtractions					
Total transfers and acquisitions	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
AU	NO	NO	NO	NO	NO	NO	NO	NO	NO	900 000	NO	NO
CH	NO	NO	NO	NO	NO	NO	NO	NO	NO	1 500 000	NO	NO
Subtotal	NO	NO	NO	NO	NO	NO	NO	NO	NO	2 400 000	NO	NO

Table A8.2c Annual transactions between PPSR accounts.

	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Subtotal	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table A8.2d Share of proceeds transactions under decision 1/CMP.8, paragraph 21 - Adaptation Fund.

	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
First international transfers of AAUs	NO						NO					
Issuance of ERU from Party-verified projects		NO						NO				
Issuance of independently verified ERUs		NO						NO				

Table A8.2f Total annual transactions.

	Additions						Subtractions					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Total (Sum of sub-totals in table 2a and table 2b)	NO	NO	NO	NO	NO	NO	NO	NO	NO	2 400 000	NO	NO

Table A8.3 Expiry, cancellation and replacement.

Transaction or event type	Requirement to replace or cancel			Replacement						Cancellation					
Transaction or event type	tCERs	lCERs	CERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Temporary CERs															
Expired in retirement and replacement accounts	NO			NO	NO	NO	NO	NO							
Expired in holding accounts	NO													NO	
Long-term CERs															
Expired in retirement and replacement accounts		NO		NO	NO	NO	NO								
Expired in holding accounts		NO													NO
Subject to reversal of Storage		NO		NO	NO	NO	NO		NO						NO
Subject to non submission of certification Report		NO		NO	NO	NO	NO		NO						NO
Carbon Capture and Storage CERs															
Subject to net reversal of storage			NO							NO	NO	NO	NO		
Subject to non submission of certification report			NO							NO	NO	NO	NO		
Total	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table A8.4 Total quantities of Kyoto Protocol units by account type at end of reported year.

Account type	Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Party holding accounts	269,377,890	NO	NO	NO	NO	NO
Entity holding accounts	NO	NO	NO	85,793	NO	NO
Retirement account	NO	NO	NO	NO	NO	NO
Previous period surplus reserve account	NO					
Article 3.3/3.4 net source cancellation accounts	NO	NO	NO	NO		
Non-compliance cancellation account	NO	NO	NO	NO		
Voluntary cancellation account	NO	NO	NO	295,556	NO	NO
Cancellation account for remaining units after carry-over	NO	NO	NO	NO	NO	NO
Article 3.1 ter and quater ambition increase cancellation account	NO					
Article 3.7 ter cancellation account	NO					
tCER cancellation account for expiry					NO	
lCER cancellation account for expiry						NO
lCER cancellation account for reversal of storage						NO
lCER cancellation account for non-submission of certification report						NO
tCER replacement account for expiry	NO	NO	NO	NO	NO	
lCER replacement account for expiry	NO	NO	NO	NO		
lCER replacement account for reversal of storage	NO	NO	NO	NO		NO
lCER replacement account for non-submission of certification report	NO	NO	NO	NO		NO
Total	269,377,890	NO	NO	381,349	NO	NO

Table A8.5(a) Summary information on additions and subtractions.

	Additions						Subtractions					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Assigned amount units issued	269 377 890											
Article 3 Paragraph 7 ter cancellations							NO					
Cancellation following increase in ambition							NO					
Cancellation of remaining units after carry over							NO	NO	NO	NO	NO	NO
Non-compliance cancellation							NO	NO	NO	NO		
Carry-over		NO		NO								
Carry-over to PPSR	NO						NO					
Total	269 377 890	NO		NO			NO	NO	NO	NO	NO	NO

Table A8.5(b) Summary information on annual transactions.

	Additions						Subtractions					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Year 1 (2013)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 2 (2014)	NO	NO	NO	37 361	NO	NO	NO	NO	NO	3 142	NO	NO
Year 3 (2015)	NO	NO	NO	815 943	NO	NO	NO	NO	NO	56 320	NO	NO
Year 4 (2016)	NO	NO	NO	60 795	NO	NO	NO	NO	NO	634 856	NO	NO
Year 5 (2017)	NO	NO	NO	77 456	NO	NO	NO	NO	NO	16 155	NO	NO
Year 6 (2018)	NO	NO	NO	5 456	NO	NO	NO	NO	NO	2 559	NO	NO
Year 7 (2019)	NO	NO	NO	3 381 133	NO	NO	NO	NO	NO	1 199	NO	NO
Year 8 (2020)	NO	NO	NO	3 981 722	NO	NO	NO	NO	NO	3 575 000	NO	NO
Year 2021	NO	NO	NO	4 091 918	NO	NO	NO	NO	NO	5 676 760	NO	NO
Year 2022	NO	NO	NO	NO	NO	NO	NO	NO	NO	2 400 000	NO	NO
Year 2023	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total	NO	NO	NO	12 451 784	NO	NO	NO	NO	NO	12 365 991	NO	NO

Table A8.5(c) Summary information on annual transactions between PPSR accounts.

	Additions						Subtractions					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Year 1 (2013)	NO						NO					
Year 2 (2014)	NO						NO					
Year 3 (2015)	NO						NO					
Year 4 (2016)	NO						NO					
Year 5 (2017)	NO						NO					
Year 6 (2018)	NO						NO					
Year 7 (2019)	NO						NO					
Year 8 (2020)	NO						NO					
Year 2021	NO						NO					
Year 2022	NO						NO					
Year 2023	NO						NO					
Total	NO						NO					

Table A8.5(d) Summary information on expiry, cancellation and replacement.

	Requirement to replace or cancel			Replacement						Cancellation					
	tCERs	lCERs	CERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Year 1 (2013)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 2 (2014)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 3 (2015)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 4 (2016)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 5 (2017)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 6 (2018)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 7 (2019)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 8 (2020)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 2021	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 2022	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 2023	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table A8.5(e) Summary information on retirement.

	Retirement – Unit type					
Year	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Year 1 (2013)	NO	NO	NO	NO	NO	NO
Year 2 (2014)	NO	NO	NO	NO	NO	NO
Year 3 (2015)	NO	NO	NO	NO	NO	NO
Year 4 (2016)	NO	NO	NO	NO	NO	NO
Year 5 (2017)	NO	NO	NO	NO	NO	NO
Year 6 (2018)	NO	NO	NO	NO	NO	NO
Year 7 (2019)	NO	NO	NO	NO	NO	NO
Year 8 (2020)	NO	NO	NO	NO	NO	NO
Year 2021	NO	NO	NO	NO	NO	NO
Year 2022	NO	NO	NO	NO	NO	NO
Year 2023	NO	NO	NO	NO	NO	NO

DENMARK'S NATIONAL INVENTORY REPORT 2023

Emission Inventories 1990-2021 – Submitted under the United Nations Framework Convention on Climate Change

This report is Denmark's National Inventory Report 2023, which serves as documentation for the Danish greenhouse gas inventories submitted to the European Union and the United Nations. The report contains information on Denmark's emission inventories for all years' from 1990 to 2021 for CO_2, CH_4, N_2O, HFCs, PFCs and SF_6.

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