DENMARK'S NATIONAL INVENTORY REPORT 2014

Emission Inventories 1990-2012 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol

Scientific Report from DCE – Danish Centre for Environment and Energy No. 101 2014

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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 2014. The report contains information on Denmark's emission inventories for all years' from 1990 to 2012 for CO_2, CH_4, N_2O, HFCs, PFCs and SF_6, NO_x, CO, NMVOC, SO_2

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
HCB	Hexachlorobenzene
HFCs	Hydrofluorocarbons
IDA	Integrated Database model for Agricultural emissions
IEF	Implied Emission Factor
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
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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- The IT section at Aarhus University for supporting the emission inventory data system.

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) 2014 for submission to the United Nations Framework Convention on Climate Change and the Kyoto Protocol, due April 15, 2014. The report contains detailed information about Denmark's inventories for all years from 1990 to 2012. The structure of the report is in accordance with the UNFCCC guidelines on reporting and review. The main difference between Denmark's NIR 2014 report to the European Commission, due March 15, 2014, and this report to UNFCCC is reporting of territories. The NIR 2014 to the EU Commission was for Denmark, while this NIR 2014 to the UNFCCC is for Denmark, Greenland and the Faroe Islands. The suggested outline provided by the UNFCCC secretariat has been followed to include the necessary information under the Kyoto Protocol. The report includes detailed and complete information on the inventories for all years from year 1990 to the year 2012, in order to ensure transparency.

The annual emission inventories for the years from 1990 to 2012 are reported in the Common Reporting Format (CRF). Within this submission separate CRF's are available for Denmark (EU), Greenland, the Faroe Islands, for Denmark and Greenland (KP) as well as 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 2-9 and Chapter 11 refers to Denmark (EU) only. Specific information regarding the submission of Greenland and the Faroe Islands is included in Chapter 16 and Annex 8, respectively. Chapter 17 contains information (e.g. on trends, uncertainties and key category analysis) on the aggregated submission of Denmark and Greenland under the Kyoto Protocol.

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 the Ministry of Climate, Energy and Building, 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 and the UNFCCC (United Nations Framework Convention on Climate Change) and UNECE CLRTAP (Convention on 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. DCE is also the body designated with overall responsibility for the national inventory under the Kyoto Protocol for Greenland and Denmark. 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

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 120 years for CH_4 and N_2O, respectively. So the time perspective clearly plays a decisive role. The life 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 Second 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): 21
- Nitrous oxide (N_2O): 310

Based on weight and a 100-year period, CH_4 is thus 21 times more powerful a greenhouse gas than CO_2 and N_2O is 310 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 23 900. 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). Since no GWPs are assigned to these gases, they do not contribute to GHG emissions in CO_2 equivalents.

ES.2 Summary of national emission and removal trends

Summary ES.2-4 refers to the inventory for Denmark only. The inventories for Greenland, Denmark and Greenland and the Faroe islands are described in Chapter 16 and 17 and Annex 8, respectively.

ES.2.1 Greenhouse gas emissions inventory

The greenhouse gas emissions are estimated according to the IPCC guidelines and guidance and are aggregated into seven main sectors. According to decisions made under the UNFCCC and the Kyoto Protocol the greenhouse gas emissions are estimated according to the IPCC 1996 guidelines and the IPCC 2000 good practice guidance. The greenhouse gases include CO_2, CH_4, N_2O, HFCs, PFCs and SF_6. Figure ES.1 shows the estimated total greenhouse gas emissions in CO_2 equivalents from 1990 to 2012. The emissions are not corrected for electricity trade or temperature variations. CO_2 is the most important greenhouse gas contributing in 2012 to national total in CO_2 equivalents excluding LULUCF (Land Use and Land Use Change and Forestry) with 76.3 % followed by N_2O with 11.6 %, CH_4 10.7 % and F-gases (HFCs, PFCs and SF_6) with 1.5 %. Seen over the time series from 1990 to 2012 these percentages have been increasing for CH_4 and F-gases and decreasing for N_2O. The percentages for CO_2 show larger fluctuations during the time series. Stationary combustion plants, Transport and Agriculture represent the largest contributing categories to emissions of greenhouse gases, followed by Industrial processes, Waste, Fugitive emissions and Solvents, see Figure ES.1. The net CO_2 uptake by LULUCF in 2012 is 0.2 % of the total emission in CO_2 equivalents excl. LULUCF. The national total greenhouse gas emission in CO_2 equivalents excluding LULUCF has decreased by 24.8 % from 1990 to 2012 and 30.5 % including LULUCF. Comments to the overall trends for the individual greenhouse gases etc. seen in Figure ES.1 are given in the sections below.

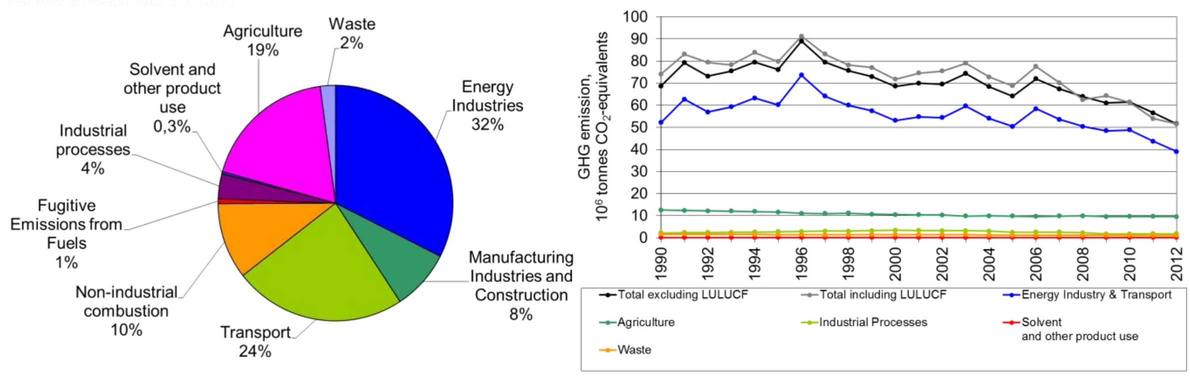


Figure ES.1 Greenhouse gas emissions in CO_2 equivalents distributed on main sectors (excl. LULUCF) for 2012 and time series for 1990 to 2012, Where data are given with or without LULUCF.

ES.2.2 KP-LULUCF activities

Net emissions from Afforestation, Reforestation and Deforestation (ARD) activities in 2012 were 148 Gg CO_2 equivalents, hereof 0.9 Gg CO_2 equivalents owe to N_2O emissions from disturbance of soils. Net removals from Forest

Matter (FM) were 4 479.6 Gg CO_2 equivalents (Table ES.1) hereof 12.1 Gg CO_2 equivalents owe to N_2O emissions from drainage of soils.

For Cropland Management (CM) the net emissions in 2012 were 2 958 Gg CO_2 equivalents compared to a net emission in 1990 of 4 845 Gg CO_2 equivalents.

For Grassland Management (GM) the net emissions in 2012 were 523 Gg CO_2 equivalents compared to a net emission in 1990 of 177 Gg CO_2 equivalents.

Table ES.1 Emissions and removals in 2012 for activities relating to Article 3.3 and Article 3.4.

	Net CO_2 emissions/ removals	CH_4	N_2O	Net CO_2 equivalent emissions/ removals
				(Gg)
A. Article 3.3 activities				107,38
A.1. Afforestation and Reforestation	76,62	NO	IE,NA,NO	76,62
A.1.1. Units of land not harvested since the beginning of the commitment period	76,62	NO	IE,NA,NO	76,62
A.1.2.Units of land harvested since the beginning of the commitment period	IE,NO	NO	IE,NO	IE,NO
A.2. Deforestation	30,50	NO	0,00	30,76
B. Article 3.4 activities				5.088,29
B.1. Forest Management	49,60	0,03	0,05	66,24
B.2. Cropland Management	4.844,66	NO	NA,NO	4.844,66
B.3. Grazing Land Management	177,39	0,00	0,00	177,39
B.4. Re-vegetation	NA	NA	NA	NA

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

ES.3.1 Greenhouse gas emissions inventory

Energy

The largest source of CO_2 emission is the energy sector, which includes the combustion of fossil fuels such as oil, coal and natural gas.

The emission of CO_2 from Energy Industries has decreased by 36.8 % from 1990 to 2012. The relatively large fluctuation in the emission is due to inter-country electricity trade. Thus, the high emissions in 1991, 1994, 1996, 2003 and 2006 reflect a large electricity export and the low emissions in 1990, 1992 and 2005, 2008, 2011 and 2012 are due to a large import of electricity. The main reason for this decrease owe to decreasing fuel consumption, mainly for coal and natural gas. This decrease is partly due to increasing import of electricity and partly to increasing production of wind power and other renewable energy sources.

The increasing emission of CH_4 during the nineties is due to the increasing use of gas engines in decentralised cogeneration plants. The CH_4 emissions from this sector have been decreasing from 2001 to 2012 due to the liberalisation of the electricity market. The CO_2 emission from the transport sector increased by 14.0 % from 1990 to 2012, mainly due to increasing road traffic.

Industrial processes

The GHG emissions from industrial processes, i.e. emissions from processes other than fuel combustion, amount in 2012 to 2.6 % of the total emission in CO_2 equivalents (excl. LULUCF). The main sources are cement production, refrigeration, foam blowing and calcination of limestone. The CO_2 emission from cement production – which is the largest source contributing in 2012 with 1.7 % of the national total – decreased by 1.3 % from 1990 to 2012. The second largest source has previously been N_2O from the production of nitric acid. However, the production of nitric acid/fertiliser ceased in 2004 and therefore the emission of N_2O also ceased.

The emission of HFCs, PFCs and SF_6 has increased by 140.7 % from 1995 until 2012, largely due to the increasing emission of HFCs. The use of HFCs, and especially HFC-134a, has increased several fold and thus HFCs have become the dominant F-gases, contributing 67 % to the F-gas total in 1995, rising to 83.9 % in 2012. HFC-134a is mainly used as a refrigerant. However, the use of HFC-134a is now stabilising. This is due to Danish legislation, which in 2007 banned new HFC-based refrigerant stationary systems. However, in contrast to this trend is the increasing use of air conditioning systems in mobile systems.

Solvent and other product use

The use of solvents in industries and households and other product use contribute 0.3 % of the total greenhouse gas emissions in CO_2 equivalents. There is a 34.6 % decrease in greenhouse gas emissions from solvent and other product use from 1990 to 2012. In 2012, N_2O comprises 11.5 % of the total CO_2 equivalent emissions for solvent and other product use.

Agriculture

The agricultural sector contributes in 2012 with 18.6 % of the total greenhouse gas emission in CO_2 equivalents (excl. LULUCF) and is the most important sector regarding the emissions of N_2O and CH_4. In 2012, the contribution of N_2O and CH_4 to the total emission of these gases was 90.5 % and 76.6 %, respectively. The N_2O emission from agriculture decreased by 34.9 % from 1990 to 2012. The main reason for the decrease is a legislative demand for an improved utilisation of nitrogen in manure. This result in less nitrogen excreted per livestock unit produced and a considerable reduction in the use of fertilisers. From 1990 to 2012, the emission of CH_4 from enteric fermentation has decreased due to decreasing numbers of cattle. However, the emission from manure management has increased due to changes in stable management systems towards an increase in slurry-based systems. Altogether, the emission of CH_4 for the agricultural sector has decreased by 0.7 % from 1990 to 2012.

Land Use and Land Use Change and Forestry (LULUCF)

The LULUCF sector alters between being a net sink and a net source of GHG. In 2012 LULUCF was a net sink with 1.6 % of the total GHG emission excluding LULUCF. In 2011 LULUCF was a net sink equivalent to 4.9 % of the total GHG emission (excluding LULUCF). The overall trend in the LULUCF sector without Forestry is a decrease of 30 % since 1990.

In 2012 Forest Land was a large sink of 4 441 CO_2 equivalents, while Cropland, Grassland, Wetlands and Settlements was net sources contributing with 2 956 Gg CO_2 equivalents, 554 Gg CO_2 equivalents, 2 Gg CO_2 equivalents and 91 Gg CO_2 equivalents, respectively.

Waste

The waste sector contributes in 2012 with 2.1 % to the national total of greenhouse gas emissions (excl. LULUCF), 15.7 % of the total CH_4 emission and 3.4 % of the total N_2O emission. The sector comprises solid waste disposal on land, wastewater handling, waste incineration without energy recovery (e.g. incineration of animal carcasses) and other waste (e.g. composting and accidental fires).

The GHG emission from the sector has decreased by 32.4 % from 1990 to 2012. This decrease is a result of (1) a decrease in the CH_4 emission from solid waste disposal sites (SWDS) by 48.9 % due to the increasing use of waste for power and heat production, and (2) a decrease in emission of N_2O from wastewater (WW) handling systems of 30.6 % due to upgrading of WW treatment plants. These decreases are counteracted by an increase in CH_4 from WW of 13.0 % due to increasing industrial load to WW systems. In 2012 the contribution of CH_4 from SWDS was 12.7 % of the total CH_4 emission. The CH_4 emission from WW amounts in 2012 to 1.3 % of the total CH_4 emissions. The emission of N_2O from WW in 2012 is 1.2 % of national total of N_2O. Since all incinerated waste is used for power and heat production, the emissions are included in the 1A CRF category.

ES.3.2 KP-LULUCF activities

In 2012 the activities under Article 3.3 was a net source of 148 Gg CO_2 equivalents and the activities under Article 3.4 was a net sink of 998 Gg CO_2 equivalents. A short overview of KP-LULUCF is given in Chapter ES.2.2 and a more detailed description is given in Chapter 11.

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

The main improvements of the inventories are:

Energy

Stationary Combustion

For stationary combustion plants, the emission estimates for the years 1990-2011 have been updated according to the latest energy statistics published by the Danish Energy Agency. The update included both end use and transformation sectors as well as a source category update. The changes in the energy statistics are largest for the years 2009, 2010 and 2011.

For CO_2 the largest recalculation is in source category Manufacturing industries and constructions. The recalculation is related to liquid fuels and is a result of correction of an error. The consumption of residual oil was underestimated in the former inventories. The CO_2 emission from liquid fuels applied in manufacturing industries and construction for 2011 is 7% higher in the 2014 reporting than in the 2013 reporting.

The CH_4 emission from residential wood combustion has been recalculated based on improved emission factors for stoves. This has caused a 16 % increase of the CH_4 emission reported for biomass fuels in residential plants for 2011.

For N_2O the largest recalculation is in source category Manufacturing industries and constructions. This recalculation is also related to the former underestimate for residual oil. The N_2O emission from liquid fuels applied in manufacturing industries and constructions for 2011 is 13 % higher in the 2014 reporting than in the 2013 reporting.

Mobile sources

The following recalculations and improvements of the emission inventories have been made since the emission reporting in 2013.

Road transport

Based on the updated version of COPERT IV launched in 2013, new vehicle sub categories have been introduced in the emission inventories for mopeds and passenger cars. For mopeds a division is now made between 2-stroke and 4-stroke engine technologies and for passenger cars small engine sizes below 0.8 l. for gasoline and below 1.4 l. for diesel have been included. Also NO_x emission factors for euro 5 diesel passenger cars have been updated in the model based on the new COPERT IV version.

Small errors in input gasoline fuel consumption for the years 2009-2011 and for input diesel fuel consumption in the years 2010-2011 have been corrected.

The percentage emission change interval and year of largest percentage differences (low %; high %, year) for the different emission components are: CO_2 (-0.5 %; -0.05 %, 2008), CH_4 (-0.2 %; 2.4 %, 2011) and N_2O (-0.4 %; 0.3 %, 2008).

Navigation
Minor changes in ferry input data has been made for the years 2008-2011 causing minor emission changes for domestic navigation. The following largest percentage differences (in brackets) for domestic navigation are noted for: CO_2 (-1.0 %), CH_4 (-0.8 %) and N_2O (-1.1 %).

Agriculture/forestry/fisheries
The number and engine size of machine pool tractors has been updated for the years 2007-2011. The number of ATV's has been changed for the years 2009-2011. Errors in the fuel consumption for fisheries in 2000, 2010 and 2011 have been corrected.

In 2000 the following percentage differences (in brackets) for agriculture/forestry/fisheries are noted for: CO_2 (9.1 %), CH_4 (3.7 %) and N_2O (11.9 %) due to fuel consumption changes in fisheries.

For other years than 2000, the following largest percentage differences (in brackets) are noted for: CO_2 (-3.7 %), CH_4 (5 %) and N_2O (-4.9 %).

Industry
The number of mini loaders has been updated for the years 2004-2011.

The following largest percentage differences (in brackets) for industrial non road machinery are noted for: CO_2 (1.0 %), CH_4 (1.6 %) and N_2O (1.6 %).

Civil aviation
An error in the CH_4 emission factor has been corrected for the years 1985-2000. The emission factors are now in line with the factors proposed by the EMEP/EEA emission inventory guidebook. The CH_4 emission percentage differences are between -31 % and -42 %.

Military
Emission factors derived from the new road transport simulations have caused some emission changes from 1985-2010.The following largest percentage differences (in brackets) for military are noted for: CO_2 (0 %), CH_4 (0.6 %) and N_2O (0.2 %).

Fugitive emissions
In the emission inventory reported in 2014 for the years 1990-2012 the following recalculations regarding fugitive emissions from fuels have been applied:

Natural gas transmission and distribution
Activity data and IEF for the time series 1990-2011 has been updated for transmission and distribution according to annual environmental reports and the latest national energy statistics, respectively. Further, the CH_4 EFs are updated for one town gas distribution company following an update of the estimated fugitive losses per distribution. The recalculation has changed the CO_2 emission by 0.01 ktonnes and CH_4 emission by (-0.09) - 0.07 ktonnes,

corresponding to < 0.003% and (-2) % - 2% of the total fugitive CO_2 and CH_4 emission.

Venting

EFs for CH_4 have been added for the years 1990-1993 for one gas storage plant. In these years the plant is treated as an area source in the national system, while it is treated separately as a point source in the following years. EFs are based on data from annual reports for 1995-1999, as no data are available for the years 1990-1994. Further, a minor error has been applied for venting in 2011, according to the annual report from one of the natural gas storage facilities. The recalculation has changed the CH_4 emission by 0.06 ktonnes, corresponding to 2% of the total fugitive CH_4 emission.

Flaring in gas storage and treatment plants

EFs for CO_2 and CH_4 have been added for the years 1990-1993 for the gas treatment plant. In these years the plant is treated as an area source in the national system, while it is treated separately as a LPS in the following years. EFs are based on data from annual reports for 1995-1999, as no data are available for the years 1990-1994. The recalculation has changed the CO_2 emission by 2.2 ktonnes and the CH_4 emission by 0.01 ktonnes, corresponding to 0.4 % and 0.4 % of the total fugitive CO_2 and CH_4 emission.

Flaring in refineries

The CO_2 EF for one refinery has been updated for the years 1994-2006 and now reflects the average EF from the first five EU-ETS reports (2007-2011). The NO_x EF for two refineries has been changed to the standard EF in the EMEP/EEA Guidebook, as references to the previously applied EFs are outdated or not existing.

The CO_2 EF for a refinery that was shut down in 1996 has been changed for the years 1990-1996 to match the existing refineries, as no better data is available. CO_2 EF for 2010-2011 has been updated and now corresponds to the EU-ETS reporting. The recalculation has changed the CO_2 emission by (-0.05) – 0.49 ktonnes and CH_4 emission by (-0.06) ktonnes, corresponding to (-0.01) – 0.1% and (-2) % of the total fugitive CO_2 and CH_4 emission.

Industrial Processes

Lime production

EU-ETS data have been implemented for one lime production plant for 2011 leading to a minor decrease in the overall emission of CO_2 emission by 5.51 ktonnes. This change in methodology will be implemented for the previous years in the next submission.

Limestone and Dolomite Use

Activity data for flue gas cleaning have been changed for three power and waste incineration plants in 2011. Consumption of $CaCO_3$ has increased with 236 tonnes and $CaCO_3$ containing residues have increased with 669 tonnes resulting in an increased CO_2 emission of 162 tonnes.

An error in transferring data from the emission database to CRF Reporter has been corrected for 1995-2011 for two individual plants.

Chemical industry

The process emission has been adjusted to reflect the total emission reported in environmental reports minus the energy related emissions reported to EU-ETS.

Consumption of Halocarbons and SF_6 – SF_6 – Other

A minor correction has been made to emission of SF_6 from double glazed windows for 2010.

Potential emissions revised for 2005-7 to reflect the fact that potential emission of SF_6 is the same as yearly consumption. Consumption of SF_6 for double glaze windows stopped in 2001.

Solvents and Other Product Use

Recalculations have been made for Other Product Use, where changes were made for the activity data of all four emission sources; candles (2009-2011), fireworks (2009-2011), tobacco (1980-1999, 2011) and charcoal used for barbeques (1980-1987, 2009-2011). These changes have caused recalculations for NMVOC, N_2O and CO_2. NMVOC emissions for the years 1980-1999 have increased between 6.0 % (1997) and 9.1 % (1982) and decreased for 2009-2011 with 2.1 % (2009) to 5.7 % (2011). CO_2 emissions have decreased for the years 2009 (13.4 %) and 2010 (6.1 %) and increased for 2011 (0.7 %), no or minor recalculations were performed for 1980-2008. N_2O emissions have increased for 1980-1999 with between 0.5 % (1999) and 2.8 % (1982) and decreased for the years 2009-2011 with between 0.3 % (2011) and 1.0 % (2009).

Agriculture

Some changes of emissions from the agricultural sector have taken place. These changes reflect decreased emissions in the years 1990-2011 up to 0.2 % compared to the total CO_2 equivalent emission from the agricultural sector. The decrease in 1990-2011 is due to a decrease in the emissions of both N_2O and CH_4.

The CH_4 emission decreases both for emission from enteric fermentation and manure management. The number of geese has been changed for all years and the number of weaners and fattening pigs has been changed for 2011, this affects both emissions from enteric fermentation and manure management. The amount of straw used for bedding for heifers has been changed for 1990-2002 and the amount of biogas treated manure in 2010 has been changed. This affects the emission of CH_4 from manure management.

For the N_2O emission a range of changes have been made, which have both increasing and decreasing effect. EF for NH_3 from synthetic fertiliser has been changed for all years and this affects the emission of N_2O. The emission of N_2O from atmospheric deposition increases due to the change for NH_3 from synthetic fertiliser while the emission of N_2O from synthetic fertiliser decreases. Change in the number of geese decrease the emission of N_2O from grazing for all years. The change of amount of biogas treated manure decreases the N_2O emission in 2010. The emission from manure, manure on soil and leaching is decreased in 2011 due to updated numbers of weaners and fattening pigs.

LULUCF

An update of the LULUCF matrix has taken place for all years. The update was necessary because there were errors in the maps received last year from the Danish Geodata Agency. The problems were especially allocated to a misclassification of recreational areas and a misclassification of parks inside some cities as being forests.

The forest area has been decreased slightly in 2011 (app. 0.3%) compared to the submission last year. This has only had a very limited effect on the total carbon stock in the Danish forest as the carbon stock is estimated in the National Forest Inventory, which is independent of the LULUCF matrix. Furthermore has some unclassified areas inside and around the cities which previous was classified as grassland now been removed to Settlement.

Cropland, grassland, wetlands and settlements

As the land use matrix is slightly changed the emissions from land use conversion for all sectors are changed slightly for the whole time series. These changes have no effect on the emissions from agricultural soils as these are based information from the EU Land Parcel Information System, i.e. the actual land use. Two minor technical errors have been found in the accounting estimate and corrected: living biomass in Settlements and the area accounted for in Cropland Management and Grazing Land Management under article 3.4. These errors have only a small impact on the inventory.

Waste

For the category 6A SWDS, an in depth disaggregation of deposited waste for the years 2010, 2011 and 2012 have been performed based on the new waste reporting system in Denmark. 18 categories have been identified of which eleven have been evaluated as inert waste. The overall results of this detailed characterisation and reallocation of the deposited waste results in a decrease in the CH4 emission in 1990 of 7.6% and an increase in the CH_4 emission in 2011 of 4.6%.

For the category 6B wastewater handling, no recalculations were made for N_2O. For the methane emissions, the methane correction factor was decreased from 1 to 0.8, which is in accordance to the IPCC guidelines 2006, and which have been further justified by plant specific data. Besides the correction of MCF, smaller corrections in plant inlet TOW data have occurred corresponding to a change below 1% throughout the time series.

There are no recalculations in the waste incineration category, however; a correction in the rounding of decimals has caused an increase of 0.07 % of the N_2O emissions from animal cremation for all years 1990-2011.

For the category waste other; changes were made in the vehicle fires and composting source categories. For vehicle fires; the time series for vehicle population has been updated along with the estimated average weights of some vehicle types, the result is a decrease of CH_4 and CO_2 emissions from 1990-2006 and an increase for 2007-2011. Emission factors have been updated for composting of sludge and organic municipal waste which have resulted in increased emissions of CH_4 and N_2O. The joint effect of these recalculations is a decrease in CH_4 emissions from 1980 (2.4 %) to 1984 (2.0 %) and an increase from 1985 (16.7 %) to 2011 (275 %), for CO_2 the emissions have decreased from 1980 (1.1 %) to 2006 (0.004 %) and increased from 2007 (0.1 %) to 2011 (0.2 %), finally the N_2O emissions have increased for all years between 1985 (1.1 %) and 2011 (238 %).

KP-LULUCF

A recalculation for KP-LULUCF has been performed for all areas as a consequence of the new land area matrix.

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 2014. Rapporten beskriver drivhusgasopgørelsen som blev fremsendt til FN's konvention om klimaændringer (UNFCCC) og Kyotoprotokollen den 15. april 2014. Rapporten indeholder detaljerede informationer om Danmarks drivhusgasudslip for alle år fra 1990 til 2012. Rapportens struktur er i overensstemmelse med UNFCCC's retningslinjer for rapportering og review. Hovedforskellen mellem Danmarks NIR 2014 som blev fremsendt til EU-Kommissionen til den 15. marts 2014, og denne rapport til UNFCCC vedrører det territorium rapporteringen omfatter. NIR 2014 til EU-Kommissionen var for Danmark, mens NIR 2014 til UNFCCC er for Danmark, Grønland og Færøerne. For at sikre at opgørelserne er sammenhængende og gennemskuelige indeholder rapporten detaljerede oplysninger om opgørelsesmetoder og baggrundsdata for alle årene fra 1990 og til 2012.

Denne emissionsopgørelse for årene 1990 til 2012, 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, for Danmark og Grønland (KP) 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 2-9 og kapitel 11 omhandler kun Danmark som omfattet af EU. Oplysninger om emissionsopgørelsen for Grønland og Færøerne er inkluderet i henholdsvis kapitel 16 og annex 8. Kapitel 17 indeholder informationer (f.eks. om udviklingen i emissioner over tid, usikkerheder og identifikation af nøglekategorier) for den samlede aflevering for Danmark og Grønland under Kyotoprotokollen.

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 Miljøministeriet samt Klima-, Energi- og Bygningsministeriet 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

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. 120 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 vedtaget at anvende GWP-værdier for en 100-årig tidshorisont, som ifølge IPCC's anden vurderingsrapport er:

- Kuldioxid, CO_2: 1
- Metan, CH_4: 21
- Lattergas, N_2O: 310

Regnet efter vægt og over en 100-årig periode er metan således ca. 21 og lattergas ca. 310 gange så effektive drivhusgasser som kuldioxid. For andre drivhusgasser der indgår i rapporteringen, de såkaldte F-gasser (HFC, PFC, SF_6) 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 23 900. I denne rapport anvendes de GWP-værdier, som UNFCCC har vedtaget.

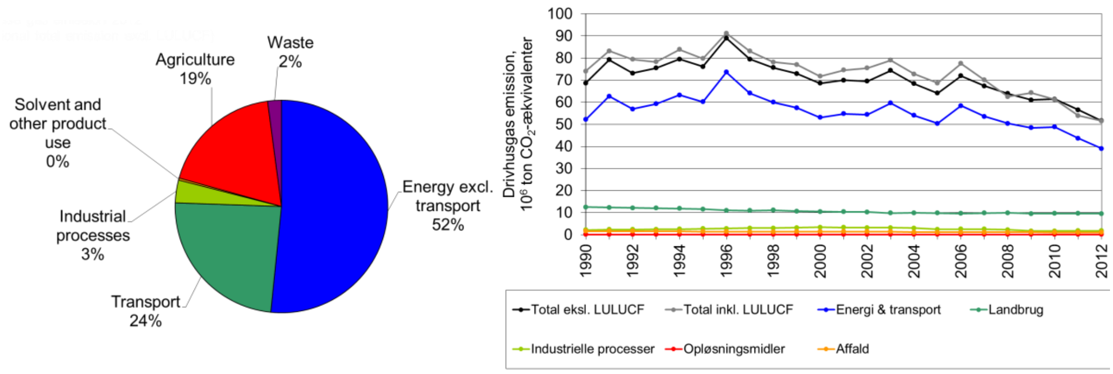
Endvidere rapporteres de indirekte drivhusgasser Kvælstofilte (NO_x), Kulilte (CO), Ikke-metan flygtige organiske forbindelser (NMVOC) og Svovldioxid (SO_2). Da der ikke tilskrives disse gasser GWP-værdier, medregnes disse ikke i drivhusgasemissioner i CO_2-ækvivalenter.

S.2 Udviklingen i drivhusgasemissioner og optag

Sammenfatning S.2.-4. omhandler alene opgørelsen for Danmark. Opgørelsen for Grønland, Danmark og Grønland samt for Færøerne beskrives i kapitel 16 og 17 samt i Annex 8.

S.2.1 Drivhusgasemissionsopgørelse

De danske opgørelser af drivhusgasemissioner følger metoderne som beskrevet i IPCC's retningslinjer. I den forbindelse skal nævnes at det under Klimakonventionen og Kyotoprotokollen er vedtaget at IPCC's 1996 retningslinjer og IPCC's 2000 anvisninger skal anvendes. Opgørelserne er opdelt i seks overordnede sektorer, 1. energi, 2. industrielle processer, 3. opløsningsmidler, 4. landbrug, 5. arealanvendelse for skove og jorder (Land Use Land Use Change and Forestry: LULUCF) og 6. affald. Drivhusgasserne omfatter CO_2, CH_4, N_2O og F-gasserne: HFC'er, PFC'er og SF_6. I Figur S.1 ses de estimerede drivhusgasemissioner for Danmark i CO_2-ækvivalenter for perioden 1990 til 2012. 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 (uden LULUCF) i 2011 for sektorerne 1. – 4. og 6. For sektor 1. energi er vejtrafik vist særskilt. Sektor 5. LULUCF indgår ikke i denne figur da sektoren omfatter kilder der bidrager med både optag og udledninger.



Figur S.1 Danske drivhusgasemissioner. Bidrag til total emission fra hovedsektorer for 2012 og tidsserier i CO_2-ækvivalenter for 1990-2012, hvor data er angivet med og uden LULUCF.

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 2012 med 76,3 % af den nationale totale udledning uden LULUCF-sektoren, efterfulgt af N_2O med 11,6 % og CH_4 med 10,7 %, mens HFC'er, PFC'er og SF_6 kun udgør 1,5 % af de totale emissioner uden LULUCF-sektoren. Set over perioden 1990-2012 så har disse procenter været stigende for CH_4 og F-gasser og faldende for N_2O. For CO_2 har procenterne fluktueret mere gennem perioden. Netto CO_2-optaget fra LULUCF er i 2012 0,2 % af den nationale totale emission eksklusiv LULUCF. Med hensyn til sektorerne (figur S.1) så bidrager energi ekskl. vejtransport (hovedsageligt stationære forbrændingsanlæg), transport og landbrug mest i 2012, efterfulgt af industrielle processer, affald, flygtige emissioner, og opløsningsmidler (Figur S.1). De nationale totale drivhusgasemissioner i CO_2-ækvivalenter er faldet med 24,8 % fra 1990 til 2012, hvis nettobidraget fra skovenes og jordernes udledninger og optag af CO_2 (LULUCF) ikke indregnes, og faldet med 30,5 % hvis LULUCF indregnes.

S.2.2 KP-LULUCF-aktiviteter

Den samlede udledning af drivhusgasser i skov omfattet af Kyotoprotokollens artikel 3.3 udgør 148 Gg CO_2-ækvivalenter i 2012, heraf stammer 0,9 Gg CO_2-ækvivalenter fra N_2O-udledning i forbindelse med skovrydning. Nettooptaget fra skov plantet før 1990 under Kyotoprotokollens artikel 3.4 udgør 4 479 Gg CO_2-ækvivalenter i 2012, heraf 12,1 Gg CO_2-ækvivalenter i form af N_2O fra dræning af jorde (tabel S.1).

Nettoemissionen fra landbrugsarealer under artikel 3.4 udgør 2 958 Gg CO_2-ækvivalenter i 2012. Til sammenligning var nettoemissionen fra samme kilde 4 845 Gg CO_2-æqvivalenter i 1990.

Det samlede emission fra permanente græsarealer under artikel 3.4 udgør 523 Gg CO_2-ækvivalenter i 2012. I 1990 var den tilsvarende emission på 177 Gg CO_2-ækvivalenter.

Tabel S.1 Emissioner og optag i 2012 for aktiviteter under Kyotoprotokollens artikel 3.3 og 3.4.

	Netto CO_2 emission/ optag (Gg)	CH_4	N_2O	Netto CO_2-ækvivalent emission/ optag
A. Aktiviteter under artikel 3.3				107,38
A.1. Skovrejsning	76,62	NO	IE,NA,NO	76,62
A.1.1. Arealer der ikke er afskovet siden starten af 2008	76,62	NO	IE,NA,NO	76,62
A.1.2. Arealer der er afskovet siden starten af 2008	IE,NO	NO	IE,NO	IE,NO
A.2. Skovrydning	30,50	NO	0,00	30,76
B. Aktiviteter under artikel 3.4				5.088,29
B.1. Forvaltning af skov plantet før 1990	49,60	0,03	0,05	66,24
B.2. Forvaltning af landbrugsarealer	4.844,66	NO	NA,NO	4.844,66
B.3. Forvaltning af permanente græsarealer	177,39	0,00	0,00	177,39
B.4. Gentilplantning	NA	NA	NA	NA

S.3 Oversigt over drivhusgasemissioner og optag fra sektorer

S.3.1 Drivhusgasemissionsopgørelse

Energi

Udledningen af CO_2 stammer altovervejende fra forbrænding af kul, olie, benzin og naturgas på kraftværker, i beboelsesejendomme, industri og vejtransport. CO_2-emissionen fra energisektorerne faldt med omkring 36,8 % fra 1990 til 2012. De relative store udsving i emissionerne fra år til år skyldes handel med elektricitet med andre lande, herunder særligt de nordiske. De høje emissioner i 1991, 1994, 1996, 2003 og 2006 er et resultat af stor eksport af elektricitet, mens de lave emissioner i 1990, 1992, 2005, 2008, 2011 og 2012 skyldes import af elektricitet. Den væsentligste årsag til dette fald skyldes faldende brændselsforbrug, hovedsageligt for kul og naturgas. Faldet skyldes delvist stigende import af elektricitet og stigende produktion af vindkraft.

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. Transportsektorens CO_2-emissioner er steget med 14,0 % siden 1990 hovedsagelig på grund af voksende vejtrafik.

Industrielle processer

Emissionen fra industrielle processer – hvilket vil sige andre processer end forbrændingsprocesser – udgør i 2012 2,6 % af de totale danske drivhusgas-emissioner. De vigtigste kilder er cementproduktion, kølesystemer, op-skumning af plast og kalcinering af kalksten. CO_2-emissionen fra cement-produktion - som er den største kilde - bidrager med 1,7 % af den totale emission i 2012. Emissionen fra cementproduktion er dog faldet med 1,3 % fra 1990 til 2012. Den anden største kilde har tidligere været N_2O fra produktion af salpetersyre. Produktionen af salpetersyre stoppede i midten af 2004, hvilket betyder, at N_2O-emissionen er nul for denne kilde fra 2005.

Emissionen af HFC'er, PFC'er og SF_6 er i perioden fra 1995 og til 2012 steget med 140,7 %, hovedsageligt på grund af stigende emissioner af HFC'er. Anvendelsen af HFC'er, og specielt HFC-134a, er steget kraftigt, hvilket har betydet, at andelen af HFC'er af den samlede F-gas-emission steg fra 67 % i 1995 og til 84 % i 2012. HFC'er anvendes primært inden for køleindustrien. Anvendelsen er dog nu stagnerende, som et resultat af dansk lovgivning, der forbyder anvendelsen af nye HFC-baserede stationære kølesystemer fra 2007. I modsætning til denne udvikling ses et stigende brug af aircondition-systemer i køretøjer. Den samlede effekt er, at emissionen forventes at falde fremover.

Opløsningsmidler og relaterede produkter

Forbrug af opløsningsmidler i industrier og husholdninger bidrager i 2012 med 0,3 % af totalmængden af emitterede drivhusgasser i CO_2-ækvivalenter. Der er en reduktion på 34,6 % i drivhusgasemissionen i perioden 1990 til 2012. Bidraget fra N_2O til den totale emission i CO_2-ækvivalenter for solventer og anden produktanvendelse er 11,5 %.

Landbrug

Landbrugssektoren bidrager i 2012 med 18,6 % til den totale drivhusgas-emission i CO_2-ækvivalenter og er den vigtigste sektor hvad angår emissioner af N_2O og CH_4. I 2012 var landbrugets bidrag til de totale emissioner af N_2O og CH_4 henholdsvis 90,5 % og 76,6 %. Fra 1990 til 2012 ses et fald på 34,9 % i N_2O-emissionen fra landbrug. Dette skyldes mindre brug af kvælstofhandelsgødning og bedre udnyttelse af kvælstof i husdyrgødningen, hvilket resulterer i mindre emissioner pr. produceret dyreenhed. Emissioner af CH_4 fra husdyrenes fordøjelsessystem er faldet fra 1990 til 2012 grundet et faldende antal kvæg. På den anden side har en stigende andel af gyllebaserede staldsystemer bevirket at emissionerne fra husdyrgødning er steget. I alt er CH_4-emissionerne fra landbrugssektoren faldet med 0,7 % fra 1990 til 2012.

Arealanvendelse - skove og jorder (LULUCF)

LULUCF-sektoren skifter mellem at udgøre et nettooptag og en nettoudledning. I 2012 udgør LULUCF et nettooptag svarende til 1,6 % af den samlede drivhusgasudledning, eksklusiv LULUCF. I 2011 udgjorde LULUCF et nettooptag svarende til 4,9 % af den samlede drivhusgasudledning eksklusiv LULUCF. Siden 1990 er LULUCF sektoren eksklusiv skov faldet med 30 %.

I 2012 bidrager arealer med skov med et optag på 4 441 Gg CO_2-ækvivalenter, mens dyrkede jorder, græsning, vådområder og bebyggelse bidrager med emissioner på henholdsvis 2 956 Gg CO_2-ækvivalenter, 554 Gg CO_2- ækvivalenter, 2 Gg CO_2- ækvivalenter og 91 Gg CO_2- ækvivalenter.

Affald

Affaldssektoren udgør i 2012 2,1 % af den danske totalemission, 15,7 % af den totale CH_4-emission og 3,4 % af den totale N_2O-emission. Sektoren omfatter lossepladser, spildevandshåndtering, affaldsforbrænding uden energiudnyttelse (f.eks. kremeringer af dyr), og andet affald (f.eks. kompostering og ildebrande). Da al traditionel affaldsforbrænding bruges til produktion af elektricitet og varme, er emissionerne herfra inkluderet i CRF-kategorien 1A.

Drivhusgasemissionen fra sektoren er faldet med 32,4 % fra 1990 til 2012. Reduktionen skyldes især (1) et fald i CH_4-emissionen fra lossepladser på 48,9 % pga. reducerede mængder affald, der går til deponi, og (2) et fald i N_2O-emissionen fra spildevandshåndtering på 30,6 % pga. fornyelse af spildvandsanlæggene. Disse fald er delvist modvirket af en stigning i CH_4-emissionen fra spildevandshåndtering på 13,0 % pga. en stigning i det industrielle spildevand. I 2012 bidrog lossepladser med 12,7 % af den totale nationale CH_4-emission. CH_4-emissionen fra spildevandshåndtering udgør i 2012 1,3 % af den totale nationale CH_4-emission. Emissionen af N_2O fra spildevandshåndtering udgør i 2012 1,2 % af den totale nationale N_2O-emission. Da al affaldsforbrænding udnyttes til el- og varmeproduktion, indgår emissionerne i CRF kategorien 1A.

S.3.2 KP-LULUCF-aktiviteter

I 2012 udgjorde aktiviteterne under Kyotoprotokollens artikel 3.3 en nettoudledning på 148 Gg CO_2- ækvivalenter mens aktiviteterne under artikel 3.4 udgjorde et nettooptag på 998 Gg CO_2- ækvivalenter. En kort oversigt over KP-LULUCF findes i kapitel S.2.2 mens en mere detaljeret redegørelse findes i kapitel 11.

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 indenfor 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 retningsliner.

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

S. 4.3 Rekalkulationer og forbedringer

De vigtigste forbedringer af opgørelserne er:

Energi

Stationær forbrænding

Den seneste officielle energistatistik er implementeret i opgørelsen for årene 1990-2011. Opdateringen omfatter både slutforbrug og konverteringssektoren samt opdatering af kilde kategorier. Ændringerne i energistatistikken er størst for årene 2009-2011.

For CO_2 er den største genberegning lavet i kategorien fremstillingsvirksomhed. Genberegningen er relateret til flydende brændsler og er resultatet af en fejlretning. Mængden af fuel olie har været underestimeret i de tidligere opgørelser. CO_2 emissionen fra fuel olie anvendt i fremstillingsvirksomhed er 7 % højere i denne rapportering sammenlignet med 2013 rapporteringen.

For CH_4 er emissionen fra træfyring i husholdninger blevet opdateret pga. opdaterede emissionsfaktorer for brændeovne. De opdaterede emissionsfaktorer har medført en stigning på 16 % i CH_4 emissionen fra forbrænding af biomasse i husholdninger.

For N_2O er den største genberegning lavet i kategorien fremstillingsvirksomhed og skyldes den samme fejlretning som beskrevet for CO_2. Konsekvensen er en stigning på 13 % for N_2O fra flydende brændsler i denne rapportering sammenlignet med 2013 rapporteringen.

Mobile kilder

Vejtransport

Baseret på den opdaterede version af COPERT IV, der blev lanceret i 2013, nye køretøjsunderkategorier er blevet introduceret i emissionsopgørelsen for passagerbiler og knallerter. For knallerter skelnes der nu mellem 2-taks og 4-taks motorer, mens der for passagerbiler er oprettet nye kategorier for benzinbiler med motorer < 0,8 l og dieselbiler med motorer < 1,4 l. NO_x emissionsfaktorerne for euro 5 passagerbiler er blevet opdateret i modellen baseret på værdierne i den nye COPERT IV version.

Små fejl i data for benzinforbruget for årene 2009-2011 og for dieselforbruget for årene 2010-2011 er blevet rettet.

Minimum og maksimum procentvis difference og år for numerisk maksimum difference (min. %, maks. %, år med maks. %) for emissionskomponenterne er: CO_2 (-0,5 %, -0,05 %, 2008), CH_4 (-0,2 %, 2,4 %, 2011) og N_2O (-0,4 %, 0,3 %, 2008).

Søfart

Ændrede forudsætninger for færgeoverfart for årene 2008-2011 har medført mindre ændringer af emissionerne for national søfart. De følgende maksimale procentvise ændringer for national søfart (i parenteser) som følge af genberegningen er: CO_2 (-1,0 %), CH_4 (-0,8 %) og N_2O (-1,1 %).

Landbrug/skovbrug/fiskeri

Antallet og motorstørrelsen af traktorer på maskinstationer er opdateret for årene 2007-2011. Antallet at terrængående maskiner (ATV'er) er blevet opdateret for årene 2009-2011.

Der er rettet fejl angående brændselsforbruget for fiskeri for årene 2000, 2010 og 2011.

For 2000 er der følgende ændringer for landbrug/skovbrug/fiskeri: CO_2 (9,1 %), CH_4 (3,7 %) og N_2O (11,9 %), pga. ændringer i brændselsforbruget for fiskeri.

For de øvrige år er der følgende ændringer for landbrug/skovbrug/fiskeri, udtrykt ved maksimum procentvis difference for emissionskomponenterne er: CO_2 (-3,7 %), CH_4 (5 %) og N_2O (-4,9 %).

Industri

Antallet af minilæssere er opdateret for årene 2004-2011.

De følgende maksimale procentvise ændringer for national søfart (i parenteser) som følge af genberegningen er: CO_2 (1,0 %), CH_4 (1,6 %) og N_2O (1,6 %).

Luftfart

En mindre fejl i CH_4 emissionsfaktoren er blevet rettet for årene 1990-2000. Emissionsfaktorerne er nu i overensstemmelse med emissionsfaktorerne i EMEP/EEA Guidebook. De procentvise ændringer i CH_4 emissionen er mellem -31 % og -42 %.

Militær

Emissionsfaktorer afledt fra de nye modelsimulationer for vejtransport har medført små ændringer i emissionerne i perioden 1990-2011. Maksimum emissionsdifference er: CO_2 (0 %), CH_4 (0,6 %) og N_2O (0,2 %).

Flygtige emissioner

I forbindelse med rapporteringen i 2014 er der foretaget en række genberegninger som specificeret nedenfor.

Transmission og distribution af naturgas

Aktivitetsdata og afledte emissionsfaktorer for tidsserien 1990-2011 er blevet opdateret for transmission og distribution af naturgas baseret på oplysninger i grønne regnskaber og den seneste energistatistik. Derudover er CH_4 emissionsfaktorerne opdateret for et bygasselskab. Genberegningen har ændret CO_2 emissionen med 0,01 kton og CH_4 emissionen med (-0,09)-0,07 kton svarende til <0,003 % og (-2) % - 2 % af henholdsvis den totale CO_2 og CH_4 emission fra flygtige kilder.

Venting

Emissionsfaktorer for CH_4 er blevet tilføjet emissionsdatabasen for årene 1990-1993 for et gaslager. I disse år er anlægget inkluderet som en arealkilde i den nationale emissionsdatabase, mens det er behandlet som en punktkilde i de følgende år. Emissionsfaktorerne er baseret på data fra grønne regnskaber for 1995-1999, da der ikke er tilgængelige data for årene 1990-1994. Derudover er en mindre fejl blevet rettet i 2011 baseret på opdaterede oplysninger i det grønne regnskab fra et af de danske naturgaslagre.

Genberegningen har betydet en stigning i CH_4 emissionen på 0,06 kton svarende til 2 % af den totale CH_4 emission fra flygtige kilder.

Flaring i forbindelse med gaslagre og naturgasbehandlingsanlæg

Emissionsfaktorer for CO_2 og CH_4 er blevet tilføjet for årene 1990-1993 for gasbehandlingsanlægget. I disse år er anlægget inkluderet som en arealkilde i den nationale emissionsdatabase, mens det er behandlet som en punktkilde i de følgende år. Emissionsfaktorerne er baseret på data fra grønne regnskaber for 1995-1999, da der ikke er tilgængelige data for årene 1990-1994.

Genberegningen har betydet en stigning i CO_2 emissionen på 2,2 kton og en stigning i CH_4 emissionen på 0,01 kton svarende til 0,4 % af både den totale CO_2 og CH_4 emission fra flygtige kilder.

Flaring i forbindelse med raffinaderier

CO_2 emissionsfaktoren for et raffinaderi er opdateret for årene 1994-2006 og afspejler nu gennemsnittet af de første 5 års rapportering (2007-2011) under EU ETS. NO_x emissionsfaktorerne for de to raffinaderier er blevet opdateret til default emissionsfaktoren i EMEP/EEA Guidebook, da referencerne til de hidtidigt anvendte emissionsfaktorer er forældede eller ikke-eksisterende.

CO_2 emissionsfaktoren for et raffinaderi der blev lukket i 1996 er blevet ændret for årene 1990-1996, så den svarer til de øvrige to raffinaderier, da der ikke er bedre data tilgængelige.

CO_2 emissionsfaktorerne for 2010 og 2011 er opdateret i henhold til EU ETS indberetningerne.

Genberegningerne har medført ændringer i CO_2 emissionen på (-0,05) – 0,49 kton og i CH_4 emissionen på (-0,06) kton svarende til (-0,01) – 0,1 % og (-2) % af henholdsvis den samlede CO_2 og CH_4 emission fra flygtige kilder.

Industrielle processer

Produktion af brændt kalk

EU ETS data er blevet indarbejdet for en producent af brændt kalk for 2011, hvilket har medført et lille fald i den samlede CO_2 emission på 5,51 kton. Ændringen vil blive tilbageført for resten af tidsserien i 2015 afleveringen.

Anvendelse af kalksten og dolomit

Aktivitetsdata for anvendelse af kalksten til røggasrensning på tre kraftværker og affaldsforbrændingsanlæg er opdateret for 2011. Den anvendte kalkmængde er steget med 236 ton og mængden af $CaCO_3$ holdige restprodukter er steget med 669 ton resulterende i en stigning i CO_2 emissionen på 162 ton.

Kemisk industri

Procesemissionen er blevet korrigeret, spå den afspejler den totale CO_2 emission rapporteret i det grønne regnskab fratrukket de energirelaterede emissioner rapporteret under EU ETS.

Anvendelse af HFC'er, PFC'er og SF_6

En mindre rettelse er foretaget for emissionen af SF_6 fra termoruder for 2010. Potentielle emissioner for 2005-2007 er ændret til at reflektere at den potentielle emission er identisk med den anvendte årlige mængde. Anvendelse af SF_6 i termoruder stoppede i 2001.

Opløsningsmidler og anden produktanvendelse

Der er foretaget genberegninger for øvrig produktanvendelse på baggrund af ændrede aktivitetsdata for alle fire produktanvendelser; lys (2009-2011), fyrværkeri (2009-2011), tobak (1980-1999, 2011) og trækul anvendt til grilning (1980-1987, 2009-2011). Disse ændringer har medført ændringer for NMVOC, N_2O og CO_2. NMVOC emissionen er steget for årene 1980-1999 med mellem 6 % (1997) og 9,1 % (1982) og faldet for årene 2009-2011 med mellem 2,1 % (2009) og 5,7 % (2011). CO_2 emissionen er faldet for 2009 (13,4 %) og 2010 (6,1 %) og steget for 2011 (0,7 %). N_2O emissionen er steget for årene 1980-1999 med mellem 0,5 % (1999) og 2,8 % (1982) og faldet for årene 2009-2011 med mellem 0,3 % (2011) og 1,0 % (2009).

Landbrug

Genberegninger for landbrugssektoren har medført et fald i emissionen for årene 1990-2011 på op til 0,2 % sammenlignet med den totale emission i CO_2-ækvivalenter fra landbrugssektoren.

CH_4 emissionen falder både for fordøjelse og gødningshåndtering. Antallet af gæs er opdateret for alle år og antallet af smågrise og slagtesvin er opdateret for 2011. Disse ændringer påvirker både emissionerne fra fordøjelsen og fra gødningshåndtering. Mængden af halm anvendt som strøelse for kvier er opdateret for årene 1990-2002 og mængden af biogas behandlet gylle i 2010 er opdateret. Disse ændringer påvirker emissionen fra gødningshåndtering.

For N_2O emissionen er der foretaget en række genberegninger, som påvirker emissionen i begge retninger. Emissionsfaktorerne for NH_3 fra handelsgødning er opdateret for alle år, og dette påvirker N_2O emissionen. Den stigende NH_3 emission fra handelsgødning medfører et fald i N_2O emissionen, men til gengæld en stigning i N_2O emissionen fra atmosfærisk deposition. Ændringen i antallet af gæs for alle år har medført et fald i N_2O emissionen fra græsning. Ændringen i mængden af biogas behandlet gylle i 2010 reducerer N_2O emissionen. Emissionerne fra gødningshåndtering, udbringning og udvaskning falder i 2011 på grund af opdaterede data for antallet af smågrise og slagtesvin.

Arealanvendelse (LULUCF)

Der er foretaget en opdatering af arealmatricen for alle år. Opdateringen var nødvendig, da der var fejl i det kortmateriale, der var leveret af Geodatastyrelsen. Fejlene var især angående klassificering af rekreative områder og fejlagtige klassificeringer af parker som skov.

Landbrugsarealer, græsningsarealer, vådområder og bebyggelse

Udover effekterne af den opdaterede arealmatrice, er der rettet to mindre fejl i forbindelse med levende biomasse i bebyggede områder samt arealerne indenfor Cropland Management og Grazing Land Management under Kyoto-protokollens artikel 3.4.

Affald

Deponier

Baseret på det nye affaldsrapporteringssystem er der foretaget en opdateret disaggregering af affaldskategorierne. Der opereres nu med 18 affaldskategorier, hvoraf 11 er inerte. Resultatet af den ændrede karakterisering og reallokering af affald er et fald i CH_4 emissionen i 1990 på 7,6 % og en stigning i CH_4 emissionen i 2011 på 4,6 %.

Spildevandshåndtering

For spildevandshåndtering er der ikke foretaget en genberegning af N_2O-emissionen. For CH_4 er MCF (Methane correction factor) værdien reduceret fra 1 til 0,8 i overensstemmelse med IPCC 2006 Guidelines og som er bekræftet af anlægsspecifikke data. Udover ændringer i MCF værdi, så er der foretaget mindre ændringer i TOW (Total organic waste) data svarende til en ændring under 1 % gennem tidsserien.

Affaldsforbrænding

Antallet af betydende cifre er blevet rettet for kremering af dyr. Genberegningen har resulteret i en stigning i N_2O emissionen for perioden 1990-2011 på 0,07 %.

Anden affaldsbehandling

For bilbrande er der foretaget en opdatering i bestandsdata, som har medført et lille fald in aktivitetsdata for brande i traktorer og mejetærskere. Derudover er gennemsnitsvægtene, der er antaget for campingvogne, campere, mejetærskere, motorcykler og knallerter blevet opdateret på baggrund af mere velfunderede ekspertvurderinger. Resultatet er et fald i emissionen af CH_4 og CO_2 fra 1990-2006 og en stigning for 2007-2011. Emissionsfaktorerne for kompostering af slam og organisk affald er opdateret, hvilket har medført stigende emissioner af CH_4 og N_2O. Den samlede effekt af genberegningerne er et fald i CH_4 emissionen fra 1980 (2,4 %) til 1984 (2,0 %) og en stigning fra 1985 (16,7 %) til 2011 (275 %). For CO_2 er emissionerne faldet mellem 1980 (1,1 %) og 2006 (0,004 %) og steget fra 2007 (0,1 %) til 2011 (0,2 %). For N_2O er emissionen steget for alle år mellem 1985 (1,1 %) og 2011 (238 %).

KP-LULUCF

Der er genberegnet for alle år som følge af den opdaterede arealmatrice.

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) 2014 for submission to the United Nations Framework Convention on Climate change and the Kyoto Protocol, due April 15, 2014. The report contains detailed information about Denmark's inventories for all years from 1990 to 2012. The structure of the report is in accordance with the UNFCCC guidelines on reporting and review. The main difference between Denmark's NIR 2014 report to the European Commission, due March 15, 2014, and this report to UNFCCC is reporting of territories. The NIR 2014 to the EU Commission was for Denmark, while this NIR 2014 to the UNFCCC is for Denmark, Greenland and the Faroe Islands. The suggested outline provided by the UNFCCC secretariat has been followed to include the necessary information under the Kyoto Protocol. The report includes detailed and complete information on the inventories for all years from year 1990 to the year 2012, in order to ensure transparency.

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 2012 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. The Danish government has ratified the Kyoto Protocol on behalf of Denmark and Greenland. The information in the sectoral chapters in this report relates to Denmark only, while information for Greenland is included in Chapter 16 and for the Faroe Islands in Annex 8. Chapter 17 contains information (e.g. on trends, uncertainties and key category analysis) on the aggregated submission of Denmark and Greenland under the Kyoto Protocol.

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 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

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 280 ppm to 379 ppm in 2005 (an increase of about 35 %), and exceeds now the natural range of 180-300 ppm over the last 650 000 years as determined by ice cores (IPCC, Fourth Assessment Report, 2007). 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 715 ppb to 1774 ppb in 2005 (an increase of about 140 %) and N_2O has increased from a pre-industrial atmospheric concentration of about 270 ppb to 319 ppb in 2005 (an increase of about 18 %) (IPCC, Fourth Assessment Report, 2007). 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 120 years approximately for CH_4 and N_2O, respectively. So 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 Second Assessment Report, which UNFCCC has decided to use as reference for reporting for inventory years throughout the commitment period 2008-2012, the global warming potentials for a 100-year time horizon are:

- Carbon dioxide (CO_2): 1
- Methane (CH_4): 21
- Nitrous oxide (N_2O): 310

Based on weight and a 100-year period, methane is thus 21 times more powerful a greenhouse gas than CO_2, and N_2O is 310 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 23 900.

The indirect greenhouse gases reported are nitrogen oxides (NO_x), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and sulphur dioxide (SO_2). Since no GWP is assigned these gases they do not contribute to GHG emissions in CO_2 equivalents.

1.1.3 The Climate Convention and the Kyoto Protocol

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) is committed to reduce greenhouse gases with 8 %. The European Union is under the KP 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) must reduce emissions by an average of 21 % in the period 2008-2012 compared with the base year emission level.

In accordance with the Kyoto Protocol, Denmark's base year emissions include the emissions of CO_2, CH_4 and N_2O in 1990 in CO_2 equivalents and Denmark has chosen 1995 as the base year for the emissions of HFCs, PFCs and SF_6.

1.1.4 The role of the European Union

The European Union (EU) is a party to the UNFCCC and the Kyoto Protocol. Therefore, the EU has to submit similar datasets and reports for the collective 15 EU Member States under the burden sharing. The EU imposes some additional guidelines and obligations to these EU Member States through Decision No. 280/2004/EC concerning a mechanism for monitoring community greenhouse gas emissions and for implementing the Kyoto Protocol (EU monitoring mechanism). In 2013 a new regulation was agreed regarding the reporting of information related to greenhouse gases in the EU, the regulation is Regulation (EU) No 525/2013.

1.1.5 Background information on supplementary information required under KP article 7.1

For the LULUCF activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol Denmark has chosen annual accounting. Article 3.3 covers direct, human induced afforestation (A), reforestation (R) and deforestation (D) activities, and accounting of these activities is mandatory. Under Article 3.4 Denmark has elected the activities Forest Management (FM), Cropland Management (CM) and Grazing Land Management (GM) for accounting in the first Commitment Period (CP). Net removals from FM can be used to compensate net emissions from activities under Article 3.3 (Article 3.3 offset), and through the issuance of removal units (RMUs) up to a cap value. Denmark's cap value for the CP is 916 667 tonnes CO_2 equivalents.

1.2 A description of the institutional arrangement for inventory preparation

On behalf of the Ministry of the Environment and the Ministry of Climate, Energy and Building 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. DCE is also the body designated with overall responsibility for the national inventory under the Kyoto Protocol for Greenland and Denmark.

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.

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 work in connection with meetings of the Conference of the Parties (COP) to the UNFCCC and the Conference of the Parties serving as the Meeting of the Parties (COP/MOP) to the Kyoto protocol and its subsidiary bodies, where the reporting rules are negotiated and settled. Furthermore, DCE participates in the EU Monitoring Mechanism, Working Group 1 (WG1), 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@dmu.dk)
Sector	Sub-sector	Expert name
Energy	Stationary combustion:	Malene Nielsen
	Transport and other mobile sources	Morten Winther
	Fugitive emissions:	Marlene Plejdrup
Industrial processes		Leif Hoffmann
Solvent and other product use		Patrik Fauser, Katja Hjelgaard
Agriculture		Mette Hjorth Mikkelsen, Rikke Albrektsen & Steen Gyldenkærne
LULUCF	Forestry	Vivian Kvist Johannsen, Thomas Nord-Larsen, Inge Stupak Møller & Lars Vesterdal
LULUCF	Cropland, grassland, wetlands, settlements	Steen Gyldenkærne
Waste	Solid waste disposal on land	Marianne Thomsen, Katja Hjelgaard
	Wastewater handling	Marianne Thomsen
	Waste incineration & Other 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, the Ministry of Climate, Energy and Building: 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, the Ministry of the Environment: Database on waste and emissions of F-gases.

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

Statistics Denmark, the Ministry of Economic Affairs and the Interior: 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).

Danish Centre for Forest, Landscape and Planning, University of Copenhagen: Background data for Forestry and CO_2 uptake by forest. Responsible for preparing estimates of emissions/removals for reporting under KP article 3.3 and for reporting FM under article 3.4.

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

Danish Railways, the 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 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.

Additionally DCE receives data from Greenland and the Faroe Islands in order to report for the Kingdom of Denmark:

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

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

The complete emission inventories for the three different submissions (EU, Kyoto Protocol and UNFCCC) by Denmark are compiled by DCE and along with the documentation report (NIR) sent for official approval. In recent years the responsibility for official approval has changed. Previously it was the Danish Environmental Protection Agency (Ministry of the Environment) now it is the Danish Energy Agency (Ministry of Climate, Energy and Building). 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 9. 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 submodels 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 journal for DCE. In this journal system, correspondence, both in-going and out-going, 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 Compliler 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, CollectEr2CRF, 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

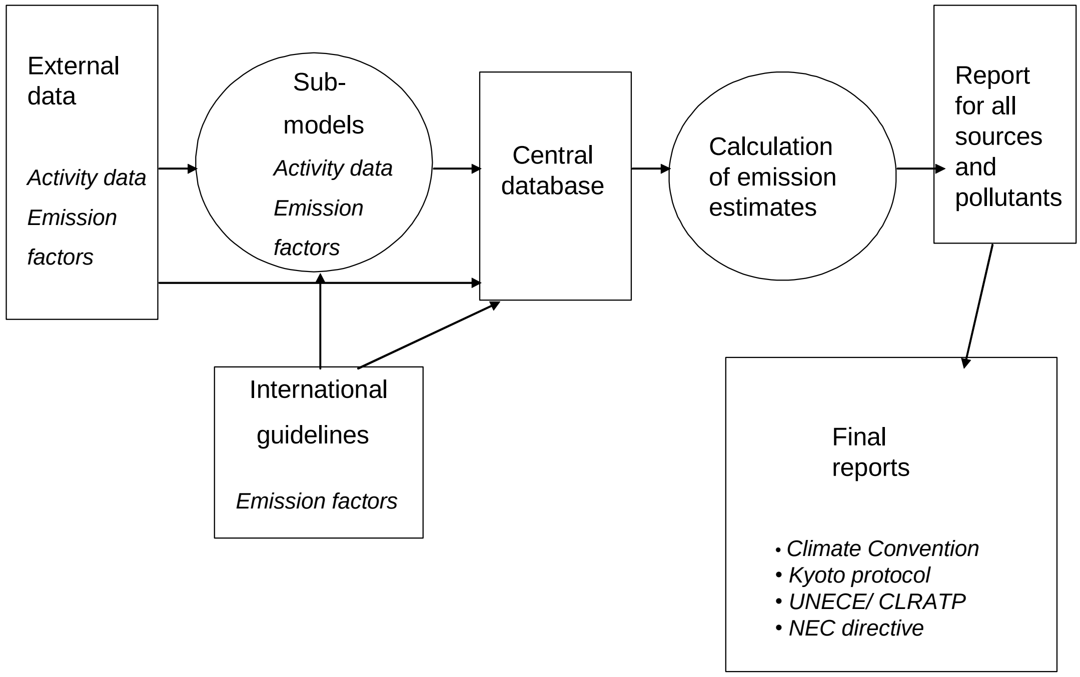


Figure 1.1 Schematic diagram of the process of inventory preparation.

Denmark has different geographical definitions for different submissions. Under the European Union only mainland Denmark is included. For the reporting under the Kyoto Protocol the submission includes Denmark and Greenland, while 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 three independent installations of the CRF Reporter software on different virtual computers.

For the preparation of the Danish submission under the Kyoto Protocol the full Danish CRF is aggregated with the Greenlandic CRF and for the UNFCCC reporting this is also aggregated with the CRF of the Faroe Islands. The process of aggregation requires additional software tools and two additional installations of CRF Reporter. The process of aggregating the KP inventory is described in Chapter 17.

1.4 Brief general description of methodologies and data sources used

Denmark's air emission inventories are based on the Revised 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 1996), 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 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.

In addition to the detailed emission calculation in the national approach, CO_2 emission from fuel combustion is aggregated using the reference approach. In 2012, the CO_2 emission inventory based on the reference approach and the national approach, respectively, differ by 0.97 %.

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 (EMEP/EEA, 2009) 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 (EMEP/EEA, 2009). 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 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 (EMEP/EEA, 2009).

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

1.4.4 Industrial processes

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 cut-back asphalt. The emission factors are default factors for consumption of asphalt and an estimated emission factor for cut-back 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 "Planmiljø". Their yearly report (DEPA, 2014) documents the inventory data up to the year 2012. The methodology is implemented for the whole time series 1990-2012, but full information on activities only exists since 1995.

Please refer to Chapter 4 for further information on industrial processes.

1.4.5 Solvents

The approach for calculating the emissions of Non-Methane Volatile Organic Carbon (NMVOC) from industrial and household use in Denmark focuses on single chemicals rather than activities. This leads to a clearer picture of the influence from each specific chemical, which enables a more detailed differentiation on products and the influence of product use on emissions. The procedure is to quantify the use of the chemicals and estimate the fraction of the chemicals that is emitted as a consequence of use.

The detailed approach in EMEP/EEA Guidebook (2009) is used. Here all relevant consumption data on all relevant solvents must be inventoried or at least those together representing more than 90 % of the total NMVOC emission. Simple mass balances for calculating the use and emissions of chemicals are set up 1) use = production + import – export, 2) emission = use x emission factor. Production, import and export figures are extracted from Statistics Denmark, from which a list of more than 400 single chemicals, a few groups and products is generated. For each of these, a "use" amount in tonnes per year (from 1990 to 2012) is calculated. For some chemicals and/or products, e.g. propellants used in aerosol cans and ethanol used in windscreen washing agents, use amounts are obtained from the industry as the information from Statistics Denmark does not comply with required specificity. It is found that approx. 40 different NMVOCs comprise over 95 % of the total use and it is these 40 chemicals that are investigated further. The "use" amounts are distributed across industrial activities according to the Nordic SPIN (Substances in Preparations in Nordic Countries) database, where information on industrial use categories is available in a NACE coding system. The chemicals are also related to specific products according to the Use Category (UCN) system. Emission factors are obtained from regulators, literature or the industry.

Outputs from the inventory are: a list where the approximately 40 most predominant NMVOCs are ranked according to emissions to air; specification of emissions from industrial sectors and from households - contribution from each chemical to emissions from industrial sectors and households; tidal (annual) trend in NMVOC emissions, expressed as total NMVOC and single chemical, and specified in industrial sectors and households.

This emission inventory includes N_2O emissions from the use of anaesthesia for 2000 onwards. Five companies sell N_2O in Denmark and only one company produces N_2O. Due to confidentiality no data on produced amount are available and thus the emissions related to N_2O production are unknown. An emission factor of one is assumed for all use, which equals the sold amount to the emitted amount.

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 5 and Annex 3D for further information on the emission inventory for solvent and other product use.

1.4.6 Agriculture

The calculation of emissions from the agricultural sector is based on methods described in the IPCC Guidelines (IPCC, 1996) and the Good Practice Guidance (IPCC, 2000). Activity data for livestock is on a one-year average basis from the agricultural statistics published by Statistics Denmark (2013). 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 (Mikkelsen et al., 2011). 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 Mikkelsen et al. (2011). 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 and Tier 2 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 6 and Annex 3E.

1.4.7 Forestry, Land Use and Land Use Change

A complete Land Use Change matrix based on satellite imaging of the whole 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 the purpose of 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 the purpose of having estimates for the KP accounting estimates for living biomass are provided for land converted from other land to other land uses.

1.4.8 Waste

For 6.A Solid Waste Disposal on Land, 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 according to an IPCC tier 2 approach (IPCC 1997, 2000 and 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, 2013). 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 8.2.

For 6.B Waste Water Handling, country-specific methodologies are used for calculating the emissions of CH_4 and N_2O at wastewater treatment plants (WWTPs). Recent expert review teams (ERTs) in the UNFCCC review have requested better documentation of derived EF and national activity data, and improvements has been performed with respect to dividing the contributions to the net methane emission into specific treatment processes. 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 waste water are included. Documentation of the improved methodology, emission factors and activity data are described in Chapter 8.3.

Regarding 6.C Waste Incineration, 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. For the 2011 submission 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.

In CRF category 6.D Other small emissions due to gasification of waste are included for the years 1994-2005. In 2006 onwards these emissions do not occur. In the 2011 submission emissions from accidental fires have been reallocated from category 6C to category 6D.

Please refer to Chapter 8 and Annex 3F for further information on emission inventories for waste.

1.4.9 KP-LULUCF

Regarding the possibility of including in the first commitment period emissions and removals associated with land use, land-use change and forestry activities under Article 3.4 of the Kyoto Protocol, Denmark decided to include emissions and removals from Forest Management (FM), Cropland Management (CM) and Grazing land Management (GM).

The national system has identified land areas associated with the activities under Article 3.4 of the Kyoto Protocol in accordance with definitions, modalities, rules and guidelines relating to land use, land-use change and forestry activities under the protocol by satellite monitoring, use of the EU Land Parcel Information System (LPIS), detailed crop information data on field level, soil mapping and sample plots from the National Forest Inventory (NFI). All land converted from other activities into cropland and grassland is accounted for. No land can leave elected areas under art. 3.4.

The forest definition adopted in the NFI is identical to the FAO definition (TBFRA, 2000). It includes "wooded areas larger than 0.5 ha, that 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. For afforestation the carbon stock change in the period 1990 - 2011 is calculated based on the area of afforestation, the information on species composition from the Forest Census 2000 and from the NFI. In the afforestation a steady increase in carbon stock is found. The estimates for the carbon pools in the afforestation are similar to previous estimates, with a slight increase due to the new knowledge on species composition, average carbon stock in those areas based on the NFI data and new data on the carbon stock in soils. Carbon stock change caused by deforestation is estimated based on the deforested area and the mean values of carbon stock in the total forest area. This is due to the fact that no specific knowledge is available on the carbon pools of the deforested areas. For Forest Management census and NFI data are used.

For cropland and grassland the same methodology is used in the KP reporting as used in the Convention reporting.

Please see Chapter 11 for further details.

1.4.10 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). These were updated in 2007 and are available from the EU Commission website (EU Commission, 2007).

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, 2007). 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 Gg CO_2, a category B installation has an annual emission of between 50 and 500 Gg CO_2 and a category C installation has an annual emission of more than 500 Gg CO_2. For each activity Table 1 of the EU ETS guidelines (EU Commission, 2007) 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, 2007).

Table 1.2 Example of minimum requirements in EU ETS guidelines (EU Commission, 2007).

	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	3	4	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 an overview is available in annex 1, chapter 13 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 an 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. The aggregation used for the analysis is not directly suited for emissions from Greenland. If Greenlandic emissions were included in the analysis, they would not affect the overall results of the key category analysis. For a key category analysis covering Greenland refer to Chapter 16 and for Denmark and Greenland refer to Chapter 17.

All KCA have been carried out in accordance with Good Practice Guidance (GPG) and IPCC Guidelines.

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

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

The KCA is based on 153 emission source categories including 22 LULUCF source categories.

The 12 different KCA for Denmark point out 25-35 key source categories each and a total of 52 different key source categories. The number of key categories in each of the main sectors is: energy 28, industrial processes 3, solvents and other product use 0, agriculture 11, LULUCF 7 and waste 3.

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

Table 1.3 shows the 50 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 (LU-LUCF included)			**Level Tier 1**	**Level Tier 1**	**Trend Tier 1**	**Level Tier 2**	**Level Tier 2**	**Trend Tier 2**
			1990	**2012**	**1990-2012**	**1990**	**2012**	**1990-2012**
Energy	Stationary Combustion, Coal	CO_2	1	2	1	22	31	27
Energy	Stationary Combustion, Fossil waste	CO_2	23	8	7		25	20
Energy	Stationary Combustion, Petroleum coke	CO_2	25	19	19			
Energy	Stationary Combustion, Residual oil	CO_2	7	21	6			
Energy	Stationary Combustion, Gas oil	CO_2	3	16	5	23		21
Energy	Stationary Combustion, Kerosene	CO_2	26		22			
Energy	Stationary Combustion, Refinery gas	CO_2	18	14	18			
Energy	Stationary Combustion, Natural gas	CO_2	4	3	2			31
Energy	Natural gas fuelled engines, GAS	CH_4			28			
Energy	Stationary Combustion, BIOMASS	CH_4					27	28
Energy	Stationary Combustion, SOLID	N_2O				20	30	23
Energy	Stationary Combustion, LIQUID	N_2O				11	29	12
Energy	Stationary Combustion, GAS	N_2O					23	22
Energy	Stationary Combustion, BIOMASS	N_2O				12	5	2
Energy	Transport, Road transport	CO_2	2	1	3	10	8	9
Energy	Transport, Railways	CO_2	30	29				
Energy	Transport, Navigation (large vessels)	CO_2	19	24				
Energy	Transport, Fisheries	CO_2	22	22				
Energy	Transport, Agriculture	CO_2	12	9	13	17	15	19
Energy	Transport, Industry (mobile)	CO_2	17	13	14	14	11	13
Energy	Transport, Commercial/institutional	CO_2			26			
Energy	Transport, Navigation (large vessels)	N_2O				26		
Energy	Transport, Agriculture	N_2O				25	24	25
Energy	Transport, Industry (mobile)	N_2O					28	30
Energy	1.B.2 Flaring off-shore	CO_2	29	32				
Energy	1.B.2 Refinery processes	CH_4						32
Industrial Proc.	2A1 Cement production	CO_2	16	15	21			
Industrial Proc.	2B2 Nitric acid production	N_2O	14		8	21		14
Industrial Proc.	2F Consumption of HFC	HFC		18	11		14	10
Agriculture	4A Enteric Fermentation	CH_4	5	5	9	7	9	15
Agriculture	4B Manure Management	CH_4	15	10	10	24	18	17
Agriculture	4.B Manure Management	N_2O	21	25		8	12	
Agriculture	4.D1.1 Synthetic Fertilizer	N_2O	9	12	12	3	4	3
Agriculture	4.D1.2 Animal waste applied to soils	N_2O	13	11	16	5	3	4
Agriculture	4.D1.3 N-fixing crops	N_2O		28		19	19	26
Agriculture	4.D1.4 Crop Residue	N_2O	27	26		13	16	29
Agriculture	4.D1.5 Cultivation of histosols	N_2O		31		18	22	
Agriculture	4.D.2 Grassing animals	N_2O	28	30		15	21	
Agriculture	4.D3 Atmospheric deposition	N_2O	24	27		9	17	33
Agriculture	4.D3 Leaching	N_2O	8	7	23	2	2	8
LULUCF	5.A.1 Forest remaining forest	CO_2		4	4		7	1
LULUCF	5.B Cropland, Living biomass	CO_2		33	20		13	5
LULUCF	5.B Cropland, Mineral soils	CO_2	10	20	17	6	10	6
LULUCF	5.B Cropland, Organic soils	CO_2	6	6		1	1	
LULUCF	5.C Grassland, Living biomass	CO_2		23	15		20	11
LULUCF	5.D Wetlands, Soils	CO_2						34
LULUCF	5(IV) Cropland Limestone	CO_2	20		25	16		18
Waste	6 A. Solid Waste Disposal on Land	CH_4	11	17	24	4	6	7
Waste	6.D Compost production	CH_4					32	24
Waste	6.D Compost production	N_2O			27		26	16

1.5.1 KP-LULUCF

See Chapter 11.9.1 for discussion on the key category analysis of KP-LULUCF.

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). The plan is in accordance with the guidelines provided by the IPCC (IPCC, 1996), and the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000). The ISO 9000 standards are also used as important input for the plan.

The QA/QC plan also covers Greenland. 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 17. The QA/QC specific to the Greenlandic emission inventory is described in Chapter 16.

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 Good Practice Guidance (IPCC, 2000):

- 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.

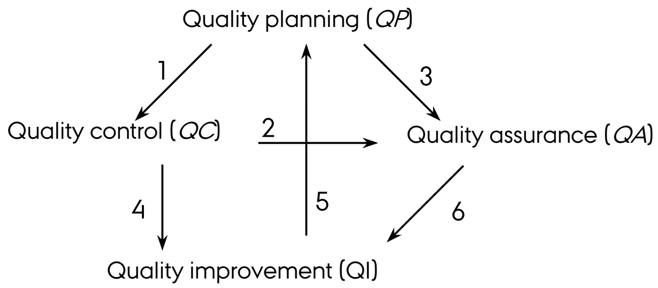


Figure 1.2 Interrelation between the activities with regard to quality. The arrows are explained in the text below this figure.

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 UNFCCCC 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 (2000), are to improve elements of transparency, consistency, comparability, completeness and confidence. In the IPCC guidelines (IPCC, 1996), the element "confidence" is replaced by "accuracy" and in this plan "accuracy" is used.

The objectives for the *QM* are used as *CCP*s, including the elements mentioned above. The following explanation is given by IPCC guidelines (IPCC, 1996) for each *CCP*:

Transparency means that the assumptions and methodologies used for an inventory should be clearly explained to facilitate replication and assessment of the inventory by users of the reported information. The transparency of the inventories is fundamental to the success of the process for communication and consideration.

Consistency means that an inventory should be internally consistent in all its elements with inventories of other years. An inventory is consistent if the same methodologies are used for the base and for all subsequent years and if consistent datasets are used to estimate emissions or removals from source or sinks. Under certain circumstances, 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 Intergovernmental Panel on Climate Change (IPCC) guidelines and good practice guidance.

Comparability means that estimates of emission and removals reported by Annex I Parties in inventories should be comparable among Annex I parties. For this purpose, Annex I Parties should use the methodologies and formats agreed upon by the COP for estimating and reporting inventories. The allocation of different source/sink categories should follow the split of *Revised 1996 IPCC Guidelines for national Greenhouse Gas Inventories* (IPCC, 1996) at the level of its summary and sectoral tables.

Completeness means that an inventory covers all sources and sinks, as well as all gases, included in the IPCC guidelines as well as other existing relevant source/sink categories, which are specific to individual Annex I Parties and, therefore, may not be included in the IPCC guidelines. Completeness also means full geographic coverage of sources and sinks of an Annex I Party.

Accuracy is a relative measure of the exactness of an emission or removal estimate. Estimates should be accurate and should systematically neither over- nor underestimate emissions nor removals. Uncertainties on estimates should be reduced if possible. Appropriate methodologies should be used in accordance with the *IPCC good practice guidance*, to promote data 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 Good Practice Guidance (IPCC, 2000) 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 either calculated 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.

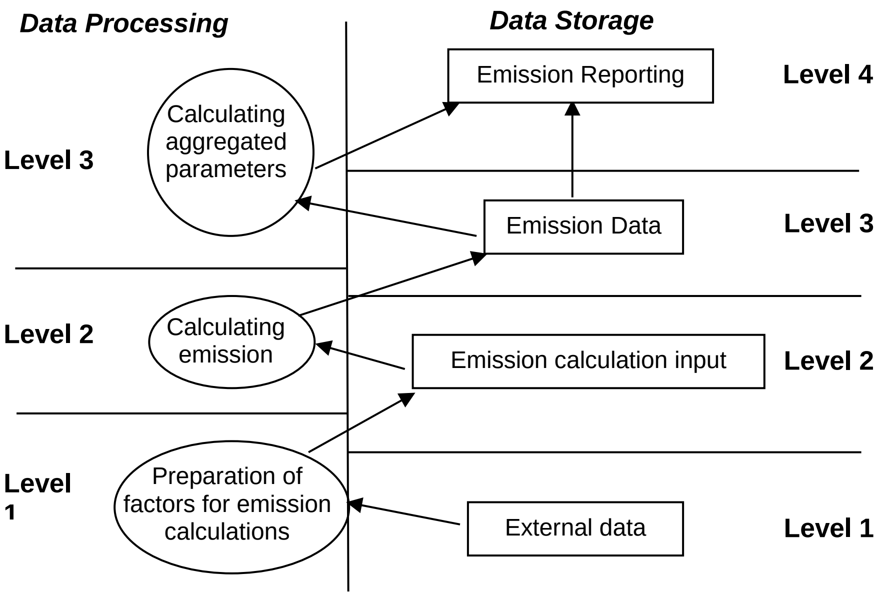


Figure 1.3 The general data structure for the emission inventory.

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 pr yr 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 1.2.

Table 1.2 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
		DP.1.5.2	Verification of calculation results using time series	Sectoral
		DP.1.5.3	Verification of calculation results using other measures	Sectoral

Level	CCP	Id	Description	
		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

Level	CCP	Id	Description	
		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 submissions for Denmark and Greenland.	General
	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
	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 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
	5.Correctness	DS.4.5.1	Check that the aggregated submissions for Denmark under the Kyoto Protocol and 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 and Greenland.	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 Government of Greenland.	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, there exist several issues regarding the listing of priority categories: (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, solvent and other 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 3-8).

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 still 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 submissions for Denmark and Greenland.

The process of generating the official submissions including the aggregation of submissions to the UNFCCC and the Kyoto Protocol 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, furthermore, 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 guidelines on reporting and review (UNFCCC, 2007). 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 submissions for Denmark under the Kyoto Protocol and the UNFCCC matches the sum of the individual submissions

To ensure that the submission for Denmark under the Kyoto Protocol matches the sum of the submissions of Denmark and Greenland a spreadsheet check has been implemented to ensure complete correctness of the submitted inventory. The same procedure is followed for the submission under the UNFCCC, where it is ensured that the submitted emissions equate to the sum of Denmark, Greenland and the Faroe Islands. 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 report provided by the Government of Greenland

The documentation report is received by DCE from the Government of Greenland in the early spring every year. The documentation report is included in the NIR as Chapter 16. 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 Tier 1 methodology in the IPCC Good Practice Guidance (GPG) (IPCC, 2000). Uncertainty estimates for the following sectors are included in the current year: stationary combustion plants, mobile combustion, fugitive emissions from fuels, industry, solid waste and wastewater treatment, CO_2 from solvents, agriculture and LULUCF. 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 1.3.

Table 1.3 Summary of base year and 2012 emissions in Gg CO_2 eqv. and activity data and emission factor uncertainties. Calculated Tier 1 and Tier 2 uncertainties for each emission source are given as % of the total 2012 emission. The base year for F-gases is 1995 and for all other gases the base year is 1990. Tier 2 uncertainty is not calculated for LULUCF.

IPCC Source category	Gas	Base year emission Gg CO_2 eqv.	2012 emission Gg CO_2 eqv.	Activity data uncertainty %	Emission factor uncertainty %	Tier 1 Combined uncertainty % of total emissions	Tier 2 uncertainty % of total emissions
Stationary Combustion, Coal	CO_2	23 834	10 005	1	1	0.203	0.190
Stationary Combustion, BKB	CO_2	11	1	3	5	0.0002	0.0002
Stationary Combustion, Coke	CO_2	138	74	2	5	0.008	0.0075
Stationary Combustion, Fossil waste	CO_2	573	1397	5	10	0.307	0.309
Stationary Combustion, Petroleum coke	CO_2	415	628	2	5	0.067	0.064
Stationary Combustion, Residual oil	CO_2	2496	571	1	2	0.026	0.025
Stationary Combustion, Gas oil	CO_2	4547	742	2	4	0.067	0.064
Stationary Combustion, Kerosene	CO_2	366	2	2	5	0.0002	0.0002
Stationary Combustion, LPG	CO_2	184	91	2	5	0.010	0.0092
Stationary Combustion, Refinery gas	CO_2	816	906	1	2	0.040	0.087
Stationary Combustion, Natural gas	CO_2	4335	8293	1	0.4	0.182	0.176
Stationary Combustion, SOLID	CH_4	13	3	1	100	0.006	0.0090
Stationary Combustion, LIQUID	CH_4	3	1	1	100	0.002	0.0032
Stationary Combustion, GAS	CH_4	3	6	1	100	0.011	0.0168
Natural gas fuelled engines, GAS	CH_4	5	120	1	2	0.005	0.0051
Stationary Combustion, WASTE	CH_4	1	2	5	100	0.003	0.0044
Stationary Combustion, BIOMASS	CH_4	102	135	16	100	0.269	0.392
Biogas fuelled engines, BIOMASS	CH_4	1	31	4	10	0.007	0.0066
Stationary Combustion, SOLID	N_2O	68	27	1	400	0.216	0.307
Stationary Combustion, LIQUID	N_2O	44	11	1	1000	0.218	0.291
Stationary Combustion, GAS	N_2O	16	24	1	750	0.361	0.476
Stationary Combustion, WASTE	N_2O	7	16	5	400	0.124	0.170
Stationary Combustion, BIOMASS	N_2O	38	91	2	1000	1.789	1.025
Transport, Road transport	CO_2	9284	11 224	2	5	1.190	1.173
Transport, Military	CO_2	119	116	2	5	0.012	0.0120
Transport, Railways	CO_2	297	249	2	5	0.026	0.0257
Transport, Navigation (small boats)	CO_2	48	99	41	5	0.080	0.0947
Transport, Navigation (large vessels)	CO_2	748	399	11	5	0.095	0.127
Transport, Fisheries	CO_2	591	479	2	5	0.051	0.0493
Transport, Agriculture	CO_2	1272	1343	24	5	0.648	0.719
Transport, Forestry	CO_2	36	17	30	5	0.010	0.0113
Transport, Industry (mobile)	CO_2	839	1021	41	5	0.830	0.955
Transport, Residential	CO_2	39	62	35	5	0.043	0.0494
Transport, Commercial/institutional	CO_2	74	171	35	5	0.119	0.134
Transport, Civil aviation	CO_2	243	133	10	5	0.029	0.0289
Transport, Road transport	CH_4	47	11	2	40	0.009	0.0103
Transport, Military	CH_4	0.1	0.1	2	100	0.0001	0.0002
Transport, Railways	CH_4	0.3	0.2	2	100	0.0003	0.0005
Transport, Navigation (small boats)	CH_4	0.3	1	41	100	0.001	0.0017
Transport, Navigation (large vessels)	CH_4	0.3	0.2	11	100	0.0004	0.0004
Transport, Fisheries	CH_4	0.3	0.2	2	100	0.000	0.0007
Transport, Agriculture	CH_4	2	2	24	100	0.004	0.0060
Transport, Forestry	CH_4	0.4	0.05	30	100	0.0001	0.0001
Transport, Industry (mobile)	CH_4	1	1	41	100	0.002	0.0024
Transport, Residential	CH_4	1	1	35	100	0.003	0.0044
Transport, Commercial/institutional	CH_4	2	3	35	100	0.007	0.0101
Transport, Civil aviation	CH_4	0.1	0.05	10	100	0.0001	0.0001
Transport, Road transport	N_2O	91	116	2	50	0.115	0.140

IPCC Source category	Gas	Base year emission Gg CO_2 eqv.	2012 emission Gg CO_2 eqv.	Activity data uncertainty %	Emission factor uncertainty %	Tier 1 Combined uncertainty % of total emissions	Tier 2 uncertainty % of total emissions
Transport, Military	N_2O	1	1	2	1000	0.025	0.0396
Transport, Railways	N_2O	3	2	2	1000	0.042	0.0606
Transport, Navigation (small boats)	N_2O	0.4	1	41	1000	0.021	0.0315
Transport, Navigation (large vessels)	N_2O	15	8	11	1000	0.153	0.171
Transport, Fisheries	N_2O	11	9	2	1000	0.185	0.244
Transport, Agriculture	N_2O	15	18	24	1000	0.349	0.511
Transport, Forestry	N_2O	0.2	0.2	30	1000	0.003	0.0049
Transport, Industry (mobile)	N_2O	11	13	41	1000	0.265	0.368
Transport, Residential	N_2O	0.2	0.3	35	1000	0.007	0.0100
Transport, Commercial/institutional	N_2O	0.3	1	35	1000	0.016	0.0215
Transport, Civil aviation	N_2O	3	2	10	1000	0.041	0.0591
1.B.2 Flaring in refinery	CO_2	23	22	11	2	0.005	0.0049
1.B.2 Flaring off-shore	CO_2	302	195	8	2	0.030	0.0300
1.B.2 Land based activities	CO_2	0.003	0.01	2	40	4.2E-06	0.000005
1.B.2 Off-shore activities	CO_2	2	4	2	30	0.002	0.002
1.B.2 Transmission of natural gas	CO_2	0.003	0.0005	15	2	1.4E-07	0.0000004
1.B.2 Distribution of natural gas	CO_2	0.005	0.005	25	10	2.5E-06	0.000003
1.B.2 Venting in gas storage	CO_2	0.001	0.001	15	2	3.7E-07	0.0000001
1.B.2. Flaring in refinery	CH_4	0.2	0.2	11	15	0.00006	0.00006
1.B.2. Flaring off-shore	CH_4	1	0.3	8	125	0.001	0.0016
1.B.2 Refinery processes	CH_4	1	47	1	125	0.115	0.186
1.B.2 Land based activities	CH_4	17	18	2	40	0.014	0.0156
1.B.2 Off-shore activities	CH_4	15	37	2	30	0.022	0.0241
1.B.2 Transmission of natural gas	CH_4	4	0.3	15	2	0.000	0.0001
1.B.2 Distribution of natural gas	CH_4	5	3	25	10	0.002	0.0017
1.B.2 Venting in gas storage	CH_4	1	1	15	2	0.0004	0.0004
1.B.2 Flaring in refinery	N_2O	0.1	0.1	11	1000	0.001	0.0016
1.B.2 Flaring off-shore	N_2O	1	0.5	8	1000	0.009	0.0122
2A1 Cement production	CO_2	882	871	1	2	0.038	0.0375
2A2 Lime production	CO_2	116	40	5	5	0.006	0.0056
2A3 Limestone and dolomite use	CO_2	14	26	5	5	0.004	0.0036
2A5 Asphalt roofing	CO_2	0.02	0.02	5	25	0.00001	0.0000
2A6 Road paving with asphalt	CO_2	2	2	5	25	0.001	0.0010
2A7a Glass and Glass wool	CO_2	17	10	5	2	0.001	0.0010
2A7b Yellow bricks	CO_2	23	17	5	2	0.002	0.0018
2A7c Expanded clay	CO_2	15	6	5	2	0.001	0.0006
2B5 Catalysts/Fertilizers, Pesticides and Sulphuric acid	CO_2	1	1	5	5	0.0002	0.0002
2C1 Iron and steel production	CO_2	28	0	5	5	0.0E+00	0
2D2 Food and Drink	CO_2	4	2	5	5	0.0003	0.0003
2G Lubricants	CO_2	50	32	2	5	0.003	0.0032
2B2 Nitric acid production	N_2O	1043	0	2	25	0.000	0
2F Consumption of HFC	HFC	218	657	10	50	0.660	0.558
2F Consumption of PFC	PFC	1	9	10	50	0.009	0.0073
2F Consumption of SF6	SF_6	107	118	10	50	0.118	0.105
3A Paint application	CO_2	13	7	10	15	0.003	0.0027
3B Degreasing and dry cleaning	CO_2	0.00004	0.000001	10	15	5.2E-10	0
3C Chemical products, manufacturing and processing	CO_2	19	12	10	15	0.004	0.0045
3D5 Other	CO_2	61	44	10	20	0.019	0.0207
3D5 Consumption of fireworks	CO_2	0.1	0.2	8	100	0.0003	0.0004
3D5 Use of candles	CO_2	22	81	10	20	0.036	0.0378

IPCC Source category	Gas	Base year emission Gg CO_2 eqv.	2012 emission Gg CO_2 eqv.	Activity data uncer-tainty %	Emission factor uncertain-ty %	Tier 1 Combined uncertainty % of total emissions	Tier 2 uncertainty % of total emissions
3D1 Other - Use of N2O for Anaesthesia	N_2O	0	9	5	5	0.001	0.0013
3D5 Use of tobacco	N_2O	0.3	0.2	20	30	0.0001	0.0001
3D5 Use of charcoal for BBQ	N_2O	0.1	0.1	10	100	0.0003	0.0004
3D5 Consumption of fireworks	N_2O	1	2	8	100	0.004	0.0063
3D5 Use of candles	N_2O	0.1	0.2	10	20	0.0001	0.0001
4A Enteric Fermentation	CH_4	3247	2904	2	20	1.149	1.192
4B Manure Management	CH_4	985	1297	5	20	0.526	0.560
4F Field burning of agricultural residues	CH_4	2	2	25	50	0.003	0.0032
4.B Manure Management	N_2O	600	391	22	100	0.788	0.525
4.D1.1 Synthetic Fertilizer	N_2O	2354	1103	25	100	2.240	3.428
4.D1.2 Animal waste applied to soils	N_2O	1112	1161	30	100	2.387	3.650
4.D1.3 N-fixing crops	N_2O	269	256	20	100	0.514	0.750
4.D1.4 Crop Residue	N_2O	361	311	20	100	0.625	0.956
4.D1.5 Cultivation of histosols	N_2O	290	198	20	100	0.398	0.599
4.D.2 Grassing animals	N_2O	334	211	25	100	0.428	0.648
4.D3 Atmospheric deposition	N_2O	496	295	19	100	0.590	0.885
4.D3 Leaching	N_2O	2447	1430	20	100	2.870	4.289
4.D1.6 Sewage sludge and Industrial waste used as fertiliser	N_2O	28	39	20	100	0.078	0.114
4.F Field Burning of Agricultural Residues	N_2O	1	1	25	50	0.001	0.0012
5.A.1 Forest remaining forest	CO_2	50	-4491	15	2	-1.338	
5.A.2 Land converted to forest	CO_2	77	38	15	9	0.013	
5(II) Forest Land.	N_2O	16	12	30	10	0.008	
5.B Cropland, Living biomass	CO_2	-74	193	10	50	0.194	
5.B Cropland, Dead organic matter	CO_2	3	12	10	50	0.012	
5.B Cropland, Mineral soils	CO_2	1415	577	10	75	0.860	
5.B Cropland, Organic soils	CO_2	2887	1981	10	90	3.531	
5(III) Disturbance, Land converted to cropland	N_2O	0.3	1	50	75	0.0018	
5.C Grassland, Living biomass	CO_2	75	463	10	50	0.465	
5.C Grassland, Dead organic matter	CO_2	2	7	10	50	0.007	
5.C Grassland, Mineral soils	CO_2	0.2	5	10	75	0.007	
5.C Grassland, Organic soils	CO_2	107	79	10	90	0.140	
5.D Wetlands, Living biomass	CO_2	3	-0.2	10	50	0.000	
5.D Wetlands, Dead organic matter	CO_2	1	0	10	100	0.000	
5.D Wetlands, Soils	CO_2	85	2	10	100	0.005	
5(II) Wetlands	N_2O	0.1	0.1	10	100	0.000	
5.E Settlements, Living biomass	CO_2	11	56	10	50	0.056	
5.E Settlements, Dead organic matter	CO_2	1	0.03	10	50	0.000	
5.E Settlements, Soils	CO_2	1	35	10	50	0.035	
5(IV) Cropland Limestone	CO_2	623	192	5	50	0.190	
5(V) Biomass Burning	CH_4	1	0.02	50	30	0.000	
5(V) Biomass Burning	N_2O	0.4	0.03	50	30	0.00004	
6 A. Solid Waste Disposal on Land	CH_4	1366	698	10	118	1.626	2.536
6 B. Wastewater Handling	CH_4	65	74	24	32	0.058	0.0743
6 B. Wastewater Handling - Direct	N_2O	23	41	22	50	0.043	0.0543
6 B. Wastewater Handling - Indirect	N_2O	82	32	59	42	0.046	0.0624
6.D Accidental fires, buildings	CO_2	11	11	10	300	0.064	0.151
6.D Accidental fires, vehicles	CO_2	6	6	10	500	0.055	0.151
6.C Incineration of corpses	CH_4	0.01	0.01	1	150	0.00003	0.0001
6.C Incineration of carcasses	CH_4	0.001	0.005	40	150	0.00001	0
6.D Compost production	CH_4	29	90	40	100	0.192	0.293

IPCC Source category	Gas	Base year emission Gg CO_2 eqv.	2012 emission Gg CO_2 eqv.	Activity data uncertainty %	Emission factor uncertainty %	Tier 1 Combined uncertainty % of total emissions	Tier 2 uncertainty % of total emissions
6.D Accidental fires, buildings	CH_4	1	1	10	500	0.013	0.0354
6.D Accidental fires, vehicles	CH_4	0.3	0.2	10	700	0.003	0.0105
6.C Incineration of corpses	N_2O	0.2	0.2	1	150	0.001	0.0010
6.C Incineration of carcasses	N_2O	0.0	0.1	40	150	0.0003	0.0005
6.D Compost production	N_2O	13	127	40	100	0.269	0.413

1.7.2 Results of the tier 1 uncertainty estimation

The estimated uncertainties for total GHG and for CO_2, CH_4, N_2O and F-gases are shown in Table 1.4. 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 ±6.9 % and the trend in net GHG emission since the base year has been estimated to be -31.6 % ± 2.6 %-age points. The GHG uncertainty estimates do not take into account the uncertainty of the GWP factors.

The uncertainty on N_2O emission from stationary biomass combustion, CH_4 emission from solid waste disposal, N_2O emission from leaching and run-off and N_2O emission from animal waste applied to soil and synthetic fertiliser are the largest sources of uncertainty for the Danish GHG inventory (excluding LULUCF). For LULUCF the largest sources of uncertainty are forest land remaining forest land and soil emissions from cropland.

The uncertainty of the GHG emission from combustion (sector 1A) is 2.2 % and the trend uncertainty is -25.3 % ±2.2 %-age points.

Table 1.4 Uncertainties 1990-2012.

	Uncertainty [%]	Trend [%]	Uncertainty in trend [%-age points]
GHG	6.9	-31.6	± 2.6
CO_2	5.6	-33.7	± 2.4
CH_4	19	-7.3	± 11.8
N_2O	42	-39.1	± 12.6
F-gases	43	141	± 41
CO_2 excl. LULUCF	2.1	-25.5	± 1.7
GHG excl. LULUCF	5.6	-25.1	± 2.5

1.7.3 Tier 2 uncertainties

On the recommendation of the UNFCCC expert review team (ERT) in 2009 Denmark has undertaken a tier 2 uncertainty analysis. Please see the sectoral chapters for the sectoral results of the tier 2 uncertainty analysis. Below is a description on the theoretical basis for the tier 2 uncertainty calculations. For the overall result please refer to Chapter 1.7.4.

When to use Tier 2

When the activity data and emission factors cannot fulfil the criteria for using the error propagation equations in Tier 1 an alternative stochastic simulation, i.e. Monte Carlo method, can be employed. The Monte Carlo method constitutes Tier 2 and Approach 2 in IPCC (2000 and 2006) and is suitable for estimating uncertainty in emission rates, from uncertainties in activity data and emission factors, when:

- Uncertainties are large.
- Their distribution is non-normal.
- The algorithms are complex function and not only simple multiplication of activity data with emission factors.
- Correlations occur between some of the activity data sets, emission factors, or both.

Uncertainties found in inventory source categories can vary widely from a few per cent to orders of magnitude. When using a normal distribution for a parameter with large uncertainty there is a risk of having a certain probability for negative values, which is not possible in reality. Furthermore large uncertainty gives a certain probability of having extremely large values, i.e. values orders of magnitude larger than the mean value. Extreme values are an often occurring quality for the distribution of realistic activity data and emission factors. However, in some cases the extreme values are unrealistic and here the method allows for upper and lower truncation of input parameters. This implies applying a lower and/or upper boundary for the distribution function of input parameters. A logarithmic plot of data with large uncertainties will transform a skewed distribution probability function (a) into a bell-shaped log-normal distribution function (b), cf. Figure 1.5. The latter can be defined by a mean value, α, and standard deviation, σ, respectively. The log-normal distribution is selected as standard in the first version of the Tier 2 and Approach 2 uncertainty assessment for year 2009. A further feature of applying truncation boundaries is that a probability distribution will converge towards a box distribution when narrowing the truncation interval.

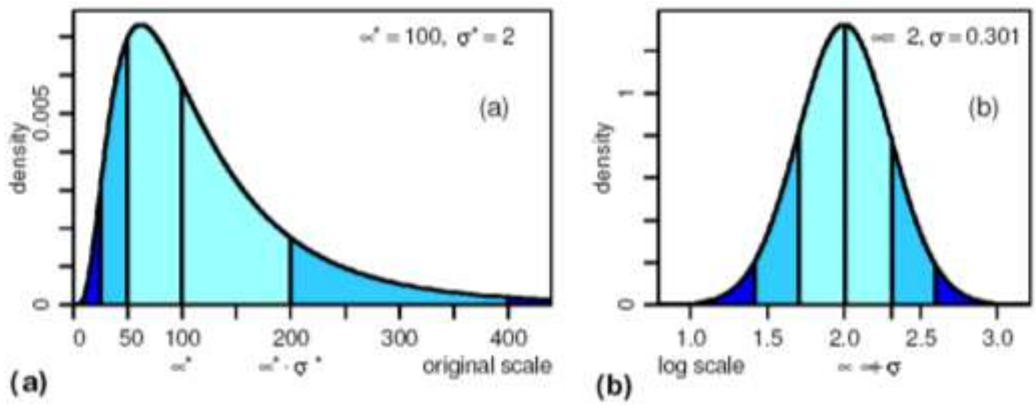


Figure 1.5 Log-normal distribution ($\log_{10}$), both on original (a) and log scale (b). The median (α^*) is 100 and the multiple standard deviation (σ^*) is 2. The resulting median (equal mean) and the standard deviation in the $\log_{10}$ distribution is respectively $\alpha = \log_{10}(100) = 2$ and $\sigma = \log_{10}(2) = 0.301$ (Limbert et al., 2001).

In case the uncertainty is much smaller than the mean value, then the normal and log-normal distributions will not differ much, cf. Figure 1.6, where the relationship between normal and log-normal distributions are illustrated (Limbert et al., 2001).

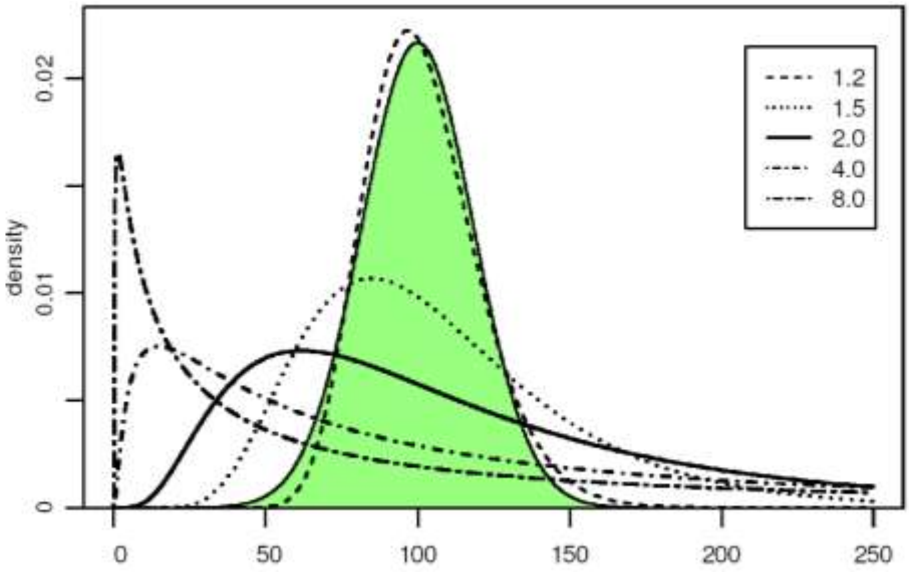


Figure 1.6 Comparison between the normal distribution (green area, median 100, standard deviation 20) the different degrees of variability (described by σ^*) for log-normal distributions that all have the same median value, i.e. α^* on original scale, of 100 (Limbert et al., 2001).

The difference in shape between a normal and log-normal distribution is seen in Figure 1.6 for different values of σ^*. The standard deviation for the normal distribution is 20 and thus equal to 20 % of the mean value and the log-normal distribution having a σ^* value of 1.2 reflects the same level of "deviation" as in the normal distribution. So, the discrepancy between the green area and the curve for σ^*=1.2 illustrates the difference in interpretation of a 20 % deviation as measured by respectively the normal and log-normal distribution. This discrepancy is so limited that it is overruled by the vagueness related to empirical quantification of the uncertainty level based on expert knowledge and data and the fact that any assumed distribution function is an approximation. Therefore, by using log-normal distributions as standard description of all uncertainty input it will in reality include normal distributions when the magnitude of uncertainty is limited to a minor fraction of the mean value.

A way of calculating the intervals of confidence, expressed by the median (α^*) and standard deviation (σ^*), for a log-normal distribution on original scale, cf. Figure 1a, is presented in Limbert et al. (2001). For normally distributed data, the interval [median ± standard deviation] covers a probability of 68.3 %, while [median ± 2*standard deviation] covers 95.5 %. Correspondingly for log normal data on original scale, cf. Figure 1a, the interval [α^* / σ^*, α^* * σ^*] covers 68.3 % and the interval [α^* / $(\sigma^*)^2$, α^* * $(\sigma^*)^2$] covers 95.5 %.

Often the default uncertainty values in IPCC (2000) e.g. for emission factors, are expressed as a percentage, e.g. 30 %. When this represents a standard deviation (68.3 %) on original scale we will proceed using σ^* = 1.3 in the uncertainty analysis. When it represents a 95 % interval of confidence, we will use σ^* = (1.3)^0.5 = 1.14 in the uncertainty analysis. When the 95 % interval of confidence on original scale is below approximately 300 % the standard deviation for a log-normal distribution on original scale, can be approximated by dividing with a factor of 2, i.e. 0.3/2 = 0.15, and thus σ^* = 1.15.

Procedure of Tier 2 (Monte Carlo method)

The procedure of the Tier 2 (MC) analysis consists of four steps where only Step 1 requires effort from the user:

- Step 1: Estimation of activity data and emission factors, their associated mean values, uncertainties such as standard deviation, probability density functions and any correlations.
- Step 2: Selection of random values of activity data and emission factors.
- Step 3: Calculate emissions from selected random values.
- Step 4: The calculated result in step 3 is stored and the process is repeated from step 2.

Repetition of steps 2 and 3 are continued until the calculated mean value and error intervals are sufficiently determined (typically 10,000 times). Each single repetition is denoted a "single sample" in the following and one execution of steps 2 and 3 is denoted a "MC sample".

The software is developed in excel VBA programming by a scientist associated with the sector experts, which enables a transparent and accurate transfer and interpretation of emission factors and activity data (input) and calculated emissions with uncertainties (output).

Different criteria and guidelines for estimation of value uncertainty for activity data and emission factors are outlined in the next section. Whether they are based on information from models, empirical data or expert judgement, they form lines of evidence towards the most appropriate estimate. The basic paradigm for a MC analysis is outlined in Figure 1.7.

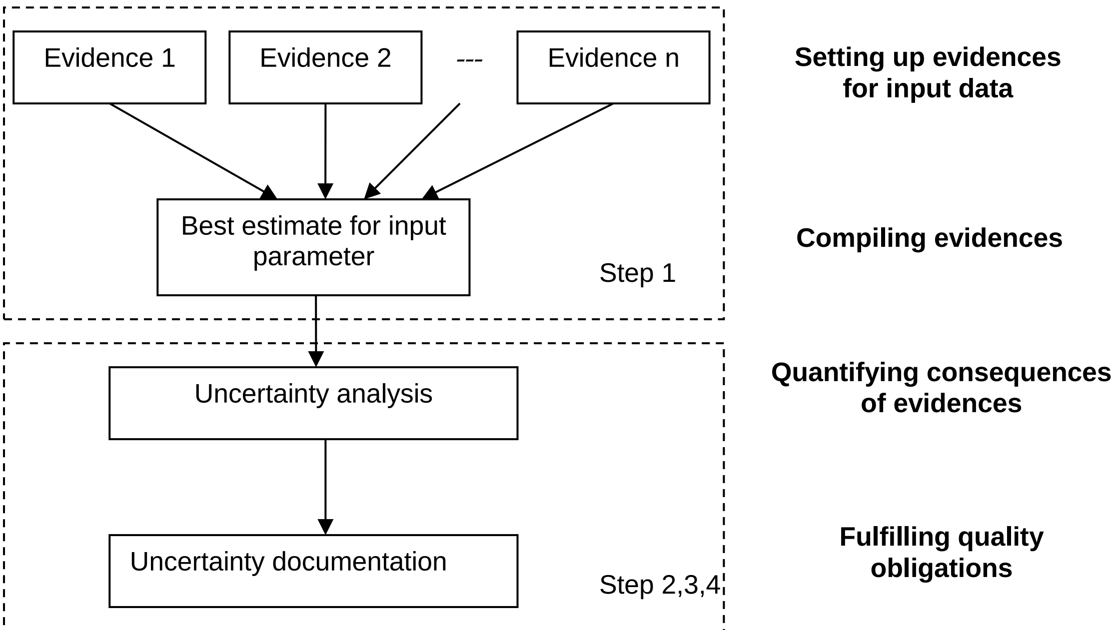


Figure 1.7 Methodological principle in compiling and quantifying input data for input parameters, e.g. emission factors, which are to be used in Tier 2 (MC) uncertainty analysis. Each evidence is formed from assessment of information from models, empirical data or expert judgement. The upper dotted box represents step 1 in the MC analysis, which is performed for each input parameter. The lower dotted box represents steps 2 to 4, and is performed in the emission modelling with all input parameters.

The principle of the MC method is to generate many "possible" calculations and thus map the resulting "possible" results. The possible calculations are made based on the "realistic" variability (uncertainty) related to the input parameter values. This variability needs to be described as a distribution function. The MC method is considered in two parts: (1) A distribution estimation part, where the variabilities of the input parameters are parameterised; (2) A technical part that makes the simulation based on the estimated distributions. The first part is highly critical and requires high attention. The second part is a question of programming and therefore mostly a technical issue. The MC method is a model for how uncertainty of input parameters influences the calculation results, so the MC also involves uncertainty in the prediction of uncertainty. It is therefore important to predict the variability of the input parameters as correctly as possible. The MC method does not include the validity of the calculations as estimators of reality but only the uncertainty of the input parameter values. Consequently, there are many fundamental types of uncertainty that are not included in the MC method.

The method is based on single samples, where the mean is unity and where the variability is determined by the uncertainty of the parameter as discussed above, see Figure 1.8. This sampled value is subsequently multiplied with the best estimate of the parameter value to yield a sampled value for this parameter. The reason for this two stage sampling is that it makes it possible directly to include correlation in uncertainty between years as explained below.

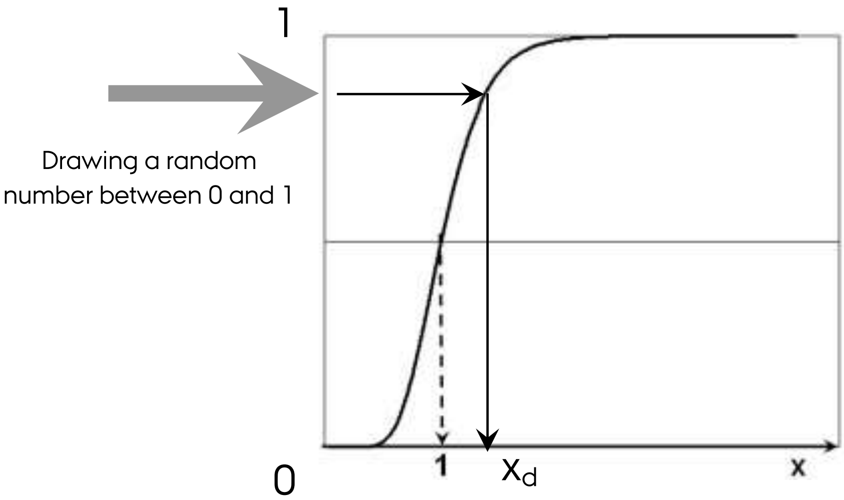


Figure 1.8 The principle in a single MC draw of the value $x_{d,}$ where the median (α^*) is unity and where the standard deviation (σ^*) determines the variation around 1.

Correlation in the uncertainty may occur between years, e.g. when the same sources are responsible for uncertainties in several years. This takes place because many sources of uncertainty are dependent between years, so if a parameter is over-estimated for one year then this parameter may also tend to be overestimated other years. This implies that when the uncertainty is high one year the uncertainty will also be high the other year(s). The principle of performing a MC analysis with an emission factor and activity data that have uncertainties that are correlated between one or more years is illustrated in Figure 1.9.

The principle in Figure 1.9 is to sample a value (x) as shown in Figure 4, where the median value is unity and subsequently multiply the sampled value with the estimated median value (e.g. $AD_{s1}=AD_1 \cdot x$). This two-step approach makes is possible to include correlating uncertainty between different years. If two years are correlated then a deviation from the estimated mean value is assumed to be the same in relative terms for the two years. By sampling, using the median of unity once, and subsequently use this value to estimate the value for the two years, using the two medians for each year, this will yield the correlation between the two years as a simple consequence and thereby be directly simulated in the MC sampling.

The MC sampling is illustrated in Figure 1.9 for a single source, where *s* is the sampling number index, counting up to e.g. 10,000. In Figure 5 there will be a strong correlation between year 2 and 3, because both the uncertainty of *EF* and *AD* is correlated, for year 1 there will be a partial correlation with respectively year 2 and 3 because the uncertainty of the *EF* value is correlated, but the uncertainty is independent for *AD*. Year 4 is completely independent of the other years. The figure is only illustrating a single source and typically the emission estimates includes several sources each having some more or less correlated uncertainty. The final emission estimates are thus more or less correlated between years in a highly complex way.

Performing MC analysis for correlated parameters corresponds to the calculation scheme for MC analysis of emissions and the trend of a category as shown in Appendix A (IPCC, 2006) (Figure 3.7 pp. 3.36). The scheme shows calculations for correlated and non-correlated parameters.

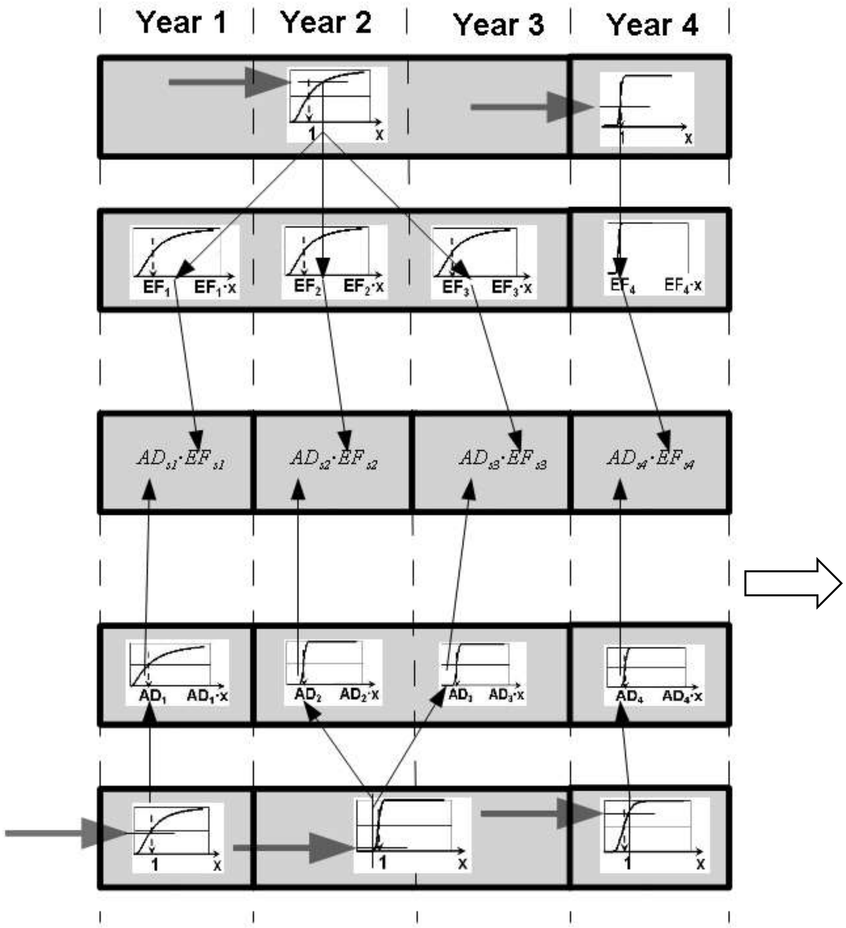


Figure 1.9 The principle of a MC sample for draws of random numbers and generation of any emission factor and activity data for a four year period. The upper half illustrates the sampling of any emission factor for year 1 to year 4. The uncertainty associated to the emission factor is correlated for year 1, 2 and 3 and therefore the same random number is used for generating EF1, EF2 and EF3. The lower half illustrates the sampling of activity data. The uncertainty associated to the activity data is correlated for year 2 and 3 and therefore the same random number is used for generating AD2 and AD3. In the middle row the emission factor and activity data are multiplied for each year.

In some cases there exists additional a priori information about categories of activity data, where the total sum is known with high certainty, but where the sub categories are more uncertain. In this case the single samples within one year are adjusted so all sub sources together adds up to the correct total number and the single sampling in this case will describe the uncertainty between the single categories.

MC analyses for emissions

When a 95% confidence interval has been entered as percentages of median values of the input parameters, i.e. emission factors and activity data, for source categories and sub-categories, the above MC procedure is executed 10,000 times. The output of the MC analysis is reported as in Table 1.5 where the median emissions are shown together with the 95% confidence interval (2.5% - 97.5%).

Two basic questions are important to answer: (1) What is the uncertainty for a time trend estimate; (2) What is the uncertainty within the same year of the single sub-categories, source categories and the total estimate. The first question takes correlation of uncertainty between years into account and the second question considers one year at a time and correlation between years is not relevant.

In the ideal case it will be possible to answer the two questions based on the same MC samples, where every single sample is stored for every source and for every year. However, this is not possible in the VBA programming due to limitations in variable table on a normal pc. Thus two MC samplings take place: (1) The total emission is calculated for every year and every MC sample, so for 10,000 MC samples and 20 years, this needs storage of 200,000 numbers; (2) Every year is analysed separately where only results for one year is stored at a time, so for 10,000 MC samples and 50 sources this yields 500,000 numbers to be stored. Using this two-stage approach it is easily possible to run the MC analysis in Excel. Consequently, the exact value for the median analysed for a specific year (question 2 above) is not similar with the medians in the time trend analysis (question 1 above) due to a finite number of MC samples, but this is not a real problem. If this discrepancy is considered as critical then it simply tells that the number of MC samples should be increased and that the analysis thus has to be redone.

Table 1.5 Example of output scheme for tier 2 MC uncertainty analysis. Median emissions and 95 % confidence intervals are calculated for total emission, emissions for source categories and emissions for sub-categories. Calculated 95% confidence intervals are furthermore calculated for activity data and emission factors.

Source category	Sub-categories	Activity			EF			Emissions			
		< 2.5%	>97.5%	Interval	< 2.5%	> 97.5%	Interval	Median	< 2.5%	> 97.5%	Interval
all	all	-	-	-	-	-	-				
A	all	-	-	-	-	-	-				
B	all	-	-	-	-	-	-				
C	all	-	-	-	-	-	-				
A	1										
A	2										
A	3										
B	1										
B	2										
C	1										
C	2										
C	3										
C	4										

Results for each row can also be reported as:

Median emission [- (median - <2.5%)/median/100%, + (>97.5% - median)/median/100%]

MC trend analysis

The trend analysis is performed by comparing emissions from two individual years at a time. The probability for Year 1 (base year) to be above Year 2 (latest year) is calculated using the equation:

$$P_{Year1>Year2} = \frac{N_{year1>year2}}{N_{total}},$$

where $N_{year1>year2}$ is the number of MC samples where year 1 is estimated to have higher emission compared to year 2 and N_{total} is the total number of MC runs. In case of $P_{year1>year2} \approx 1$ it is strongly significant to conclude that year 1 has higher emission than year 2, and reverse for $P_{year1>year2} \approx 0$. This is a comparison between years in pairs that can be filled in to a matrix, where all years are compared with all other years.

Table 1.6 Comparison of emissions between years in trend analysis.

	Year 1	Year 2	Year 3	Year 4
Year 1	0			
Year 2		0		
Year 3			0	
Year 4				0

Results for trend analysis of emissions between two years, year 1 and year 2, can be reported as median difference, <2.5% and >97.5%, or as:

Median difference [- (median difference - <2.5%)/median difference/100%, + (>97.5% - median difference)/median difference/100%]

Quantifying uncertainties in Tier 2

In order to perform the four steps of a Tier 2 (MC) uncertainty analysis as described in the previous paragraph the user has to gather the information stated in step 1. It is essential to establish the best possible estimate, and the following guide sets up a procedure for assessing, quantifying and compiling uncertainties for the parameters that are entered in the emission models. The guide is based on IPCC guidelines (IPCC, 2000 & 2006) and NUSAP and expert elicitation in van der Sluijs et al. (2004).

The uncertainty of a parameter, e.g. activity data and emission factor, is considered to be proportional to the associated parameter. This means that the uncertainty is expressed as a percentage of the parameter value. The median value is used and the uncertainties represent the parameter standard deviation, σ^*. We assume log-normal distributions, which equals normal distributions at low uncertainty values. Although van der Sluijs et al. (2004) suggest different probability distribution functions depending on the level of knowledge on input parameters we will use log-normal distributions for all parameters, as argued in the previous section.

The methodology offers a possibility for correlating the uncertainties of two or more parameters. When uncertainties of two or more parameters are assumed to be correlated they will be attributed the same random number in any MC sample, as explained in the previous paragraph.

Uncertainties will be reported according to the IPCC General Reporting Table for Uncertainty. Uncertainties will be reported for:

- Total uncertainty of the entire sector
- Key source categories
- Aggregated CRF levels
- Most differentiated CRF category levels that are entered by the user

IPCC guideline - Sources of data

Quantifying uncertainties is dependent on the source of data, and in general there are three broad sources of data and information (IPCC, 2000 & 2006):

Information contained in models

A model is a representation of the real world and does therefore not exactly mimic real-world systems. The structure of a model is often thought of in terms of the equations used. The key considerations in model uncertainty are; has the correct, most relevant real-world system been identified and are the model equations accurate representations of the chosen system. Typically the model equations are the product of activity data and emission factors, cf. Eq 1, but there may also be more complex model equations for emissions and also for derivation of activity data and emission factors.

In some cases, model uncertainty can be significant. It is typically poorly characterised and may not be characterised at all. The inventory expert must consider the parameters that are used and assess if there are model assumptions that are imprecise or inaccurate. For the most critical models an effort can be made to evaluate and quantify the size of the potential error that occurs from using the model. There are at least three approaches for estimating the model uncertainty: 1) comparison of a model result with independent data, 2) comparison of a model result with the result of alternative models, and 3) expert judgement regarding the magnitude of the model uncertainty. These approaches can be used in combination.

Empirical data for sources and sinks and activity

This implies empirical data associated with measurements of emissions, emission factors and activity data from surveys and censuses. When estimating uncertainty from measured emissions data, considerations include; representativeness of the data and potential for bias, precision and accuracy of the measurements, sample size and inter-individual variability in measurements and their implications for uncertainty in mean annual emissions, inter-annual variability in emissions and whether estimates are based on an average of several years or on the basis of a particular year.

Quantification of uncertainties and defining the probability distribution function (PDF) for empirical data can be summarised as follows: 1) Compilation of activity data, emission factors and other parameters. These data typically represent variability, 2) Visualisation of data by plotting empirical distribution functions for each parameter; horizontally according to numerical value or interval and vertically by frequency, 3) Fitting, evaluation and selection of PDFs for representing variability of data, 4) Characterisation of mean value and of uncertainty in the mean of the distributions for variability. If the standard error of the mean is small, a normality assumption can be made regardless of the sample size or skewness of data. If the standard error of the mean is large, then typically a log-normality assumption can be made, 5) Once mean values, uncertainties and standard errors have been specified, these can be used as input to Tier 2 MC analysis for estimating uncertainties in total emissions, 6) Sensitivity analysis can be used to determine which parameters induce highest uncertainties in the total uncertainty, and prioritise efforts to develop good estimates of these key uncertainties.

Expert judgement as a source of information

In many situations, relevant empirical data are not available for activity data, emission factors etc. to an inventory. In such situations, a practical solution is to obtain well informed judgements from domain experts regarding best estimates and uncertainties of input data.

Commonly used methods for converting an expert's judgement regarding uncertainty into a quantitative PDF are: 1) Fixed value; Estimate the probability of being higher (or lower) than an arbitrary value and repeat, three or five times. For example, what is the probability that an emission factor would be less than 100? 2) Fixed probability; Estimate the value associated with a specified probability of being higher (or lower). For example, what is the emission factor such that there is only a 2.5% probability that the emission factor could be lower (or higher) than that value, 3) Interval methods; For example, choose a value of the emission factor such that it is equally likely that the true emission factor would be higher or lower than that value. This yields the median. Then divide the lower range into two bins such that there is assumed to be equally likely (25% probability) that the emission factor could be in either bin. Repeat this for the other end of the distribution. Finally, either fixed probability or fixed value methods could be used to get judgements for extreme values, 4) Graphing; the expert draws a distribution. This should be used cautiously because some experts are overconfident about their knowledge of PDFs.

Sometimes the only available expert judgement consists of a range, maybe quoted together with a most likely value. Under these circumstances the following rules are considered good practice: Where experts only provide an upper and a lower value, assume that the PDF is uniform and that the range corresponds to the 95 per cent confidence interval. Where experts also provide a most likely value (point estimate), assume a triangular PDF using the most likely values as the mode and assume that the upper and lower values each exclude 2.5% of the population. The distribution needs not to be symmetrical. Normal or log-normal distributions can be used given appropriate justifications.

Concluding remarks and planned improvements

Tier 2 uncertainties are typically found to be greater than Tier 1 uncertainties. When large input uncertainties, e.g. > 10%, are used, the deviation becomes pronounced. For smaller input uncertainties, e.g. < 1%, Tier 1 approximates Tier 2 calculations.

The Log-normal distribution was selected due the likely conditions for the distribution as being close to a normal distribution for smaller uncertainties on one hand and close to the understanding of larger uncertainties on the other hand. However, in case of larger uncertainty the outcome of the MC analysis includes rather extreme values that in some cases are unrealistic. The method therefore allows for truncation of input uncertainties, either a lower boundary, upper boundary or both, depending of which truncation are most realistic.

1.7.4 Results of the tier 2 uncertainty estimation

Tier 2 uncertainty results for sectors and categories are shown in Table 1.3. The input uncertainties for activity data and emission factors stated in Table 1.3 are used both in Tier 1 and Tier 2 uncertainty calculations. The total Danish net GHG emission for 2012 is estimated with an uncertainty of +6.7 % and -4.5 % and the trend in net GHG emission since 1990 is estimated with an uncertainty of +9.2 and -7.4 %-age points.

Tier 2 uncertainties are typically larger than Tier 1 uncertainties when input uncertainties are larger than approximately 25%, which corresponds to the model domain of Tier 1 method. This implies that the Tier 2 method is more reliable for large input uncertainties.

1.8 General assessment of the completeness

The present Danish greenhouse gas emission inventory includes all major sources identified by the Revised 1996 IPPC Guidelines. Please see Annex 5 for detailed discussion on minor sources that are not included.

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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 the trends are very similar in fact close to identical. A trend discussion of the aggregated greenhouse gas emissions from Denmark and Greenland is included in Chapter 17.1.

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 seven main sectors. The greenhouse gases include CO_2, CH_4, N_2O, HFCs, PFCs and SF_6. Figure 2.1 shows the estimated total greenhouse gas emissions in CO_2 equivalents from 1990 to 2012. The emissions are not corrected for electricity trade or temperature variations. CO_2 is the most important greenhouse gas contributing in 2012 to the national total in CO_2 equivalents excluding LULUCF (Land Use and Land Use Change and Forestry) with 76.3 % followed by N_2O with 11.5 %, CH_4 10.6 % and F-gases (HFCs, PFCs and SF_6) with 1.5 %. Seen over the time-series from 1990 to 2012 these percentages have been increasing for CH_4 and F-gases, and decreasing for N_2O. The percentages for CO_2 show larger fluctuations during the time series. Stationary combustion plants, Transport and Agriculture represent the largest contributing categories to emissions of greenhouse gases, followed by Industrial processes, Waste, fugitive emissions and Solvents, see Figure 2.1. The net CO_2 uptake by LULUCF in 2012 is 1.6 % of the total emission in CO_2 equivalents excl. LULUCF. The national total greenhouse gas emission in CO_2 equivalents excluding LULUCF has decreased by 24.8 % from 1990 to 2012 and decreased 31.3 % including LULUCF. From 2011 to 2012 the total greenhouse gas emission excluding LULUCF decreased by 8.6 %. The decrease is mainly caused by decreasing emissions from the energy sector due to increasing import of electricity and increasing production of wind power. Comments on the overall trends etc. seen in Figure 2.1 are given in the sections below on the individual greenhouse gases.

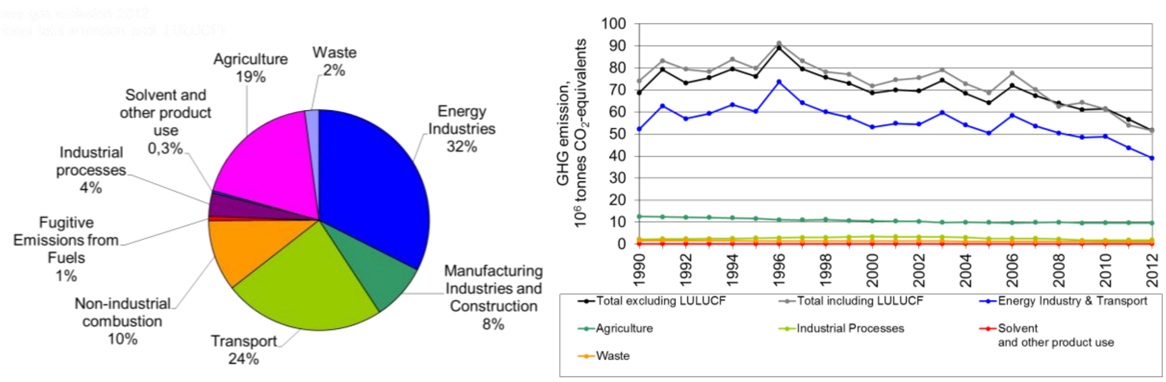


Figure 2.1 Greenhouse gas emissions in CO_2 equivalents distributed on main sectors for 2012 (excluding LULUCF) and time series for 1990 to 2012 (including LULUCF).

2.2 Description and interpretation of emission trends by gas

2.2.1 Carbon dioxide

The largest source of the emission of CO_2 is the energy sector, which includes the combustion of fossil fuels such as oil, coal and natural gas (Figure 2.2). Energy Industries contribute with 42.0 % of the emissions (excl. LULUCF). About 31 % come from the transport sector. The CO_2 emission (excl. LULUCF) decreased by 10.5 % from 2011 to 2012. The main reason for this decrease owe to decreasing fuel consumption, mainly for coal and natural gas. The decrease partly owe to increasing import of electricity and increasing production of wind power. In 2012, the actual CO_2 emission (incl. LULUCF) was 33.7 % less than the emission in 1990.

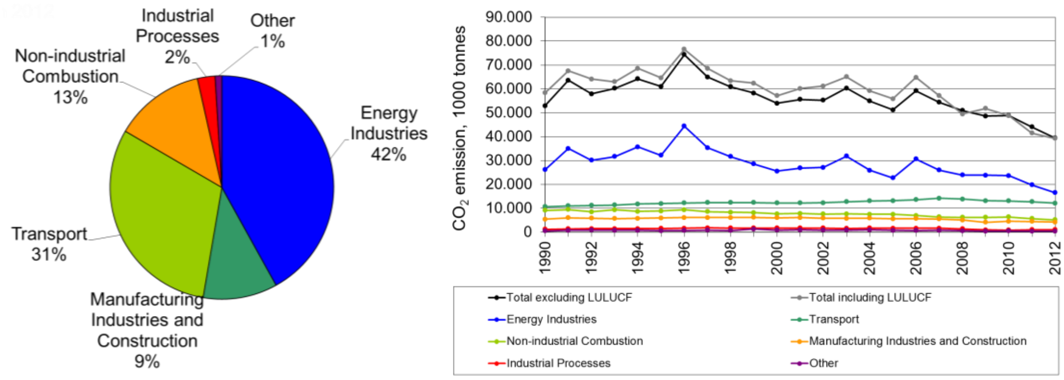


Figure 2.2 CO_2 emissions. Distribution according to the main sectors (2012) and time series for 1990 to 2012.

2.2.2 Nitrous oxide

Agriculture is the most important N_2O emission source in 2012 contributing 90.7 % (Figure 2.3) of which N_2O from agricultural soils accounts for 92.8 %. N_2O is emitted as a result of microbial processes in the soil. Substantial emissions also 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 nitrogen fertilisers. The main reason for the drop in the emissions of N_2O in the agricultural sector of 34.9 % from 1990 to 2012 is legislation to improve the utilisation of nitrogen in manure. The legislation has resulted in less nitrogen excreted per unit of livestock produced and a considerable reduction in the use of nitrogen fertilisers. The basis for the N_2O emission is then reduced. Combustion of fossil fuels in the energy sector, both stationary and mobile sources, contributes 5.8 %. The N_2O emission from transport contributed with 2.5 % in 2012. This emission has increased during the nineties because of the increase in the use of catalyst cars. Production of nitric acid stopped in 2004 and the emissions from industrial processes is therefore not occurring from 2005 onwards. The sector Solvent and Other Product Use covers N_2O from e.g. anaesthesia.

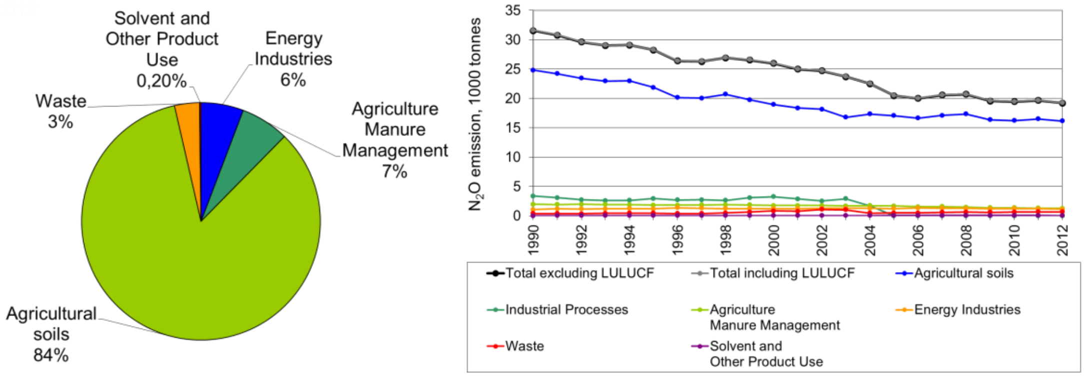


Figure 2.3 N_2O emissions. Distribution according to the main sectors (2012) and time series for 1990 to 2012.

2.2.3 Methane

The largest sources of anthropogenic CH_4 emissions are agricultural activities contributing in 2012 with 76.5 %, waste (15.8 %), public power and energy industries (2.5 %), see Figure 2.4. The emission from agriculture derives from enteric fermentation and management of animal manure contributing with 52.9 % and 23.6 % of the national CH_4 emission excl. LULUCF in 2012. The CH_4 emission from public power and district heating plants increased in the nineties, mainly 1992-1996, due to the increasing use of gas engines in the decentralised cogeneration plant sector. Up to 3 % of the natural gas in the gas engines is not combusted. The deregulation of the electricity market has made production of electricity in gas engines less favourable, therefore the fuel consumption has decreased and hence the CH_4 emission has decreased. Over the time series from 1990 to 2012, the emission of CH_4 from enteric fermentation has decreased 10.6 % due to the decrease in the number of cattle. However, the emission from manure management has in the same period increased 31.7 % due to a change in traditional stable systems towards an increase in slurry-based stable systems. Altogether, the emission of CH_4 from the agriculture sector has decreased by 0.7 % from 1990 to 2012. The emission of CH_4 from solid waste disposal has decreased 48.9 % since 1990 due to an increase in the incineration of waste and hence a decrease in the waste being deposited at landfills and a ban on depositing waste fit for incineration.

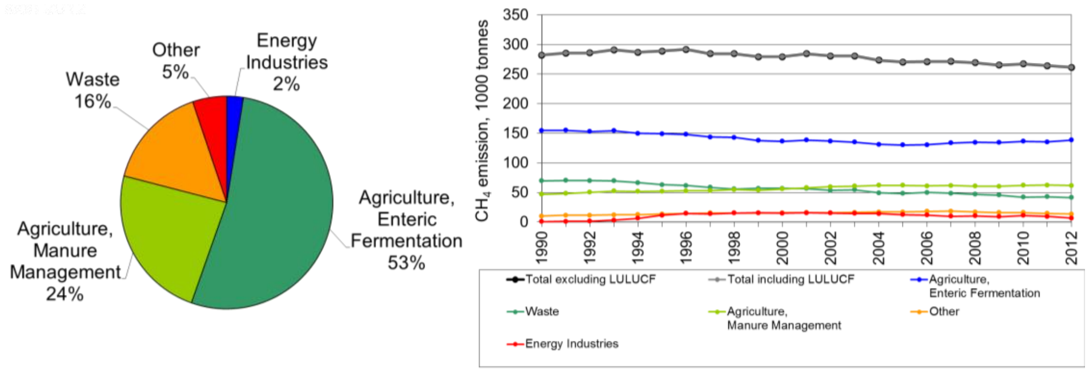


Figure 2.4 CH_4 emissions. Distribution according to the main sectors (2012) and time series for 1990 to 2012.

2.2.4 HFCs, PFCs and SF_6

This part of the Danish inventory only comprises a full data set for all substances from 1995. From 1995 to 2000, there has been a continuous and substantial increase in the contribution from the range of F-gases as a whole, calculated as the sum of emissions in CO_2 equivalents, see Figure 2.5. This increase is simultaneous with the increase in the emission of HFCs. For the time series 2000-2012, the increase is lower than for the years 1995 to 2000. The increase from 1995 to 2012 for the total F-gas emission is 140.7 %, while emissions decreased from 2011 to 2012 by 7.0 % mainly due to decreasing emissions of HFCs. SF_6 contributed considerably to the F-gas sum in earlier years, with 33 % in 1995. Environmental awareness and regulation of this gas under Danish law has reduced its use in industry, see Figure 2.5. A further result is that the contribution of SF_6 to F-gases in 2012 was only 15.0 %. The use of HFCs has increased several folds. HFCs have, therefore, become even more dominant, comprising 66.9 % in 1995, but 83.9 % in 2012. HFCs are mainly used as a refrigerant. 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 is still allowed. The use of air conditioning in mobile systems and the amount of HFC for this purpose increases.

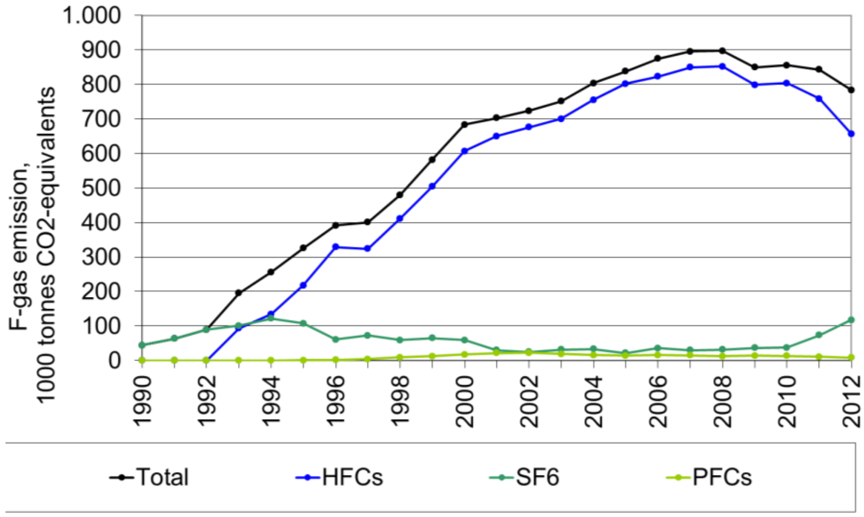


Figure 2.5 F-gas emissions. Time series for 1990 to 2012.

2.3 Description and interpretation of emission trends by source

2.3.1 Energy

The emission of CO_2 from Energy Industries has decreased by 36.8 % from 1990 to 2012. The relatively large fluctuation in the emission is due to inter-country electricity trade. Thus, the high emissions in 1991, 1994, 1996, 2003 and 2006 reflect a large electricity export and the low emissions in 1990, 1992, 2005, 2008, 2011 and 2012 are due to a large import of electricity. The large decrease from 2011 to 2012 owe to decreasing fuel consumption, mainly for coal and natural gas. The decrease is mainly caused by decreasing emissions from fuel combustion due to increasing import of electricity and increasing production of wind power.

The increasing emission of CH_4 during the nineties is due to the increasing use of gas engines in decentralised cogeneration plants. The CH_4 emissions from this sector have been decreasing since 2001 due to the liberalisation of the electricity market. The CO_2 emission from the transport sector increased by 14.0 % from 1990 to 2012, mainly due to increasing emissions from road traffic.

2.3.2 Industrial processes

The emissions from industrial process, i.e. emissions from processes other than fuel combustion, amount in 2012 to 2.6 % of the total emission in CO_2 equivalents (excl. LULUCF). The main sources are cement production, refrigeration, foam blowing and calcination of limestone. The CO_2 emission from cement production – which is the largest source contributing in 2012 with 1.7 % of the national total – decreased by 1.3 % from 1990 to 2012. The second largest source has previously been N_2O from the production of nitric acid. However, the production of nitric acid/fertiliser ceased in 2004 and therefore the emission of N_2O also ceased. The total emission in CO_2 equivalents has decreased by 3.3 % from 2011 to 2012 due to decreasing F-gas emissions, especially of HFCs. This follows the recent trend in emissions of HFCs caused by the legislation banning certain uses.

2.3.3 Agriculture

The agricultural sector contributes in 2012 with 18.6 % of the total greenhouse gas emission in CO_2 equivalents (excl. LULUCF) and is the most important sector regarding the emissions of N_2O and CH_4. In 2012, the contribution of N_2O and CH_4 to the total emission of these gases was 90.5 % and 76.6 %, respectively. The N_2O emission from agriculture decreased by 34.9 % and the CH_4 emission including field burning and reduction of biogas decreased by 0.7 % from 1990 to 2012. The CH_4 emission has decreased by 1.3 % from 2011 to 2012, while the N_2O emission has increased by 0.3 %.

2.3.4 Forestry

The trend in CO_2 uptake from forests varies greatly due to several factors both relating to weather and other effects. The calculations for 2012 estimates the Danish forests to be a large sink of 4 441 Gg CO_2 equivalents.

The area of forests established before 1990 has decreased by 1 % from 1990 to 2012, leading to a decrease of the carbon stock. From 2011 to 2012 the area has decreased by 364 ha, leading to an emission of 4 491 Gg. The area of afforestation for the years 1990-2012 is 94 kha and the area of deforestation for the years 1990-2012 is 5.8 kha.

2.3.5 Cropland, Grassland and Wetlands

The carbon stock change for organic soils has been estimated to 540 Gg C in 2012. For the same year the total emission from Cropland is estimated to 2995 Gg CO_2.

Grassland is estimated to have an emission of 554 Gg CO_2 equivalents in 2012, which is an increase since 1990, where the emission from grassland is estimated to 184 Gg CO_2 equivalents.

Emissions from managed wetlands with peat extraction are at a low level for all years in the time series. In 2012 the emission from wetlands was 2.3 Gg CO_2 equivalents. In 1990 the estimated emission is 88 Gg equivalents.

The overall trend in the LULUCF sector without Forestry is a decrease of 30 % since 1990.

2.3.6 Waste

The waste sector contributes in 2012 with 2.1 % to the national total of greenhouse gas emissions (excl. LULUCF), 15.7 % of the total CH_4 emission and 3.4 % of the total N_2O emission. In 2012 the contribution of CH_4 from SWDS was 12.7 % of the total CH_4 emission. The CH_4 emission from WW amounts in 2012 to 1.3 % of the total CH_4 emissions. The emission of N_2O from WW in 2012 is 1.2 % of national total of N_2O. Since all incinerated waste is used for power and heat production, the emissions are included in the 1A CRF category.

The emission in CO_2 equivalents has decreased by 2.9 % from 2011 to 2012 mainly due to decreasing CH_4 emissions from solid waste disposal on land. The GHG emission from the sector has decreased by 32.4 % from 1990 to 2012. This decrease is a result of (1) a decrease in the CH_4 emission from solid waste disposal sites (SWDS) by 48.9 % due to the increasing use of waste for power and heat production, and (2) a decrease in emission of N_2O from wastewater (WW) handling systems of 30.6 % due to upgrading of WW treatment plants. These decreases are counteracted by an increase in CH_4 from WW of 13.0 % due to increasing industrial load to WW systems. The emission in CO_2 equivalents has decreased by 2.9 % from 2011 to 2012.

2.4 Description and interpretation of emission trends for indirect greenhouse gases and SO_2

2.4.1 NO_x

The largest sources of emissions of Nitrogen oxide (NO_x) are road transport followed by other mobile sources and combustion in energy industries (mainly public power and district heating plants). The transport sector is the sector contributing the most to the emission of NO_x and, in 2012, 49 % of the Danish emissions of NO_X stems from road transport, national navigation, railways and civil aviation. Also emissions from national fishing and off-road vehicles contribute significantly to the NO_x emission. For non-industrial combustion plants, the main sources are combustion of gas oil, natural gas and wood in residential plants. The emissions from energy industries have decreased by 76.9 % from 1990 to 2012. In the same period, the total emission decreased by 58.3 %. The reduction is due to the increasing use of catalyst cars and installation of low-NO_x burners and denitrifying units in power plants and district heating plants.

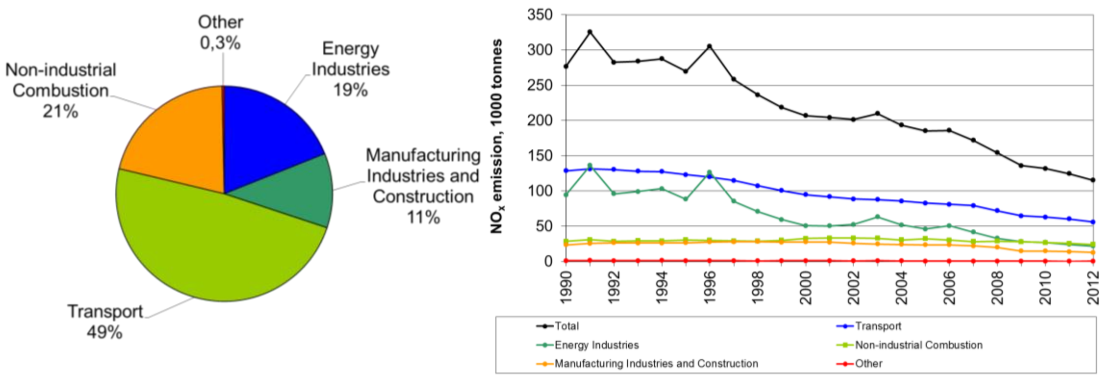


Figure 2.6 NO_X emissions. Distribution according to the main sectors (2012) and time series for 1990 to 2012.

2.4.2 CO

Non-industrial combustion plants and transport are by far the major contributors to the total emission of this pollutant with 63.5 % and 28.4 % of the total CO emission. The total CO emission decreased by 50.8 % from 1990 to 2012, largely because of decreasing emissions from road transportation due to the introduction of private catalyst cars in 1990 and the introduction of even more emission efficient private cars in the following years.

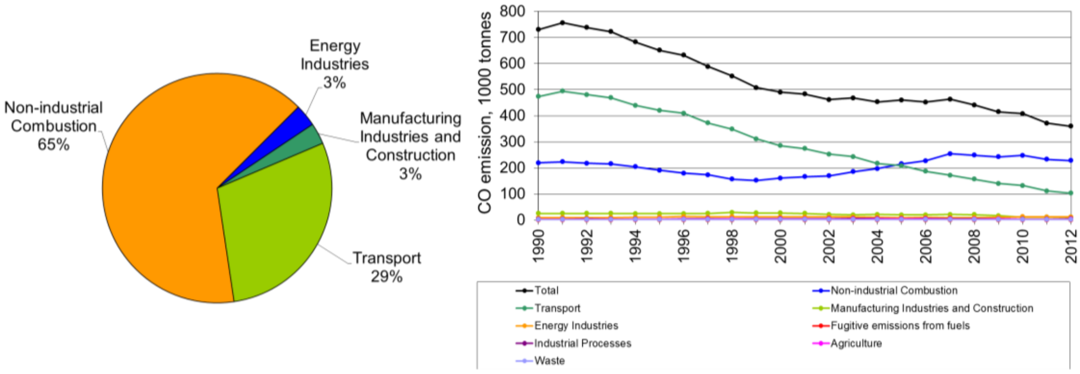


Figure 2.7 CO emissions. Distribution according to the main sectors (2012) and time series for 1990 to 2012.

2.4.3 NMVOC

The emissions of NMVOC originate from many different sources and can be divided into two main groups: incomplete combustion and evaporation.

In the nineties road vehicles and other mobile sources such as national navigation vessels and off-road machinery were the main sources of NMVOC emissions from incomplete combustion processes. Road transportation is still a main contributor even though the emissions have declined since the introduction of catalyst cars in 1990, but since 2006 emissions from non-industrial combustion, mainly residential wood combustion, has been the largest source. In 2012 non-industrial combustion and transport contribute 27.5 % and 14.5 % of the total NMVOC emission.

The evaporative emissions mainly originate from the use of solvents and the extraction, handling and storage of oil and natural gas. The emissions from the energy industries have increased during the nineties due to the increasing use of stationary gas engines, which have much higher emissions of NMVOC than conventional boilers.

The total NMVOC emissions have decreased by 58.7 % from 1990 to 2012, mainly due to the increased use of catalysts in cars and reduced emissions from use of solvents.

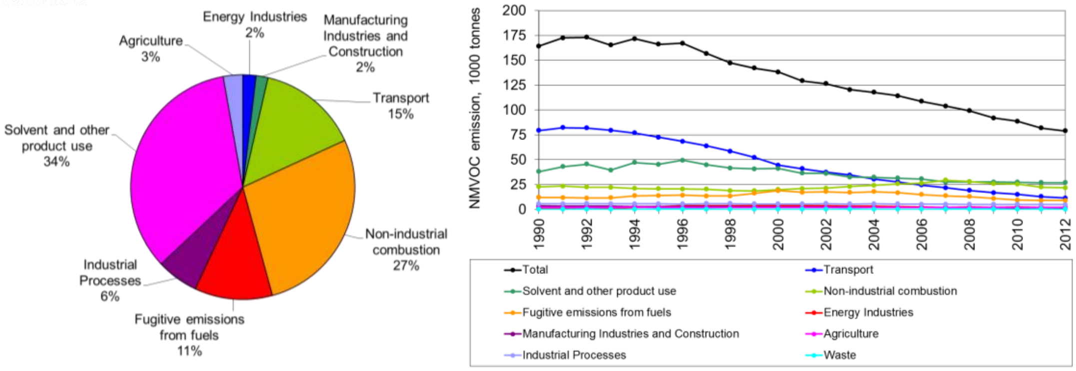


Figure 2.8 NMVOC emissions. Distribution according to the main sectors (2012) and time series for 1990 to 2012.

2.4.4 SO_2

The main part of the SO_2 emission originates from combustion of fossil fuels, i.e. mainly coal and oil, in public power and district heating plants. From 1990 to 2012, the total emission decreased by 93.0 %. The large reduction is mainly due to installation of desulphurisation plant and use of fuels with lower content of sulphur in public power and district heating plants. Despite the large reduction of the SO_2 emissions, these plants make up 24.6 % of the total emission in 2012. Also emissions from industrial combustion plants, non-industrial combustion plants and other mobile sources are important. National sea traffic (navigation and fishing) contributes with about 13.1 % of the total SO_2 emission. This is due to the use of residual oil with high sulphur content.

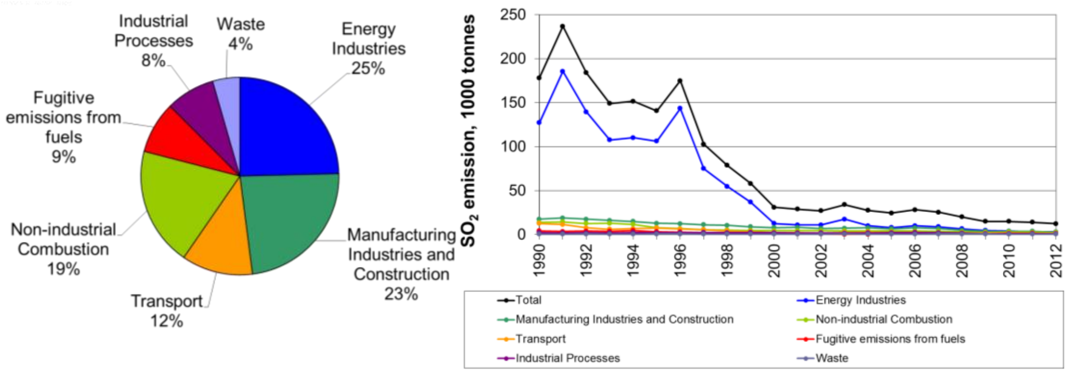


Figure 2.9 SO_2 emissions. Distribution according to the main sectors (2012) and time series for 1990 to 2012.

2.5 Description and interpretation of emission trends for KP-LULUCF inventory in aggregate, by activity and by gas

Coverage relating to reporting of activities under Article 3.3 and selected activities under Article 3.4 are listed in Table 2.1 for reporting concerning change in carbon pool and for greenhouse gas sources. All pools are reported. Carbon stock change in below-ground biomass for Cropland Management and Grazing Land Management under Article 3.4 are included under Above-ground biomass for the same area categories. Fertilisation of forests and other land is negligible and all fertiliser consumption is therefore reported in the agricultural sector. All liming is reported under Cropland because only very limited amounts are used in forestry and on permanent grassland. Field burning of wooden biomass is prohibited in Denmark and therefore reported as not occurring. Wildfires are very seldom and if occurring very small in Denmark.

CO_2 is by far the most important greenhouse gas relating to activities under Article 3.3 and Article 3.4. There is however a minor contribution of N_2O due to Deforestation (0.9 % of GHG from Deforestation in 2012) and Forest Management (0.3 % of GHG from Forest Management in 2012). Additionally, there is a small emission of greenhouse gases from biomass burning of 0.05 Gg CO_2 equivalents in 2012.

Table 2.1 Coverage of reporting of change of carbon pools relating to activities under Article 3.3 and elected activities under Article 3.4.

		Change in carbon pool reported					Greenhouse gas sources reported						
		Above-ground biomass	Below-ground biomass	Litter	Dead wood	Soil	Fertilization	Drainage of soils under forest management	Disturbance associated with land-use conversion to croplands	Liming	Biomass burning		
							N_2O	N_2O	N_2O	CO_2	CO_2	CH_4	N_2O
Article 3.3	Afforestation and Reforestation	R	R	R	R	R	IE			IE	NO	IE	IE
	Deforestation	R	R	R	R	R			R	IE	NO	IE	IE
Article 3.4	Forest Management	R	R	R	R	R	IE	R		IE	NO	R	R
	Cropland Management	R	IE	NO	NO	R			R	R	NO	NO	NO
	Grazing Land Management	R	IE	NO	NO	R				IE	NO	R	R
	Revegetation	NA	NA	NA	NA	NA				NA	NA	NA	NA

R: reported, NR: not reported, IE: included elsewhere, NO: not occurring, NA: not applicable. Biomass burning does not occur in all years and therefore sometimes reported as NO in the CRF.

2.5.1 Forest

The trends in forest in the first commitment period are dependent on both the current structure of the forests and the management actions in the coming years. If similar management is applied as in the previous 15 years a decline in the total carbon stock in the forest is expected. However, for 2008 to 2012 a sink in forest is reported. For the afforestated areas a steady increase in carbon stocks is expected also in the future years. The rate of increase of area will depend on both availability of land and on possible subsidies for afforestation. Deforestation occurs mainly in relation to other specific projects e.g. for nature restoration or test areas for wind turbines.

2.5.2 Cropland, Grassland and Wetlands

The trend for the Cropland Management and Grazing Land Management under KP-LULUCF indicates that there has been a stabilisation of the loss of carbon from agricultural soils compared to previous due to an increased input of organic matter in the soil. However, the loss depends much of the climatic conditions. As a consequence of the global warming, where 18 years out of the last 20 years has been above the average for 1961-1990, it is difficult to avoid substantial losses of carbon from the agricultural soils in the future. The changes in Cropland Management since 1990 have undoubtedly prevented further losses of soil carbon. A further increase in the actual temperature will affect the ability to prevent further losses of soil carbon.

The reestablishment of wetlands on agricultural land is especially targeted towards organic soils, which leads to a decreased emission from these soils. Further reestablishments are expected to take place in the future.

3 Energy (CRF sector 1)

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 8.

The energy sector has been reported in four main chapters:

3.2 Stationary combustion plants (CRF sector 1A1, 1A2 and 1A4)
3.3 Transport (CRF sector 1A2, 1A3, 1A4 and 1A5)
3.4 Additional information on fuel combustion (Reference approach)
3.5 Fugitive emissions (CRF sector 1B)

Though industrial combustion is part of stationary combustion, detailed documentation for some of the specific industries is discussed in the industry chapters. Table 3.1.1 shows detailed source categories for the energy sector and plant category in which the sector is discussed in this report.

Table 3.1.1 CRF energy sectors and relevant NIR chapters.

IPCC id	IPCC sector name	NIR chapter
1	Energy	
1A	Fuel Combustion Activities	
1A1	Energy Industries	
1A1a	Electricity and Heat Production	Stationary combustion
1A1b	Petroleum Refining	Stationary combustion, Fugitive
1A1c	Solid Fuel Transf./Other Energy Industries	Stationary combustion
1A2	Fuel Combustion Activities/Industry (ISIC)	
1A2a	Iron and Steel	Stationary combustion, Industrial processes
1A2b	Non-Ferrous Metals	Stationary combustion, Industrial processes
1A2c	Chemicals	Stationary combustion, Industrial processes
1A2d	Pulp, Paper and Print	Stationary combustion
1A2e	Food Processing, Beverages and Tobacco	Stationary combustion, Industrial processes
1A2f	Other (please specify)	Stationary combustion, Transport, Industrial processes
1A3	Transport	
1A3a	Civil Aviation	Transport
1A3b	Road Transportation	Transport
1A3c	Railways	Transport
1A3d	Navigation	Transport
1A3e	Other (please specify)	NO
1A4	Other Sectors	
1A4a	Commercial/Institutional	Stationary combustion, Transport
1A4b	Residential	Stationary combustion, Transport
1A4c	Agriculture/Forestry/Fishing	Stationary combustion, Transport
1A5	Other (please specify)	
1A5a	Stationary	NO
1A5b	Mobile	Transport
1B	Fugitive Emissions from Fuels	
1B1	Solid Fuels	
1B1a	Coal Mining	NO
1B1a1	Underground Mines	NO
1B1a2	Surface Mines	NO
1B1b	Solid Fuel Transformation	NO
1B1c	Other (please specify)	NO
1B2	Oil and Natural Gas	
1B2a	Oil	Fugitive
1B2a2	Production	Fugitive
1B2a3	Transport	Fugitive
1B2a4	Refining/Storage	Fugitive
1B2a5	Distribution of oil products	Fugitive
1B2a6	Other	NO
1B2b	Natural Gas	Fugitive
1B2b1	Production/processing	Fugitive

Continued		
1B2b2	Transmission/distribution	Fugitive
1B2c	Venting and Flaring	Fugitive
1B2c1	Venting and Flaring Oil	Fugitive
1B2c2	Venting and Flaring Gas	Fugitive
1B2d	Other	NO

Summary tables for the energy sector are shown below.

Table 3.1.2 CO_2 emissions from the energy sector.

Greenhouse gas source categories	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
					(Gg)					
1. Energy	51,630	62,133	56,287	58,596	62,548	59,342	72,554	63,058	59,015	56,436
A. Fuel Combustion (Sectoral Approach)	51,303	61,487	55,621	58,017	61,979	58,893	72,061	62,363	58,500	55,343
1. Energy Industries	26,146	35,015	30,086	31,662	35,723	32,168	44,432	35,320	31,677	28,588
2. Manufacturing Industries and Construction	5,444	5,975	5,837	5,702	5,786	5,909	6,058	6,110	6,129	6,219
3. Transport	10,619	11,002	11,201	11,321	11,803	11,940	12,189	12,381	12,353	12,373
4. Other Sectors	8,976	9,209	8,355	9,094	8,414	8,623	9,206	8,382	8,137	7,980
5. Other	119	287	141	237	252	252	176	171	204	182
B. Fugitive Emissions from Fuels	327	645	666	580	570	449	494	695	515	1,094
1. Solid Fuels	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO
2. Oil and Natural Gas	327	645	666	580	570	449	494	695	515	1,094

Continued	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
					(Gg)					
1. Energy	52,083	53,756	53,349	58,605	53,015	49,430	57,362	52,594	49,406	47,508
A. Fuel Combustion (Sectoral Approach)	51,363	52,986	52,702	57,936	52,263	48,888	56,830	52,050	49,014	47,243
1. Energy Industries	25,554	26,852	27,071	31,815	25,933	22,731	30,644	26,006	23,890	23,823
2. Manufacturing Industries and Construction	6,016	6,107	5,816	5,780	5,836	5,551	5,672	5,519	5,061	4,111
3. Transport	12,173	12,184	12,282	12,738	13,047	13,166	13,544	14,161	13,860	13,135
4. Other Sectors	7,509	7,745	7,444	7,511	7,209	7,168	6,843	6,188	6,096	6,014
5. Other	111	97	89	92	239	271	126	175	108	160
B. Fugitive Emissions from Fuels	720	770	647	670	752	543	532	544	392	265
1. Solid Fuels	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO
2. Oil and Natural Gas	720	770	647	670	752	543	532	544	392	265

Continued	**2010**	**2011**	**2012**
		(Gg)	
1. Energy	47,891	42,856	38,244
A. Fuel Combustion (Sectoral Approach)	47,533	42,600	38,023
1. Energy Industries	23,625	19,746	16,531
2. Manufacturing Industries and Construction	4,524	4,494	4,235
3. Transport	13,068	12,703	12,103
4. Other Sectors	6,209	5,465	5,038
5. Other	107	193	116
B. Fugitive Emissions from Fuels	357	256	221
1. Solid Fuels	NA,NO	NA,NO	NA,NO
2. Oil and Natural Gas	357	256	221

Table 3.1.3 CH_4 emissions from the energy sector.

Greenhouse gas source categories	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
					(Gg)					
1. Energy	10.82	12.34	12.81	15.12	18.66	24.98	29.09	29.05	30.45	30.74
A. Fuel Combustion (Sectoral Approach)	8.71	9.71	10.32	12.40	15.65	21.52	25.76	25.47	26.92	26.85
1. Energy Industries	0.68	1.03	1.44	3.05	6.13	11.47	14.64	13.97	15.34	15.45
2. Manufacturing Industries and Construction	0.36	0.38	0.36	0.37	0.37	0.42	0.79	0.79	0.89	0.88
3. Transport	2.28	2.38	2.39	2.38	2.36	2.28	2.21	2.14	2.07	1.96
4. Other Sectors	5.38	5.90	6.11	6.59	6.78	7.33	8.12	8.55	8.61	8.55
5. Other	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
B. Fugitive Emissions from Fuels	2.11	2.63	2.49	2.73	3.01	3.46	3.33	3.58	3.53	3.89
1. Solid Fuels	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO
2. Oil and Natural Gas	2.11	2.63	2.49	2.73	3.01	3.46	3.33	3.58	3.53	3.89

Continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
					(Gg)					
1. Energy	30.42	31.45	30.90	30.62	31.22	29.58	29.59	27.83	27.25	24.88
A. Fuel Combustion (Sectoral Approach)	26.41	27.17	26.59	26.21	25.98	24.37	23.07	21.53	21.21	19.24
1. Energy Industries	14.74	15.64	15.22	14.49	14.18	12.55	11.64	9.72	10.25	8.98
2. Manufacturing Industries and Construction	1.08	1.11	0.99	0.97	0.96	0.84	0.76	0.55	0.60	0.55
3. Transport	1.83	1.72	1.62	1.54	1.44	1.32	1.22	1.12	0.96	0.82
4. Other Sectors	8.75	8.70	8.76	9.20	9.39	9.65	9.45	10.13	9.40	8.88
5. Other	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.01
B. Fugitive Emissions from Fuels	4.02	4.27	4.30	4.41	5.24	5.21	6.52	6.30	6.05	5.64
1. Solid Fuels	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO
2. Oil and Natural Gas	4.02	4.27	4.30	4.41	5.24	5.21	6.52	6.30	6.05	5.64

Continued	2010	2011	2012
		(Gg)	
1. Energy	26.92	23.82	20.18
A. Fuel Combustion (Sectoral Approach)	21.60	18.54	15.14
1. Energy Industries	11.17	9.42	6.61
2. Manufacturing Industries and Construction	0.62	0.58	0.44
3. Transport	0.74	0.66	0.58
4. Other Sectors	9.07	7.87	7.50
5. Other	0.00	0.01	0.00
B. Fugitive Emissions from Fuels	5.32	5.28	5.05
1. Solid Fuels	NA,NO	NA,NO	NA,NO
2. Oil and Natural Gas	5.32	5.28	5.05

Table 3.1.4 N_2O emissions from the energy sector.

Greenhouse gas source categories	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
					(Gg)					
1. Energy	1.05	1.18	1.14	1.16	1.20	1.19	1.35	1.28	1.23	1.23
A. Fuel Combustion (Sectoral Approach)	1.04	1.17	1.14	1.16	1.19	1.19	1.35	1.28	1.22	1.22
1. Energy Industries	0.28	0.36	0.32	0.35	0.38	0.36	0.49	0.42	0.38	0.38
2. Manufacturing Industries and Construction	0.18	0.19	0.19	0.17	0.16	0.15	0.15	0.15	0.15	0.15
3. Transport	0.36	0.37	0.39	0.40	0.42	0.44	0.46	0.47	0.47	0.47
4. Other Sectors	0.23	0.24	0.23	0.24	0.23	0.23	0.23	0.22	0.21	0.21
5. Other	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.01
B. Fugitive Emissions from Fuels	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01
1. Solid Fuels	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO
2. Oil and Natural Gas	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01

Continued	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
					(Gg)					
1. Energy	1.20	1.22	1.23	1.29	1.24	1.22	1.31	1.28	1.25	1.20
A. Fuel Combustion (Sectoral Approach)	1.19	1.22	1.23	1.29	1.23	1.22	1.31	1.27	1.24	1.19
1. Energy Industries	0.36	0.37	0.38	0.42	0.37	0.33	0.40	0.34	0.33	0.33
2. Manufacturing Industries and Construction	0.15	0.14	0.14	0.13	0.13	0.12	0.15	0.14	0.14	0.11
3. Transport	0.46	0.46	0.46	0.47	0.48	0.47	0.47	0.48	0.47	0.44
4. Other Sectors	0.23	0.24	0.24	0.26	0.25	0.28	0.29	0.30	0.31	0.30
5. Other	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.01
B. Fugitive Emissions from Fuels	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
1. Solid Fuels	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO
2. Oil and Natural Gas	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00

Continued	2010	2011	2012
		(Gg)	
1. Energy	1.23	1.17	1.11
A. Fuel Combustion (Sectoral Approach)	1.23	1.17	1.10
1. Energy Industries	0.35	0.31	0.28
2. Manufacturing Industries and Construction	0.13	0.12	0.12
3. Transport	0.44	0.44	0.42
4. Other Sectors	0.31	0.29	0.28
5. Other	0.00	0.01	0.00
B. Fugitive Emissions from Fuels	0.00	0.00	0.00
1. Solid Fuels	NA,NO	NA,NO	NA,NO
2. Oil and Natural Gas	0.00	0.00	0.00

3.2 Stationary combustion (CRF sector 1A1, 1A2 and 1A4)

Stationary combustion is the largest source of CO_2 emission in Denmark accounting for 58 % of the national total CO_2 emissions (excl. LULUCF) in 2012. The CO_2 emission from stationary combustion has decreased by 15 % since 2011 and decreased by 40 % since 1990. The decreased emission since 1990 is a result of a change of fuels; the consumption of coal has decreased whereas the consumption of natural gas and biomass has increased since 1990. The relatively large fluctuations in the CO_2 emission time series from 1990 to 2012 are due to inter-country electricity trade fluctuations caused mainly by variation in hydropower generation in Norway and Sweden. The

CO_2 emission in 2012 was lower than in 2011 due to a higher electricity import in 2012 than in 2011.

The methane (CH_4) emission from stationary combustion plants accounted for 5 % of the national CH_4 emission in 2012. The CH_4 emission from stationary combustion has increased by a factor of 2.3 since 1990. This results from the considerable number of lean-burn gas engines installed in CHP plants in Denmark during the 1990s. 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 2012 was 19 % lower than in 2011 due to lower fuel consumption in gas engines.

The nitrous oxide (N_2O) emission from stationary combustion plants accounted for 3 % of the national N_2O emission in 2012. The N_2O emission from stationary combustion has increased by 2 % since 1990, but as for CO_2, fluctuations in emission level due to electricity import/export are considerable. The emission in 2012 was 7 % lower than in 2011 as a result of the higher electricity import in 2012.

3.2.1 Source category description

Source category definition

Stationary combustion plants are included in the emission source subcategories to *Energy*, *Fuel combustion*:

- 1A1 Energy Industries.
- 1A2 Manufacturing Industries and Construction.
- 1A4 Other Sectors.

However, the emission source categories *1A2 Manufacturing Industries and Construction* and *1A4 Other Sectors* also include emissions from mobile combustion. The emission source category *Manufacturing Industries and Construction* includes emissions from non-road machinery reported separately in the CRF. The emission source *1A4* also includes non-road machinery and in the CRF, the emissions from stationary and mobile sources have been reported together.

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 source category. The CRF source category codes have been applied unchanged, but some source category names have been changed to reflect the stationary combustion element of the source.

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 1996 IPCC Guidelines (IPCC, 1997).

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 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 IPCC tier 2 emission factors.
- Tier 3: Based on plant specific emission data or on a country specific emission factor based on a considerable number of plant specific emission measurements and detailed technology knowledge.

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, tier 1/tier 2, level/trend).

Table 3.2.1 Methodology and type of emission factor.

		Tier	EMF[1)]	Key category[2)]
Stationary Combustion, Coal	CO_2	Tier 3[2] (Tier 3) /Tier 1[3]	PS (CS) / D	Yes
Stationary Combustion, BKB	CO_2	Tier 1	D	No
Stationary Combustion, Coke	CO_2	Tier 1	D	No
Stationary Combustion, Fossil waste	CO_2	Tier 3	CS	Yes
Stationary Combustion, Petroleum coke	CO_2	Tier 3	PS/CS	Yes
Stationary Combustion, Residual oil	CO_2	Tier 3 / Tier 3 / Tier 1	PS / CS / D[4]	Yes
Stationary Combustion, Gas oil	CO_2	Tier 2 / Tier 3	CR / PS	Yes
Stationary Combustion, Kerosene	CO_2	Tier 1	D	Yes
Stationary Combustion, LPG	CO_2	Tier 1	D	No
Stationary Combustion, Refinery gas	CO_2	Tier 3	PS / CS	Yes
Stationary Combustion, Natural gas	CO_2	Tier 3	CS / PS[5]	Yes
Stationary Combustion, SOLID	CH_4	Tier 2 / Tier 1	D(2) / D	No
Stationary Combustion, LIQUID	CH_4	Tier 2 / Tier 2 / Tier 1	D(2) / CS / D	No
Stationary Combustion, GAS	CH_4	Tier 2 / Tier 3	D(2) / CS	No
Natural gas fuelled engines, GAS	CH_4	Tier 3	CS	Yes
Stationary Combustion, WASTE	CH_4	Tier 2	CS	No
Stationary Combustion, BIOMASS	CH_4	Tier 2 / Tier 1	D(2) / CS / D	Yes
Biogas fuelled engines, BIOMASS	CH_4	Tier 3	CS	No
Stationary Combustion, SOLID	N_2O	Tier 2 / Tier 1	CS / D	Yes
Stationary Combustion, LIQUID	N_2O	Tier 2 / Tier 1	D(2) / D / CS	Yes
Stationary Combustion, GAS	N_2O	Tier 1 / Tier 2	D / CS / D(2)	Yes
Stationary Combustion, WASTE	N_2O	Tier 2	CS	No
Stationary Combustion, BIOMASS	N_2O	Tier 1 / Tier 2	D / CS / D(2)	Yes

1) D: IPCC tier 1, D(2): IPCC tier 2/3, CR: Corinair default, CS: Country specific, PS: Plant specific.
2) KCA tier 1 or tier 2 for Denmark (excluding Greenland and Faroe Islands), including LULUCF, level 1990/ level 2012/ trend.

1 Key category according to the KCA tier 1 or tier 2 for Denmark (excluding Greenland and Faroe Islands), including LULUCF, level 1990/ level 2012/ trend.
2 For 2006 onwards. Country specific emission factors and tier 2 have been applied for 1990-2005.
3 Tier 1 and IPCC default emission factor is only applied for 2 % of the coal consumption in 2012.
4 Residual oil not applied in source category 1A1a.
5 Off shore gas turbines and some power plants.

The CO_2 emission factor for kerosene is a default emission factor referring to guidelines. Since the source category is a key category the emission factor will have to be revised prior to the 2015 emission inventory.

Key Categories

Key Category Analysis (KCA) tier 1 and 2 for year 1990, 2012 and trend for Denmark has been carried out in accordance with the IPCC Good Practice Guidance (IPCC, 2000) and IPCC Guidelines (IPCC, 2006). Table 3.2.2 shows which of the stationary combustion source categories that are 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 for all the major fuels. In addition, CH_4 from combustion of biomass emission is a key category in the tier 2 KCA. Due to the relatively high uncertainty for N_2O, emission factors the N_2O emission from solid, liquid, gaseous and biomass fuels are key categories in the tier 2 analysis.

Table 3.2.2 Key categories[6], stationary combustion.

			Tier 1			Tier 2		
			1990	2012	1990-2012	1990	2012	1990-2012
Energy	Stationary Combustion, Coal	CO_2	Level	Level	Trend	Level	Level	Trend
Energy	Stationary Combustion, BKB	CO_2						
Energy	Stationary Combustion, Coke	CO_2						
Energy	Stationary Combustion, Fossil waste	CO_2	Level	Level	Trend		Level	Trend
Energy	Stationary Combustion, Petroleum coke	CO_2	Level	Level	Trend			
Energy	Stationary Combustion, Residual oil	CO_2	Level	Level	Trend			
Energy	Stationary Combustion, Gas oil	CO_2	Level	Level	Trend	Level		Trend
Energy	Stationary Combustion, Kerosene	CO_2	Level		Trend			
Energy	Stationary Combustion, LPG	CO_2						
Energy	Stationary Combustion, Refinery gas	CO_2	Level	Level	Trend			
Energy	Stationary Combustion, Natural gas	CO_2	Level	Level	Trend			Trend
Energy	Stationary Combustion, SOLID	CH_4						
Energy	Stationary Combustion, LIQUID	CH_4						
Energy	Stationary Combustion, GAS	CH_4						
Energy	Natural gas fuelled engines, GAS	CH_4						
Energy	Stationary Combustion, WASTE	CH_4						
Energy	Stationary Combustion, BIOMASS	CH_4					Level	Trend
Energy	Biogas fuelled engines, BIOMASS	CH_4						
Energy	Stationary Combustion, SOLID	N_2O				Level	Level	Trend
Energy	Stationary Combustion, LIQUID	N_2O				Level	Level	Trend
Energy	Stationary Combustion, GAS	N_2O					Level	Trend
Energy	Stationary Combustion, WASTE	N_2O						
Energy	Stationary Combustion, BIOMASS	N_2O				Level	Level	Trend

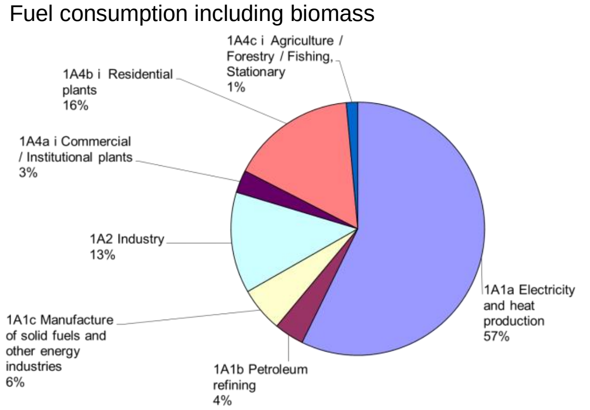
3.2.2 Fuel consumption data

In 2012, the total fuel consumption for stationary combustion plants was 439 PJ of which 310 PJ was fossil fuels and 129 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 majority - 57 % - of all fuels is combusted in the source category, *Public electricity and heat pro-*

[6] For Denmark not including Greenland and Faroe Island.

duction. Other source categories with high fuel consumption are *Residential* and *Industry*.



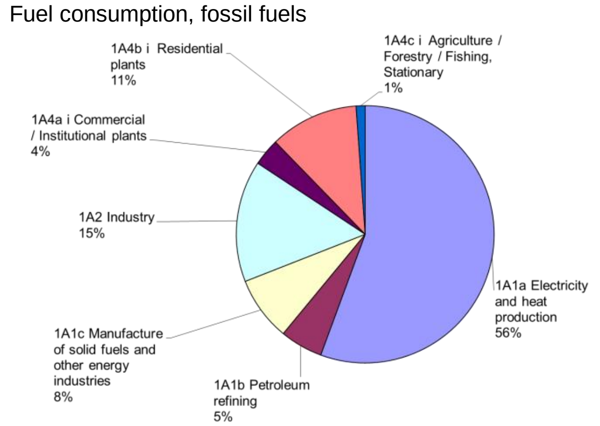


Figure 3.2.1 Fuel consumption of stationary combustion source categories, 2012. Based on DEA (2013a).

Coal, natural gas and wood are the most utilised fuels for stationary combustion plants. Coal is mainly used in power plants and natural gas is used in power plants and decentralised combined heating and power (CHP) plants, as well as in industry, district heating, residential plants and offshore gas turbines (see Figure 3.2.2). Wood is mainly applied for public electricity and heat production and in residential plants.

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

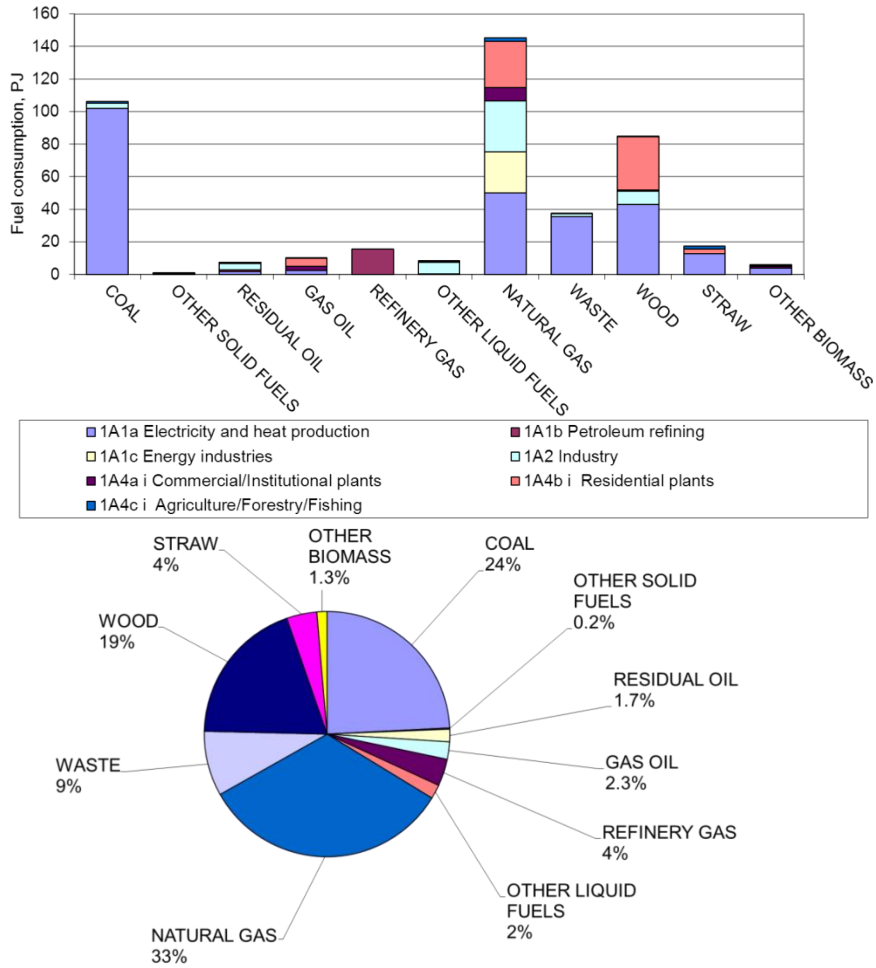


Figure 3.2.2 Fuel consumption of stationary combustion 2012, disaggregated to fuel type. Based on DEA (2013a).

Fuel consumption time series for stationary combustion plants are presented in Figure 3.2.3. The fuel consumption for stationary combustion was 12 % lower in 2012 than in 1990, while the fossil fuel consumption was 32 % lower and the biomass fuel consumption 3.2 times the level in 1990.

The consumption of natural gas, waste and biomass has increased since 1990 whereas coal and oil consumption has decreased.

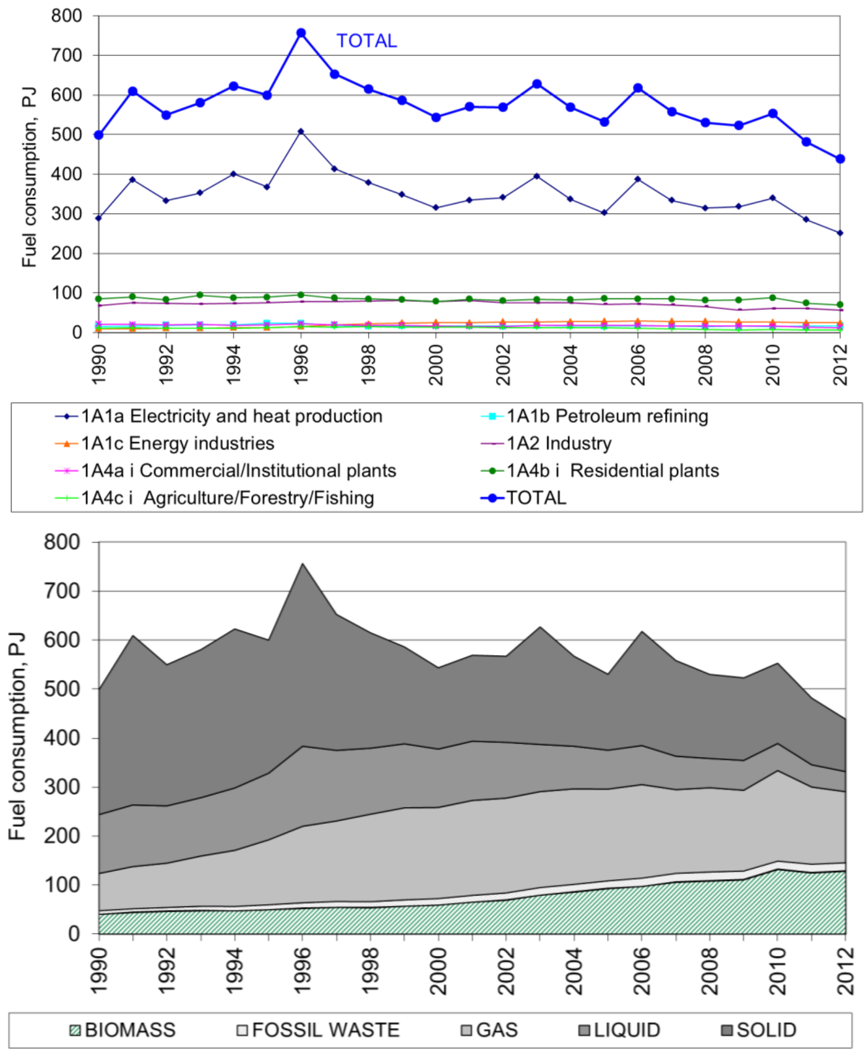


Figure 3.2.3 Fuel consumption time series, stationary combustion. Based on DEA (2013a).

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 electricity import was large causing relatively low fuel consumption, whereas the fuel consumption was high in 1996 due to a large electricity export. In 2012, the net electricity import was 18.8, whereas there was a 4.7 PJ electricity import in 2011. The large 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.

To be able to follow the national energy consumption as well as for statistical and reporting purposes, the Danish Energy Agency (DEA) produces a correction of the actual 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 corrections are included here to explain the fluctuations in the time series for fuel rate and emission.

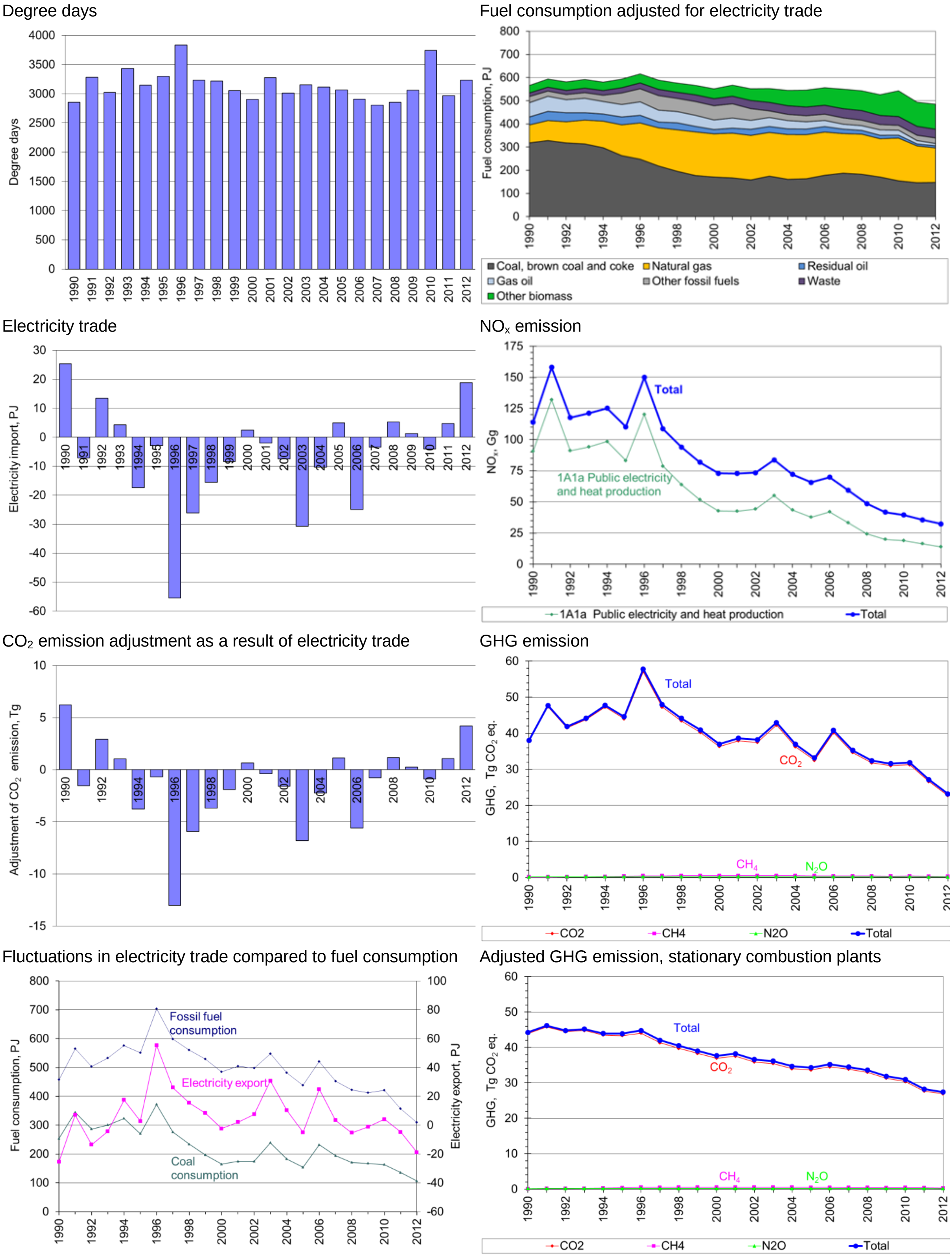


Figure 3.2.4 Comparison of time series fluctuations for electricity trade, fuel consumption, CO_2 emission and NO_x emission. Based on DEA (2013a).

Fuel consumption time series 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 2012 was 7 % lower than in 1990. The fluctuation in electricity production is based on fossil fuel consumption in the subcategory *Public electricity and heat production*. The energy consumption in *Other energy industries* is mainly natural gas used in gas turbines in the off-shore industry. The biomass fuel consumption in *Energy industries* in 2012 added up to 79 PJ, which is 4.8 times the level in 1990 and a 5 % increase since 2011.

The fuel consumption in *Industry* was 17 % lower in 2012 than in 1990 (Figure 3.2.6). The fuel consumption in industrial plants has decreased considerably as a result of the financial crisis. However, the fuel consumption is unchanged since 2009. The biomass fuel consumption in *Industry* in 2012 added up to 9 PJ, which is a 53 % increase since 1990.

The fuel consumption in *Other Sectors* has decreased 24% since 1990 and decreased 7 % since 2011 (Figure 3.2.7). The biomass fuel consumption in *Other sectors* in 2012 added up to 41 PJ which is 2.2 times the consumption in 1990 and a 1 % decrease since 2011. Wood consumption in residential plants in 2012 was 2.2 times the consumption in year 2000.

Time series for subcategories are shown in Chapter 3.2.4.

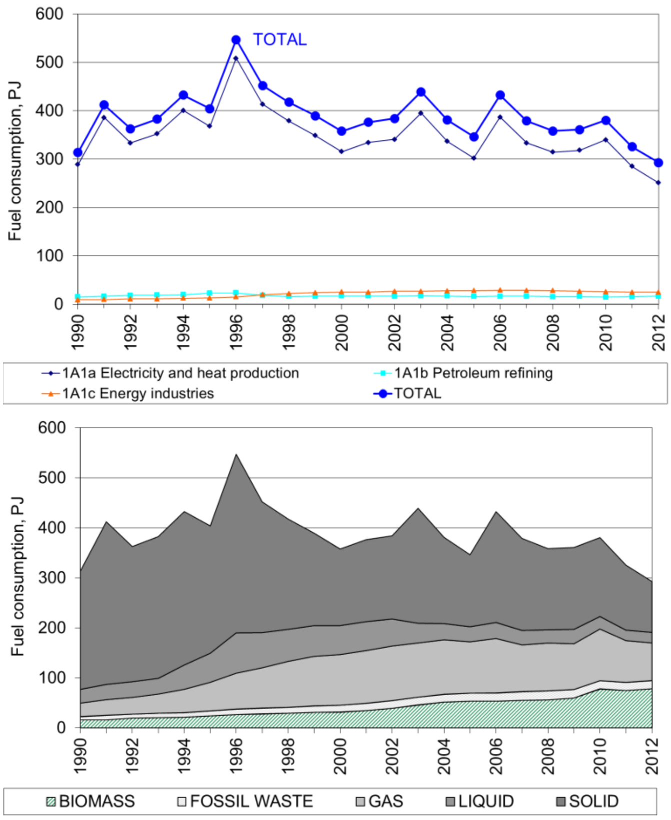


Figure 3.2.5 Fuel consumption time series for subcategories - 1A1 Energy Industries.

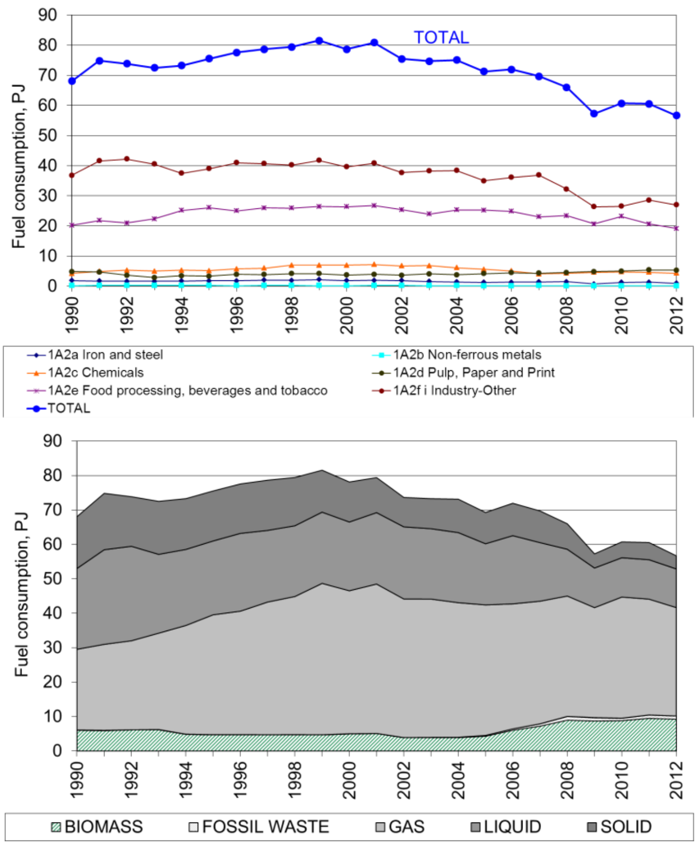


Figure 3.2.6 Fuel consumption time series for subcategories - 1A2 Industry.

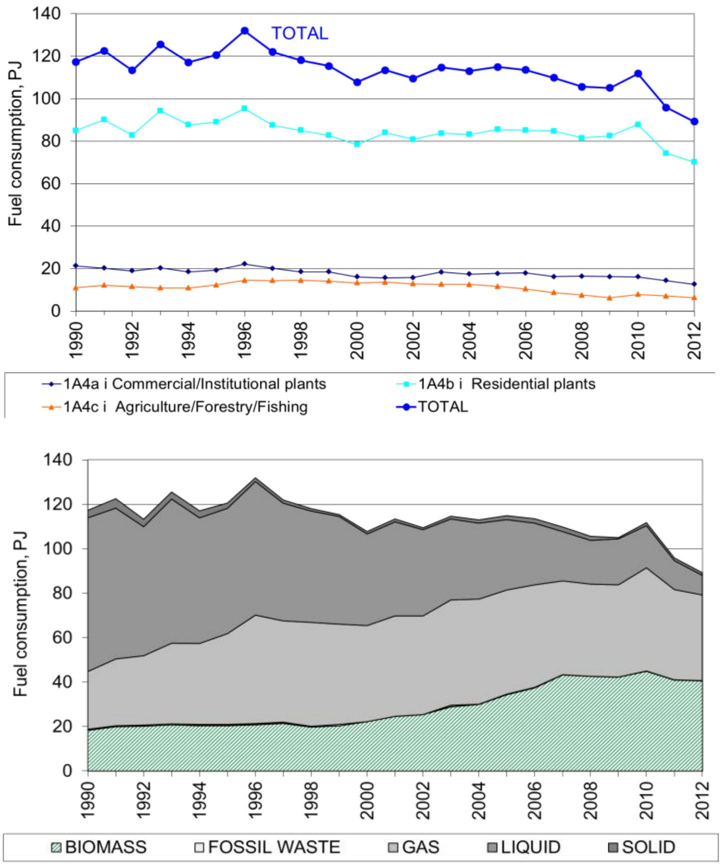


Figure 3.2.7 Fuel consumption time series for subcategories - 1A4 Other Sectors.

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 45 % of the national greenhouse gas emission (excluding LULUCF) in 2012.

The CO_2 emission from stationary combustion plants accounts for 58 % of the national CO_2 emission (excluding LULUCF). The CH_4 emission accounts for 5 % of the national CH_4 emission and the N_2O emission for 3 % of the national N_2O emission.

Table 3.2.3 Greenhouse gas emission, 2012 [1].

	CO_2	CH_4	N_2O
	Gg CO_2 equivalent		
1A1 Fuel Combustion, Energy industries	16531	139	88
1A2 Fuel Combustion, Manufacturing Industries and Construction[1]	3214	9	23
1A4 Fuel Combustion, Other sectors [1]	2965	151	58
Emission from stationary combustion plants	22710	298	170
Emission share for stationary combustion	58%	5%	3%

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

CO_2 is the most important greenhouse gas accounting for 98.0 % of the greenhouse gas emission (CO_2 eq.) from stationary combustion. CH_4 accounts for 1.3 % and N_2O for 0.7 % of the greenhouse gas emission (CO_2 eq.) from stationary combustion (Figure 3.2.8).

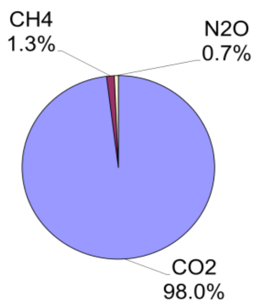


Figure 3.2.8 Stationary combustion - Greenhouse gas emission (CO_2 equivalent), contribution from each pollutant.

Figure 3.2.9 depicts the time series of greenhouse gas emissions (CO_2 eq.) from stationary combustion and it can be seen that the greenhouse gas emission development follows the CO_2 emission development very closely. Both the CO_2 and the total greenhouse gas emission are lower in 2012 than in 1990, CO_2 by 40 % and greenhouse gas by 39 %. However, fluctuations in the GHG emission level are large.

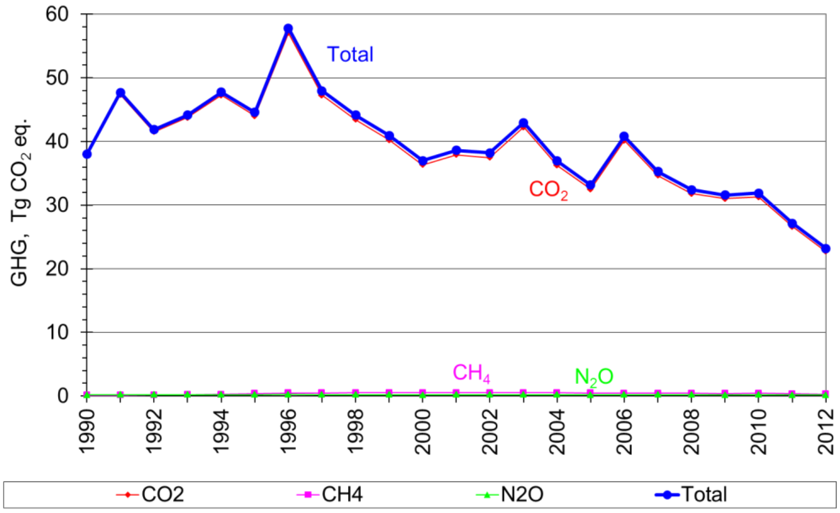


Figure 3.2.9 GHG emission time series for stationary combustion.

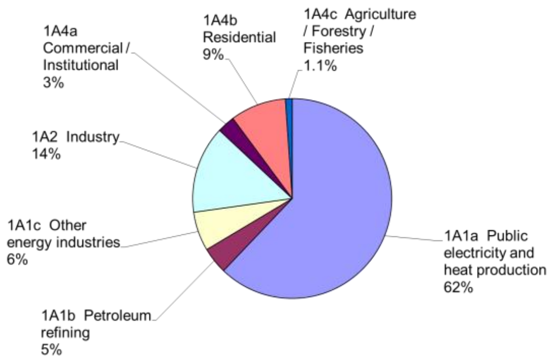
The fluctuations in the time series are largely a result of electricity import/export, but also of outdoor temperature variations from year to year. The fluctuations follow the fluctuations in fuel consumption discussed in Chapter 3.2.2. As mentioned in Chapter 3.2.2, the Danish Energy Agency estimates a correction of the actual 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 38 % since 1990, and the CO_2 emission by 39 %. 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 58 % of the national CO_2 emission. Table 3.2.4 lists the CO_2 emission inventory for stationary combustion plants for 2012. *Public electricity and heat production* accounts for 62 % of the CO_2 emission from stationary combustion. This share is somewhat higher than the fossil fuel consumption share for this category, which is 56 % (Figure 3.2.1). This is due to a large share of coal in this category. Other large CO_2 emission sources are *Industry* 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, 2012[1)].

	CO_2 Gg
1A1a Public electricity and heat production	14111
1A1b Petroleum refining	984
1A1c Other energy industries	1437
1A2 Industry	3214
1A4a Commercial/Institutional	653
1A4b Residential	2062
1A4c Agriculture/Forestry/Fisheries	249
Total	26393

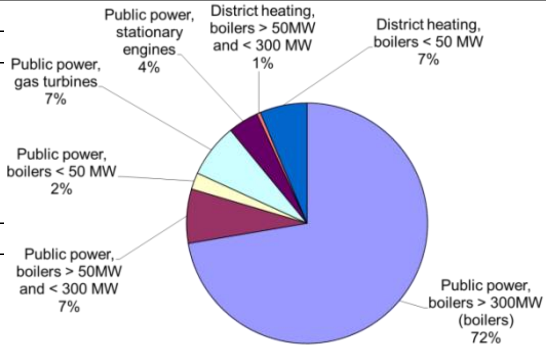


[1)] Only emission from stationary combustion plants in the categories is included.

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.

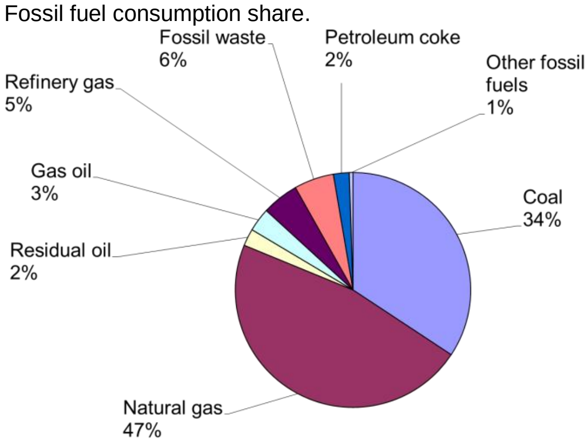
SNAP	SNAP name	CO_2, Gg
0101	Public power	
010101	Combustion plants ≥ 300MW (boilers)	10204
010102	Combustion plants ≥ 50MW and < 300 MW (boilers)	1029
010103	Combustion plants <50 MW (boilers)	315
010104	Gas turbines	1021
010105	Stationary engines	578
0102	District heating plants	
010202	Combustion plants ≥ 50MW and < 300 MW (boilers)	71
010203	Combustion plants <50 MW (boilers)	894



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 2012, the CO_2 emission from biomass combustion was 18 763 Gg.

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. Coal accounts for 34 % of the fossil fuel consumption and for 44 % of the CO_2 emission. Natural gas accounts for 47 % of the fossil fuel consumption but only 37 % of the CO_2 emission.

Fossil fuel consumption share.



CO_2 emission, fuel origin

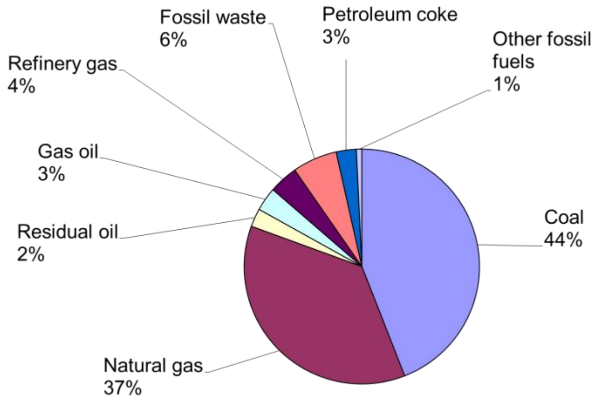


Figure 3.2.10 CO_2 emission, fuel origin.

The time series for CO_2 emission is provided in Figure 3.2.11. Despite a decrease in fuel consumption of 12 %[7] since 1990, the CO_2 emission from stationary combustion has decreased by 40 % because of 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.

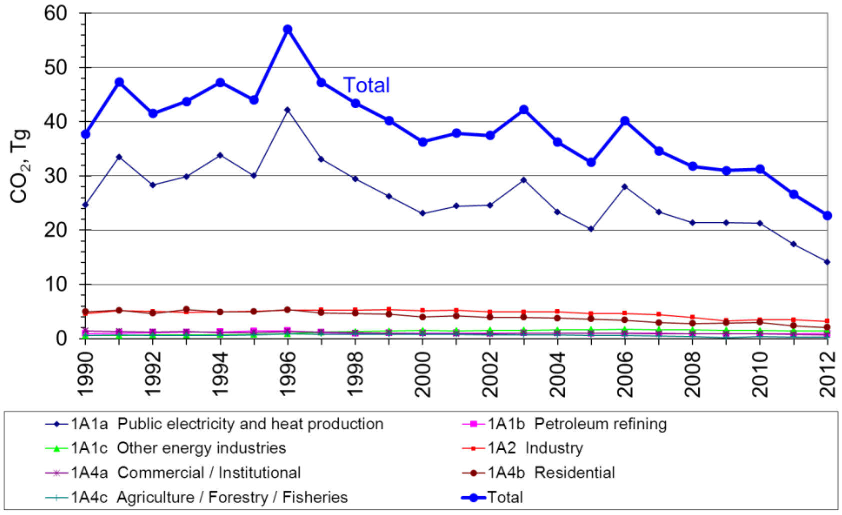


Figure 3.2.11 CO_2 emission time series for stationary combustion plants.

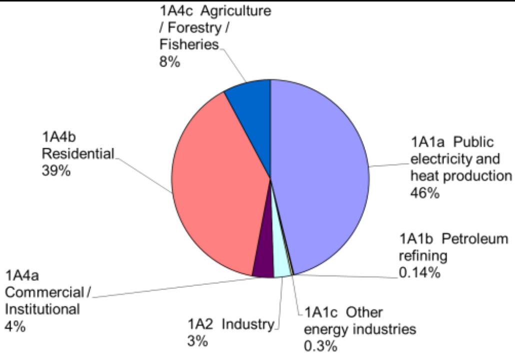
CH_4

The methane (CH_4) emission from stationary combustion plants accounts for 5 % of the national CH_4 emission. Table 3.2.6 lists the CH_4 emission inventory for stationary combustion plants in 2012. *Public electricity and heat production* accounts for 46 % of the CH_4 emission from stationary combustion. The emission from residential plants adds up to 39 % of the emission.

[7] The consumption of fossil fuels has decreased 32 %.

Table 3.2.6 CH_4 emission from stationary combustion plants, 2012[1)].

	CH_4 Mg
1A1a Public electricity and heat production	6547
1A1b Petroleum refining	20
1A1c Other energy industries	43
1A2 Industry	409
1A4a Commercial/Institutional	498
1A4b Residential	5561
1A4c Agriculture/Forestry/Fisheries	1111
Total	14189



[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 2012, these plants accounted for 51 % 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 30 % of the emission in 2012.

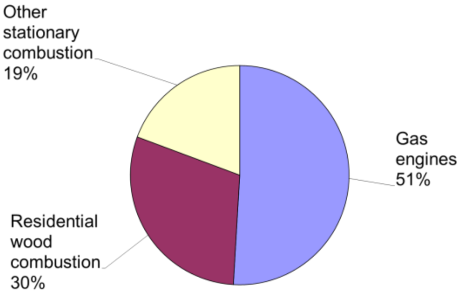


Figure 3.2.12 CH_4 emission share for gas engines and residential wood combustion, 2012.

Figure 3.2.13 shows the time series for CH_4 emission. The CH_4 emission from stationary combustion has increased by a factor of 2.3 since 1990. This results from 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 has increased since 1990 due to increased combustion of biomass in residential plants. Combustion of wood accounted for 76 % of the CH_4 emission from residential plants in 2012.

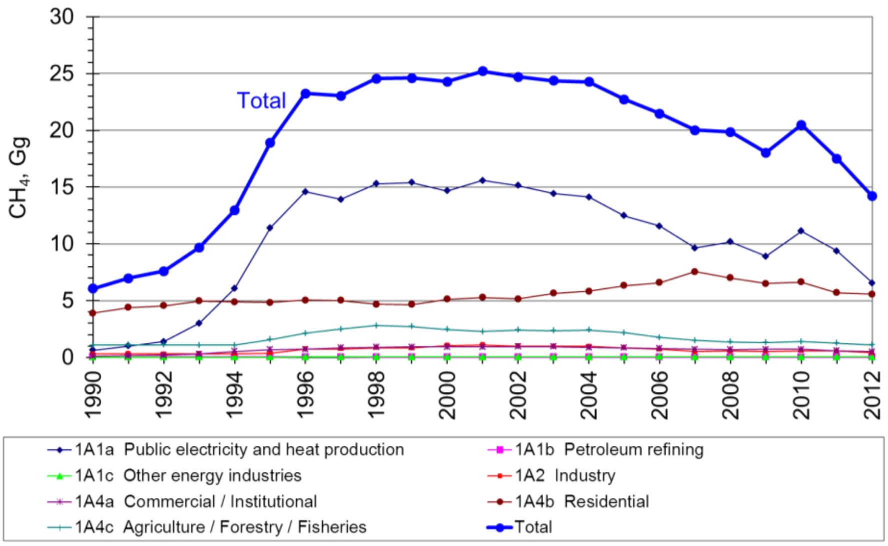


Figure 3.2.13 CH_4 emission time series for stationary combustion plants.

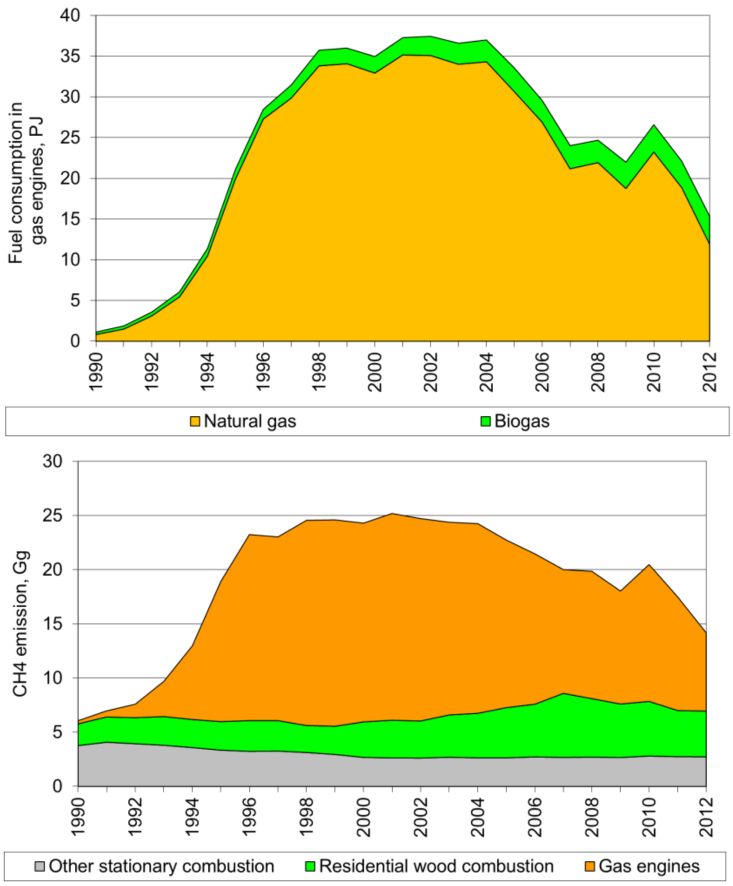


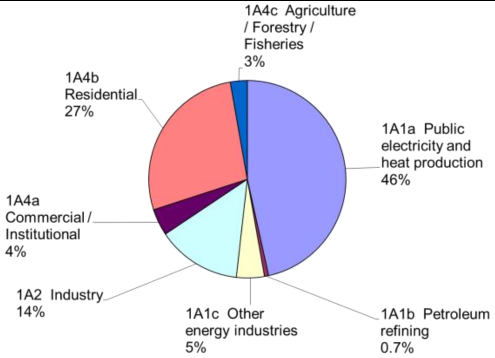
Figure 3.2.14 Time series for a) fuel consumption in gas engines and b) CH_4 emission from gas engines, residential wood combustion and other plants.

N_2O

The nitrous oxide (N_2O) emission from stationary combustion plants accounts for 3 % of the national N_2O emission. Table 3.2.7 lists the N_2O emission inventory for stationary combustion plants in the year 2012. *Public electricity and heat production* accounts for 46 % of the N_2O emission from stationary combustion.

Table 3.2.7 N_2O emission from stationary combustion plants, 2012[1).]

	N_2O, Mg
1A1a Public electricity and heat production	255
1A1b Petroleum refining	4
1A1c Other energy industries	25
1A2 Industry	76
1A4a Commercial/Institutional	24
1A4b Residential	149
1A4c Agriculture/Forestry/Fisheries	15
Total	547



[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 has decreased by 2 % from 1990 to 2012, but again fluctuations in emission level due to electricity import/export are considerable.

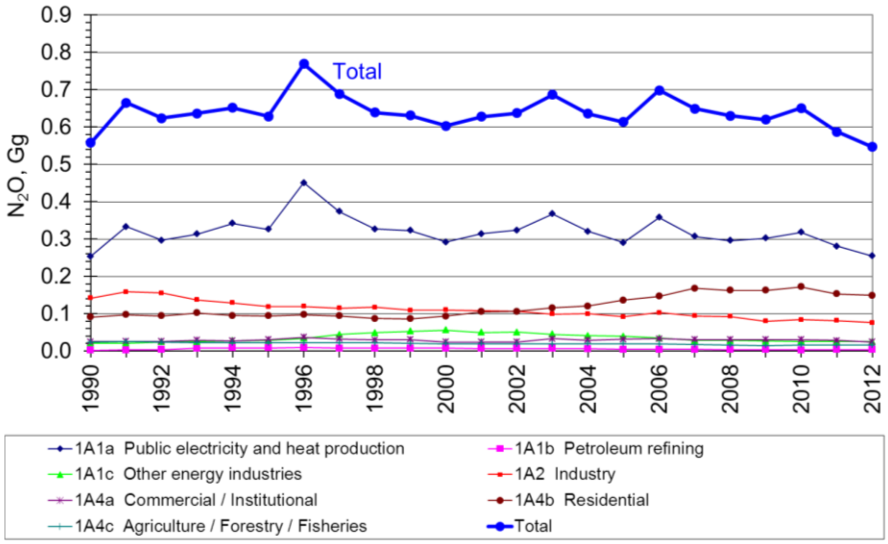


Figure 3.2.15 N_2O emission time series for stationary combustion plants.

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 2012 are presented in Table 3.2.8.

SO_2 from stationary combustion plants accounts for 64 % of the national emission. NO_x, CO and NMVOC account for 28 %, 35 % and 20 % of national emissions, respectively.

Table 3.2.8 SO_2, NO_x, NMVOC and CO emission, 2012[1)].

Pollutant	NO_x Gg	CO Gg	NMVOC Gg	SO_2 Gg
1A1 Fuel consumption, Energy industries	21.8	11.0	1.5	3.1
1A2 Fuel consumption, Manufacturing Industries and Construction[1)]	5.3	4.2	0.3	2.9
1A4 Fuel consumption, Other sectors[1)]	5.2	109.6	14.0	2.1
Emission from stationary combustion plants	32.3	124.8	15.7	8.1
Emission share for stationary combustion, %	28	35	20	64

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

SO_2

Stationary combustion is the most important emission source for SO_2 accounting for 64 % of the national emission. Table 3.2.9 presents the SO_2 emission inventory for the stationary combustion subcategories.

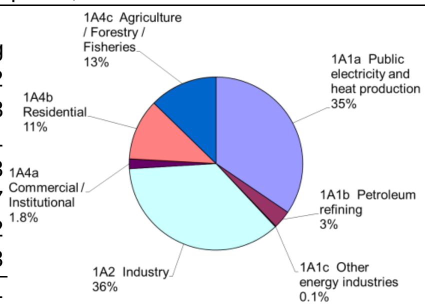
Public electricity and heat production is the largest emission source accounting for 35 % of the emission. However, the SO_2 emission share is lower than the fuel consumption share for this source category, which is 57 %. This is a result of effective flue gas desulphurisation equipment installed in power plants combusting coal. In the Danish inventory, the source category *Public electricity and heat production* is further disaggregated. Figure 3.2.16 shows the SO_2 emission from *Public electricity and heat production* on a disaggregated level. Power plants >300MW$_{th}$ are the main emission source, accounting for 41 % of the emission.

The SO_2 emission from industrial plants adds up to 36 % of the emission from stationary combustion, a remarkably high emission share compared to fuel consumption. The main emission sources in the industrial category are combustion of coal and residual oil, but emissions from the cement industry is also a considerable emission source. Until year 2000, the SO_2 emission from the industrial category only accounted for a small part of the emission from stationary combustion, but as a result of reduced emissions from power plants, the share has now increased.

The time series for SO_2 emission from stationary combustion are shown in Figure 3.2.17. The SO_2 emission from stationary combustion plants has decreased by 95 % since 1990. The large emission decrease is mainly a result of the reduced emission from *Public electricity and heat production*, made possible due to installation of desulphurisation units and due to the use of fuels with lower sulphur content. Despite the considerable reduction in emission from public electricity and heat production plants, these still account for 35 % of the emission from stationary combustion, as mentioned above. The emission from other source categories also decreased considerably since 1990. Time series for subcategories are shown in Chapter 3.2.4.

Table 3.2.9 SO_2 emission from stationary combustion plants, 2012[1].

	SO_2, Mg
1A1a Public electricity and heat production	2782
1A1b Petroleum refining	273
1A1c Other energy industries	11
1A2 Industry	2903
1A4a Commercial/Institutional	147
1A4b Residential	922
1A4c Agriculture/Forestry/Fisheries	1023
Total	8061



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

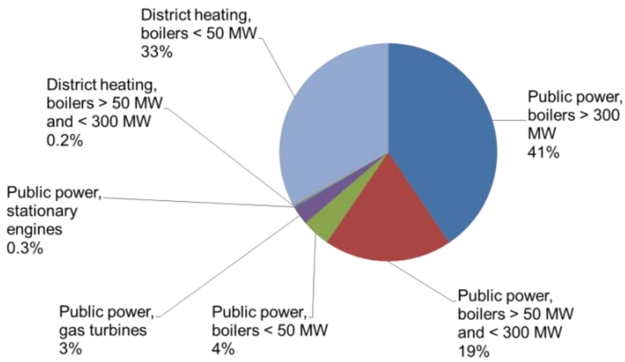


Figure 3.2.16 Disaggregated SO_2 emissions from 1A1a Energy and heat production.

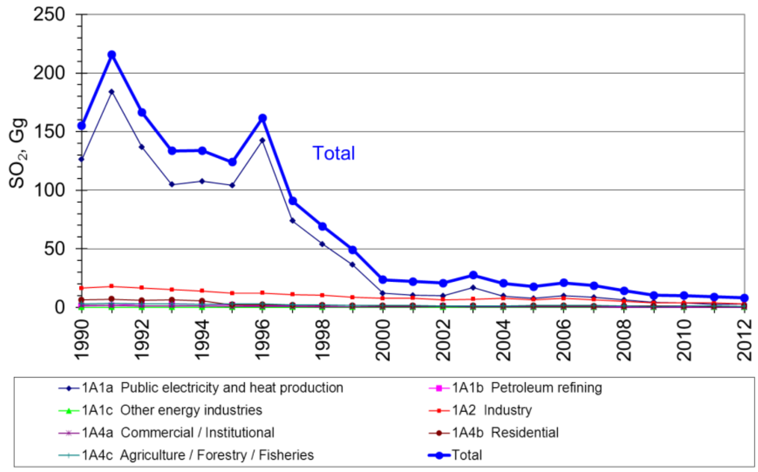


Figure 3.2.17 SO_2 emission time series for stationary combustion.

NO_x

Stationary combustion accounts for 28 % of the national NO_x emission. Table 3.2.10 shows the NO_x emission inventory for stationary combustion subcategories.

Public electricity and heat production is the largest emission source accounting for 43 % of the emission from stationary combustion plants. The emission from public power boilers > 300 MWth accounts for 29 % of the emission in this subcategory.

Industrial combustion plants are also an important emission source accounting for 17 % of the emission. The main industrial emission source is cement production, which accounts for 30 % of the emission.

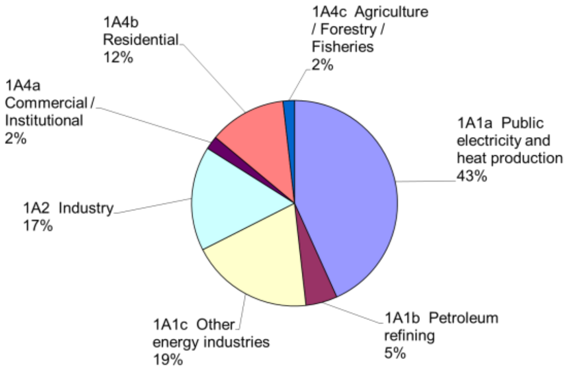
Residential plants account for 12 % of the NO_x emission. The fuel origin of this emission is mainly wood accounting for 61 % of the residential plant emission.

Other energy industries, which is mainly off-shore gas turbines accounts for 19 % of the NO_x emission.

Time series for NO_x emission from stationary combustion are shown in Figure 3.2.18. NO_x emission from stationary combustion plants has decreased by 72 % since 1990. The reduced emission is largely a result of the reduced emission from public electricity and heat production due to installation of low NO_x burners, selective catalytic reduction (SCR) units and selective non-catalytic reduction (SNCR) units. The fluctuations in the time series follow the fluctuations in public electricity and heat production, which, in turn, result from electricity trade fluctuations.

Table 3.2.10 NO_x emission from stationary combustion plants, 2012[1).]

		NOx, Mg
1A1a	Public electricity and heat production	13994
1A1b	Petroleum refining	1604
1A1c	Other energy industries	6248
1A2	Industry	5316
1A4a	Commercial/Institutional	678
1A4b	Residential	3928
1A4c	Agriculture/Forestry/Fisheries	581
Total		32349



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

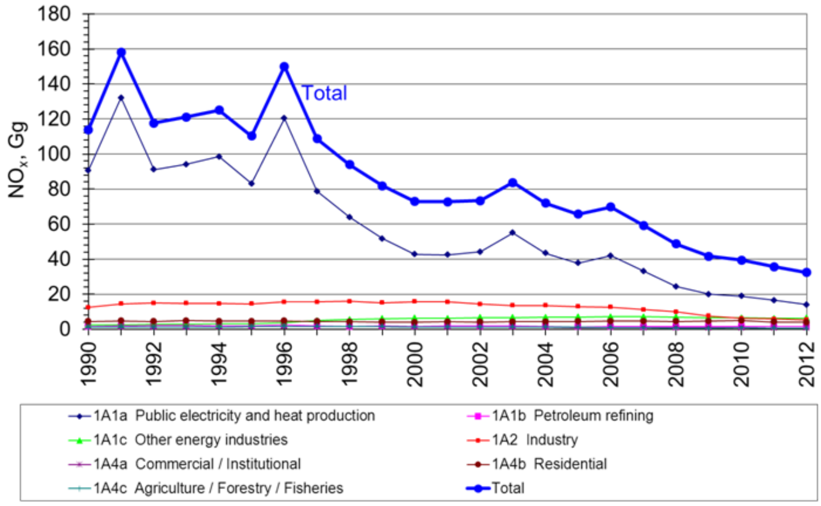


Figure 3.2.18 NO_x emission time series for stationary combustion.

NMVOC

Stationary combustion plants accounted for 20 % of the national NMVOC emission in 2012. Table 3.2.11 presents the NMVOC emission inventory for the stationary combustion subcategories.

Residential plants are the largest emission source accounting for 85 % of the emission from stationary combustion plants. For residential plants NMVOC is mainly emitted from wood and straw combustion, see Figure 3.2.19.

Public electricity and heat production is also a considerable emission source, accounting for 9 % of the emission. Lean-burn gas engines have a relatively high NMVOC emission factor and are the most important emission source in this subcategory (see Figure 3.2.19). The gas engines are either natural gas or biogas fuelled.

Time series for NMVOC emission from stationary combustion are shown in Figure 3.2.20. The emission has increased by 12 % from 1990. The increased emission is mainly a result of the increasing wood consumption in residential plants and of the increased use of lean-burn gas engines in CHP plants.

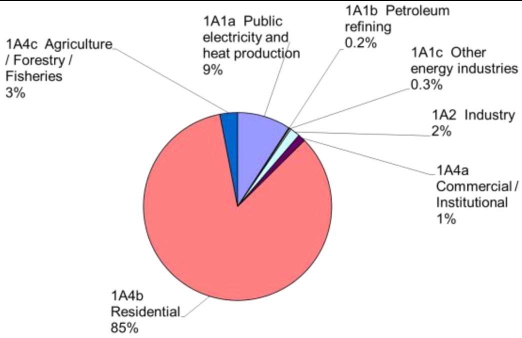
The emission from residential plants increased 15 % since 1990. The NMVOC emission from wood combustion in 2012 was 2.3 times the 1990 level due to increased wood consumption. However, the emission factor has decreased since 1990 due to installation of modern stoves and boilers with improved combustion technology. Further the emission from straw combustion in farmhouse boilers has decreased (75 %) over this period due to both a decreasing emission factor and decrease in straw consumption in this source category.

The use of wood in residential boilers and stoves was relatively low in 1998-99 resulting in a lower emission level.

The increasing consumption of wood in residential plants ceased in 2007. The improved technology that has been implemented in residential wood combustion have led to lower emission factors and thus decreasing NMVOC emission since 2007.

Table 3.2.11 NMVOC emission from stationary combustion plants, 2012[1)].

	NMVOC, Mg
1A1a Public electricity and heat production	1445
1A1b Petroleum refining	24
1A1c Other energy industries	40
1A2 Industry	271
1A4a Commercial/Institutional	201
1A4b Residential	13289
1A4c Agriculture/Forestry/Fisheries	476
Total	15746



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

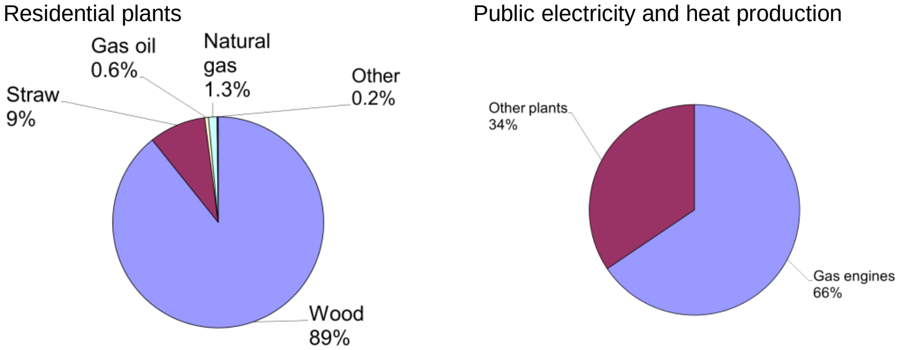


Figure 3.2.19 NMVOC emission from Residential plants and from Public electricity and heat production, 2012.

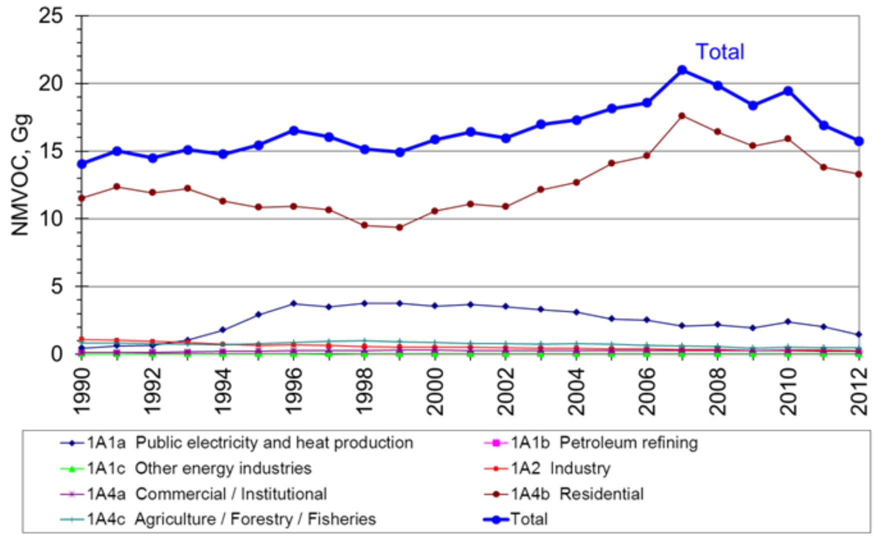


Figure 3.2.20 NMVOC emission time series for stationary combustion.

CO

Stationary combustion accounted for 35 % of the national CO emission in 2012. Table 3.2.12 presents the CO emission inventory for stationary combustion subcategories.

Residential plants are the largest emission source, accounting for 80 % of the emission. Wood combustion accounts for 88 % of the emission from residential plants, see Figure 3.2.21. This is in spite of the fact that the fuel consumption share is only 47 %. Combustion of straw is also a considerable emission source whereas the emission from other fuels used in residential plants is almost negligible.

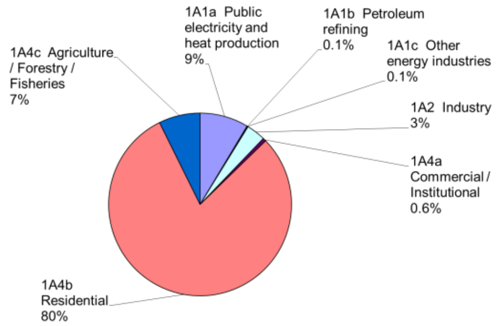
Time series for CO emission from stationary combustion are shown in Figure 3.2.22. The emission has increased by 5 % from 1990. The time series for CO from stationary combustion plants follows the time series for CO emission from residential plants.

The increase of wood consumption in residential plants in 1999-2007 is reflected in the time series for CO emission. The consumption of wood in residential plants in 2012 was 3.6 times the 1990 level. The decreased emission in 2007-2012 is a result of implementation of improved residential wood combustion technologies and the fact that the rapid increase of wood consumption until 2007 have stopped.

Both straw consumption and CO emission factor for residential plants have decreased since 1990.

Table 3.2.12 CO emission from stationary combustion plants, 2012[1)].

	CO, Mg
1A1a Public electricity and heat production	10728
1A1b Petroleum refining	126
1A1c Other energy industries	120
1A2 Industry	4201
1A4a Commercial/Institutional	715
1A4b Residential	99781
1A4c Agriculture/Forestry/Fisheries	9131
Total	124802



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

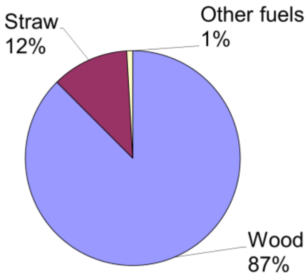


Figure 3.2.21 CO emission sources, residential plants, 2012.

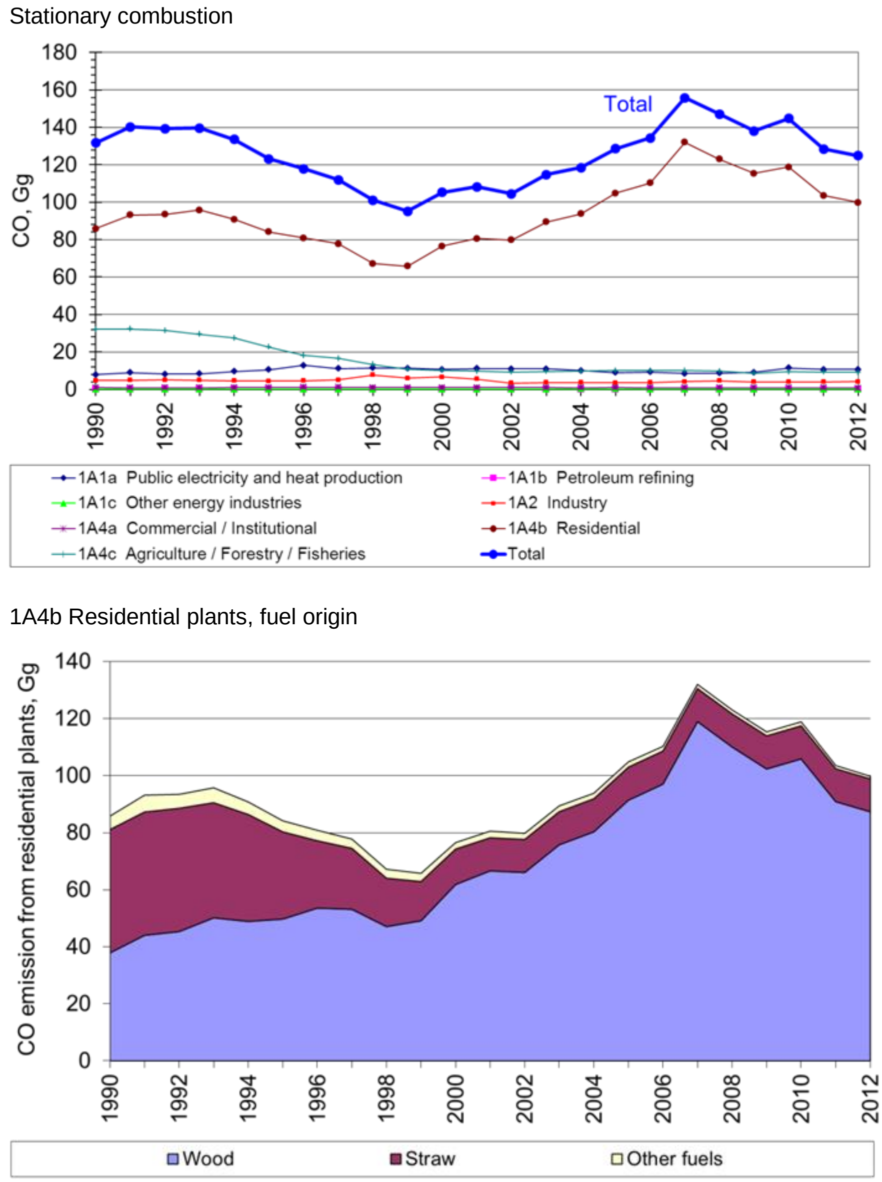


Figure 3.2.22 CO emission time series for stationary combustion.

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 Other energy industries.

Figure 3.2.23 – 3.2.25 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.

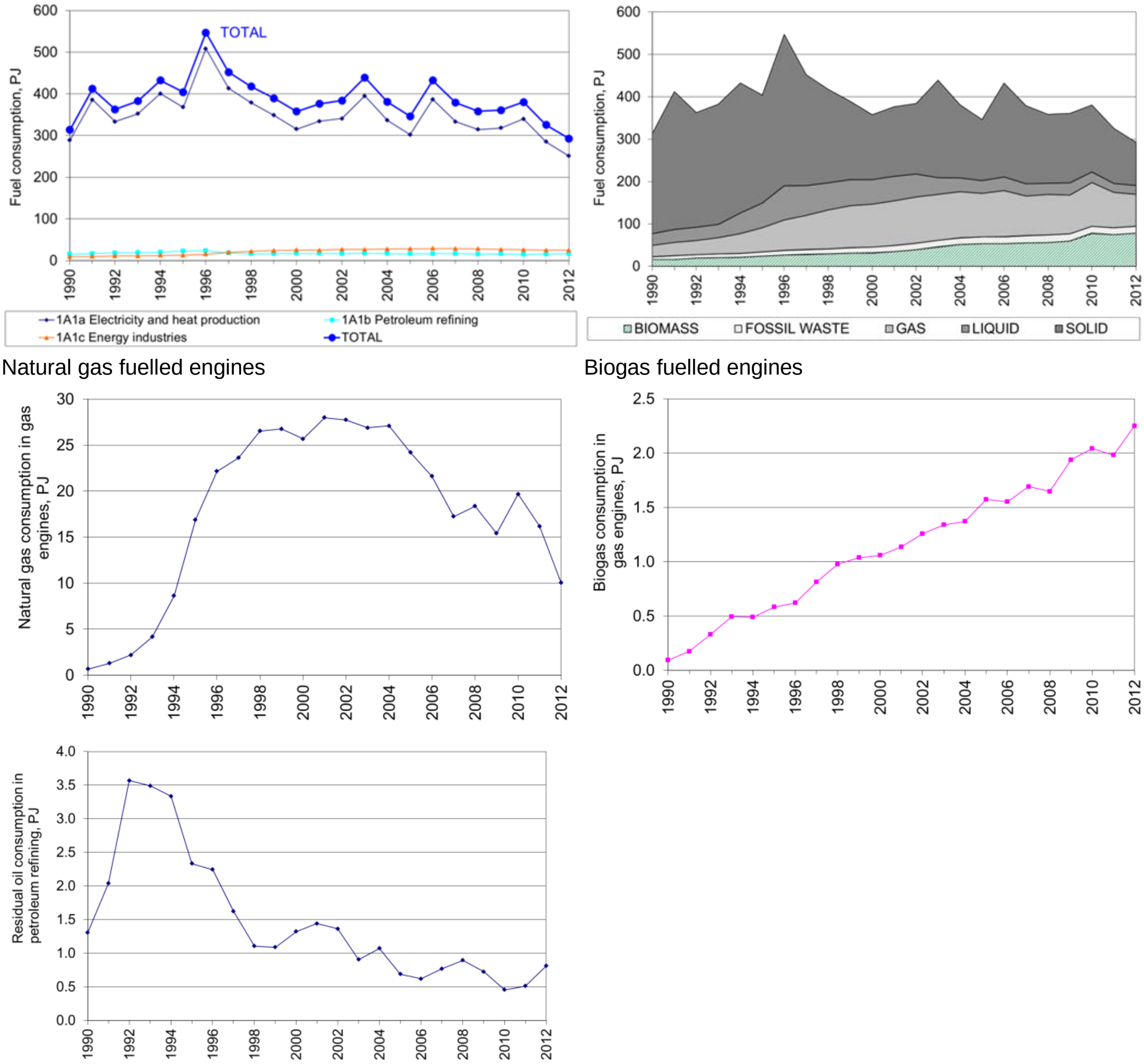


Figure 3.2.23 Time series for fuel consumption, 1A1 Energy industries.

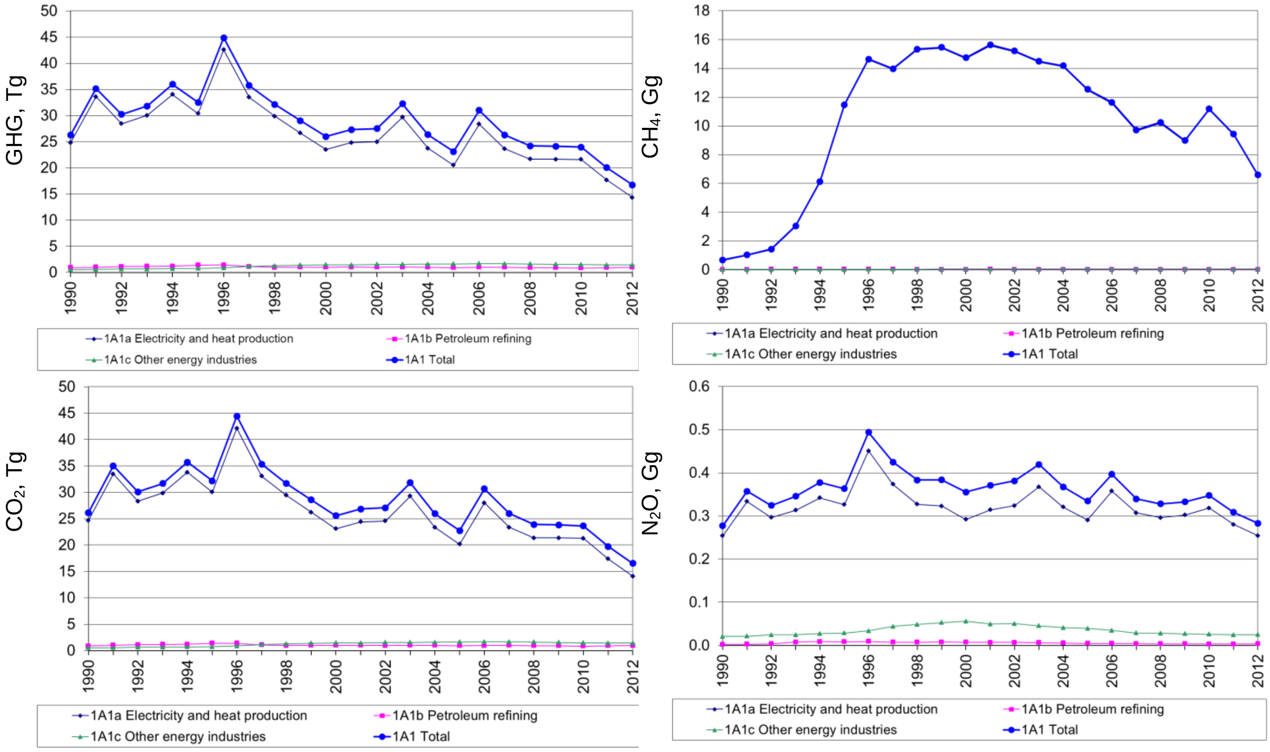


Figure 3.2.24 Time series for greenhouse gas emission, 1A1 Energy industries.

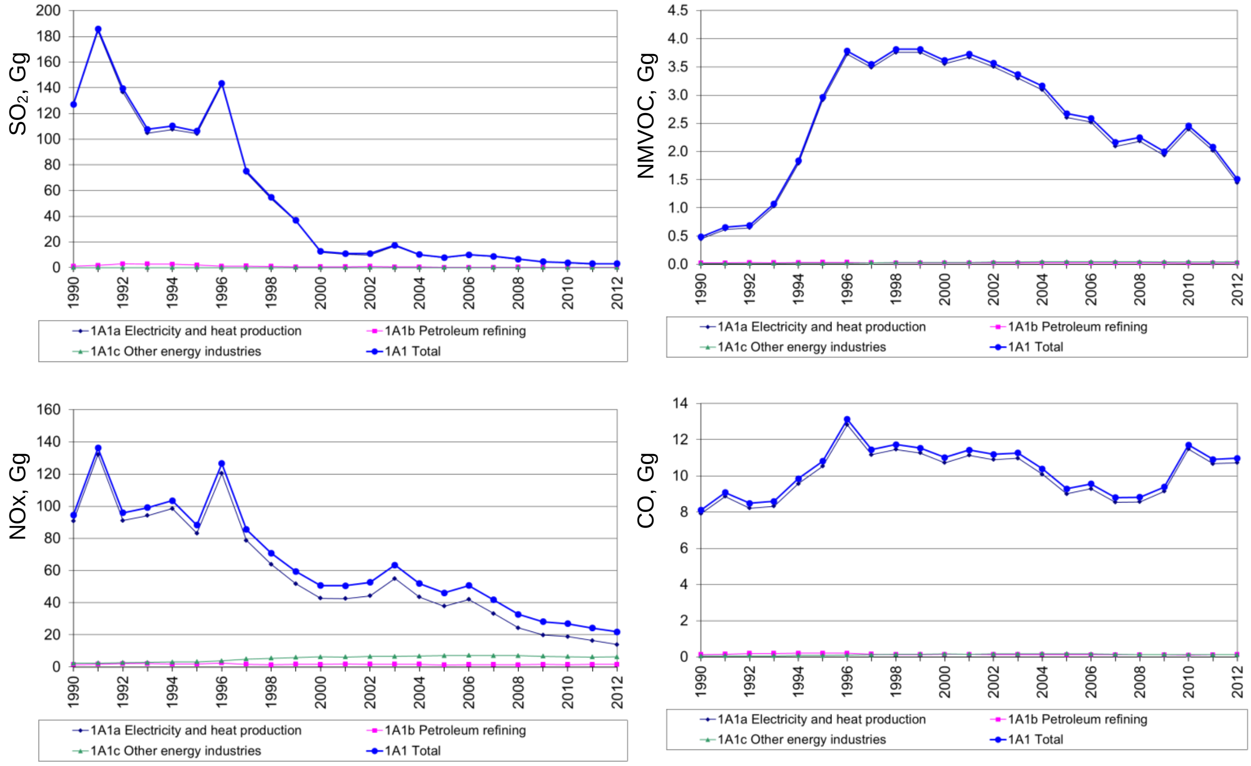


Figure 3.2.25 Time series for SO_2, NO_x, NMVOC and CO emission, 1A1 Energy industries.

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 3.2.26 shows the time series for fuel consumption and emissions.

The fuel consumption in public electricity and heat production was 13 % lower in 2012 than in 1990. As discussed in Chapter 3.2.2 the fuel consumption fluctuates mainly as a consequence of electricity trade. Coal is the fuel that is affected the most by the fluctuating electricity trade. Coal is the main fuel in the source category even in years with electricity import. The coal consumption in 2012 was 57 % lower than in 1990. Natural gas is also an important fuel and the consumption of natural gas has increased since 1990, but decreased since 2003. A considerable part of the natural gas is combusted in gas engines (Figure 3.2.23). The consumption of waste and biomass has increased.

The CO_2 emission was 43 % lower in 2012 than in 1990. This decrease – in spite of only a 13 % decrease in fuel consumption - is a result of the change of fuels used as discussed above.

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 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 (Figure 3.2.23). The emission in 2012 was 10 times the 1990 emission level.

The N_2O emission in 2012 was equal to the 1990 emission level. The emission fluctuates similar to the fuel consumption.

The SO_2 emission has decreased 98 % from 1990 to 2012. This decrease is a result of both lower sulphur content in fuels and installation and improved performance of desulphurisation plants. The emission was higher in 2012 than in 2011, but the emission has however decreased 64 % since 2005.

The NO_x emission has decreased 85 % since 1990 due to installation of low NO_x burners, selective catalytic reduction (SCR) units and selective non-catalytic reduction (SNCR) units. The fluctuations in time series follow the fluctuations in fuel consumption and electricity trade.

The emission of NMVOC in 2012 was 3.2 times the 1990 emission level. This is a result of the large number of gas engines that has been installed in Danish CHP plants. The decreasing emission in 2004-2012 is results of the time series for natural gas consumption in gas engines (Figure 3.2.23). In addition, the emission of NMVOC from engines decreased in 1995-2007 as a result of introduction of an emission limits for unburned hydrocarbon[8] (DEPA, 2005).

The CO emission was 35 % higher in 2012 than in 1990. The fluctuations follow the fluctuations of the fuel consumption. In addition, the emission from gas engines is considerable.

[8] Including methane.

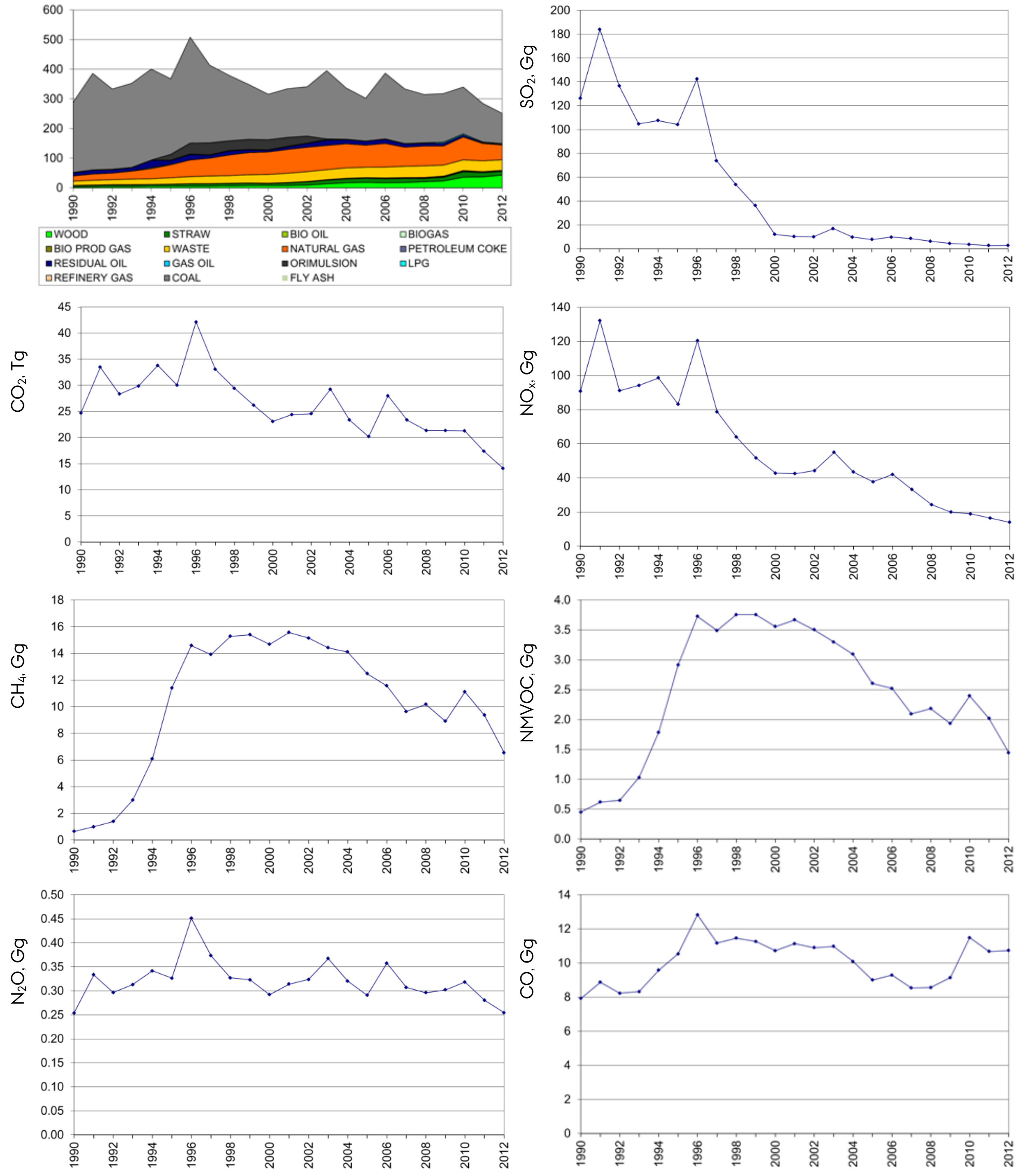


Figure 3.2.26 Time series for 1A1a Public electricity and heat production.

1A1b Petroleum refining

Petroleum refining is a small source category regarding both fuel consumption and greenhouse gas emissions for stationary combustion. There are presently only two refineries operating in Denmark. Figure 3.2.27 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 also increased 9 %.

The CH_4 emission has increased 11 % since 1990 and 6 % since 2011. The reduction in CH_4 emission from 1995 to 1996 is caused by the closure of a refinery.

The N_2O emission was 71 % higher in 2012 than in 1990. The emission increased in 1990 – 1993 as a result of the installation of a gas turbine in one of the refineries. The gas turbine was installed in 1993 (DEA, 2013b).

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 and thus the emission factor have been decreasing since 1994. This causes the decreasing trend in the time series since 1994.

The emission of SO_2 has shown a pronounced decrease (74 %) since 1990, mainly due to the decreased consumption of residual oil (38 %) also shown in Figure 3.2.27. The NO_x emission in 2012 was 10 % lower than in 1990. Since 2005, data for both SO_2 and NO_x are plant specific data stated by the refineries.

The NMVOC emission time series follows the time series for fuel consumption.

Emissions from refineries are further discussed in Chapter 3.5.

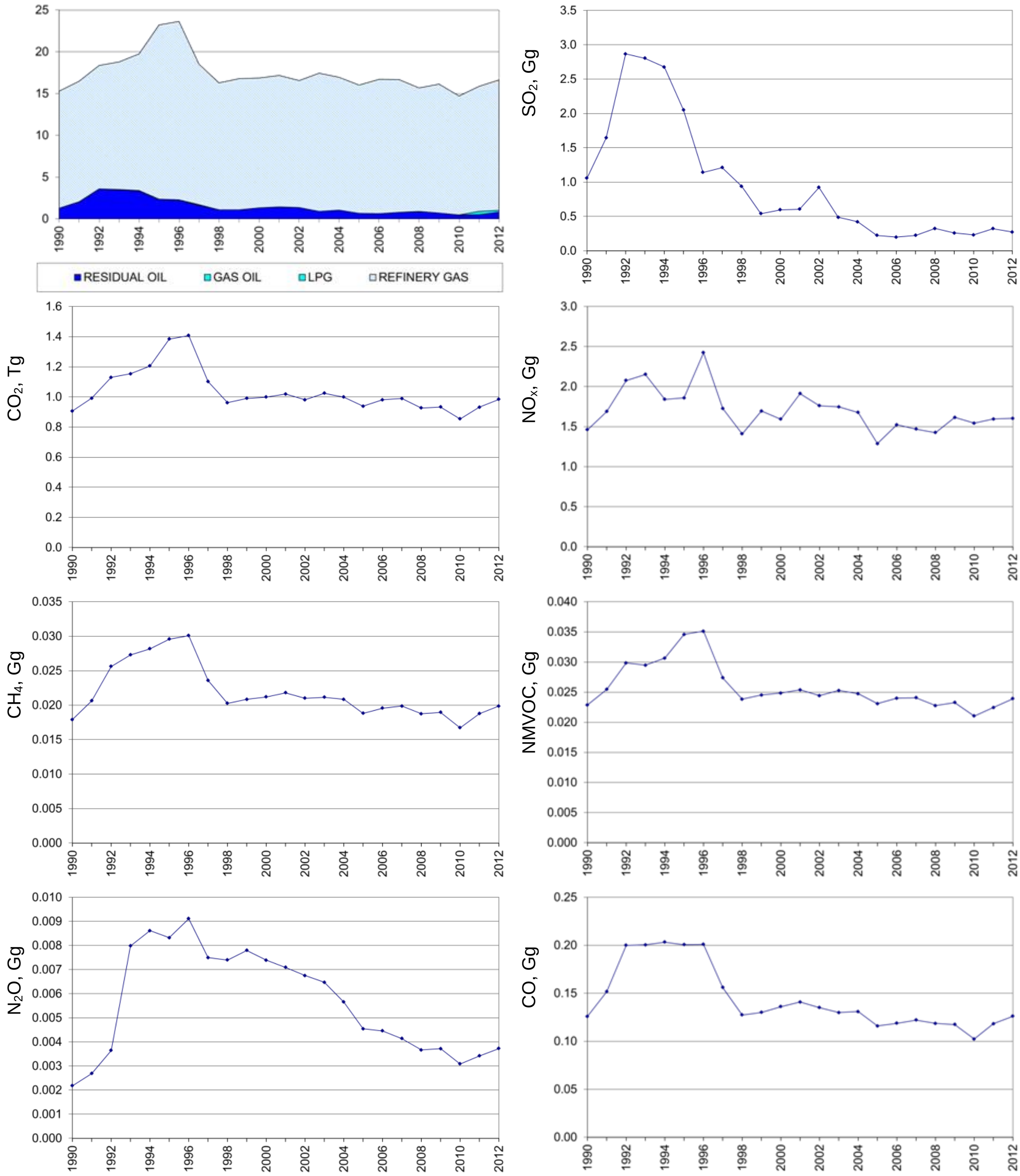


Figure 3.2.27 Time series for 1A1b Petroleum refining.

1A1c Other energy industries

The source category *Other energy industries* comprises natural gas consumption in the off-shore industry and in addition a small consumption in the Danish gas treatment plant[9]. Gas turbines are the main plant type. Figure 3.2.28 shows the time series for fuel consumption and emissions.

The fuel consumption in 2012 was 2.6 times the consumption in 1990. The CO_2 emission follows the fuel consumption and the emission in 2012 was also 2.6 times the emission in 1990.

[9] Nybro.

The time series for CO and N_2O will be recalculated in the next inventory. The decreasing emission factor time series will be corrected in the next inventory. The current emission factor time series for CO and N_2O follow the emission factors for gas turbines applied in CHP plants.

The emissions from all other pollutants follow the increase of fuel consumption.

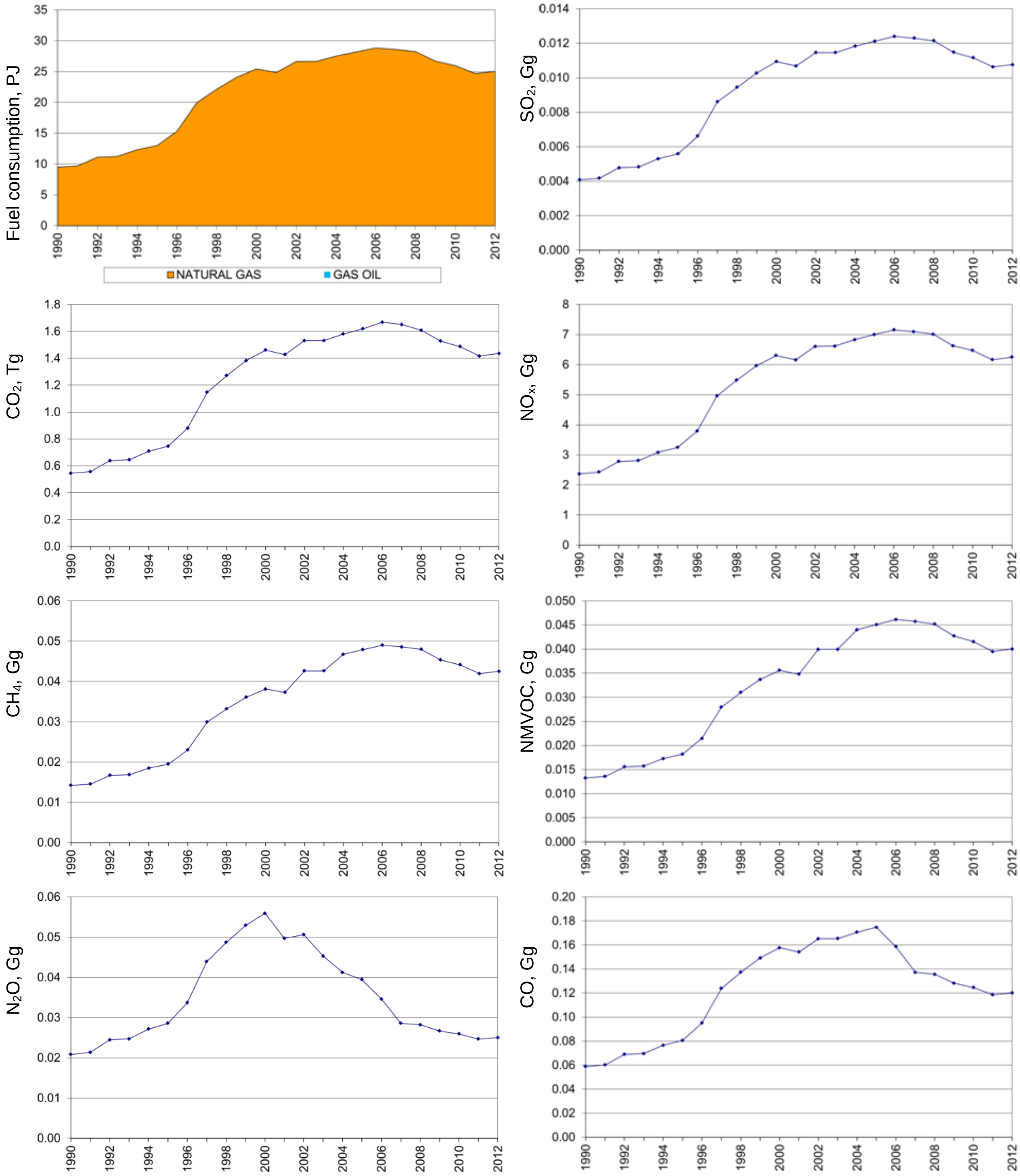


Figure 3.2.28 Time series for 1A1c Other energy industries.

1A2 Industry

Manufacturing industries and construction (Industry) consists of both stationary and mobile sources. In this chapter, only stationary sources are included.

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 i Industry-Other

Figures 3.2.29-3.2.31 show the time series for fuel consumption and emissions. The subsector *Industry – Other* is the main subsector for fuel consumption and emissions. *Food processing, beverages and tobacco* is also an important subsector.

The total fuel consumption in industrial combustion was 17 % lower in 2012 than in 1990. The consumption of natural gas has increased since 1990 whereas the consumption of coal has decreased. The consumption of residual oil has decreased, but the consumption of petroleum coke increased. The biomass consumption has increased 53 % since 1990.

The greenhouse gas emission and the CO_2 emission are both rather stable until 2006 following the small fluctuations in fuel consumption. After 2006, the fuel consumption has decreased. Due to change of applied fuels, the greenhouse gas and CO_2 emissions have decreased more than the fuel consumption since 1990; both emissions have decreased 30 %.

The CH_4 emission has increased from 1994-2001 and decreased again from 2001 - 2007. In 2012, the emission was 34 % higher than in 1990. The CH_4 emission follows the consumption of natural gas in gas engines (Figure 3.2.29). Most industrial CHP plants based on gas engines came in operation in the years 1995 to 1999. The decrease in later years is a result of the liberalisation of the electricity market.

The N_2O emission has decreased 47 % since 1990, mainly due to the decreased residual oil consumption. In recent years, combustion of wood is a considerable emission source.

The SO_2 emission has decreased 82 % since 1990. This is mainly a result of lower consumption of residual oil in the industrial sector. Further, the sulphur content of residual oil and several other fuels has decreased since 1990 due to legislation and tax laws.

The NO_x emission has decreased 57 % since 1990 due to the reduced emission from industrial boilers in general. Cement production is the main emission source accounting for more than 50 % of the industrial emission in 1990-2009[10]. In 2012, the NO_x emission from cement industry was 33 % of the industrial emission. The NO_x emission from cement production was reduced 75 % since 1990. The reduced emission is a result of installation of

[10] More than 65 % of sector 1A2f i.

SCR on all production units at the cement production plant in 2004-2007[11] and improved performance of the SCR units in recent years. A NO_x tax was introduced in 2010 (DMT, 2008).

The NMVOC emission has decreased 75 % since 1990. The decrease is a mainly result of decreased emission factor for combustion of wood in industrial boilers. The emission from gas engines has however increased considerably after 1995 due to the increased fuel consumption that is a result of the installation of a large number of industrial CHP plants (Figure 3.35). The NMVOC emission factor for gas engines is much higher than for boilers regardless of the fuel.

The CO emission in 2012 was 11 % lower than in 1990. The main source of emission is combustion in *Industry – Other*, primarily in wood and cement production. The CO emission from mineral wool production is included in the industry sector (2A7d).

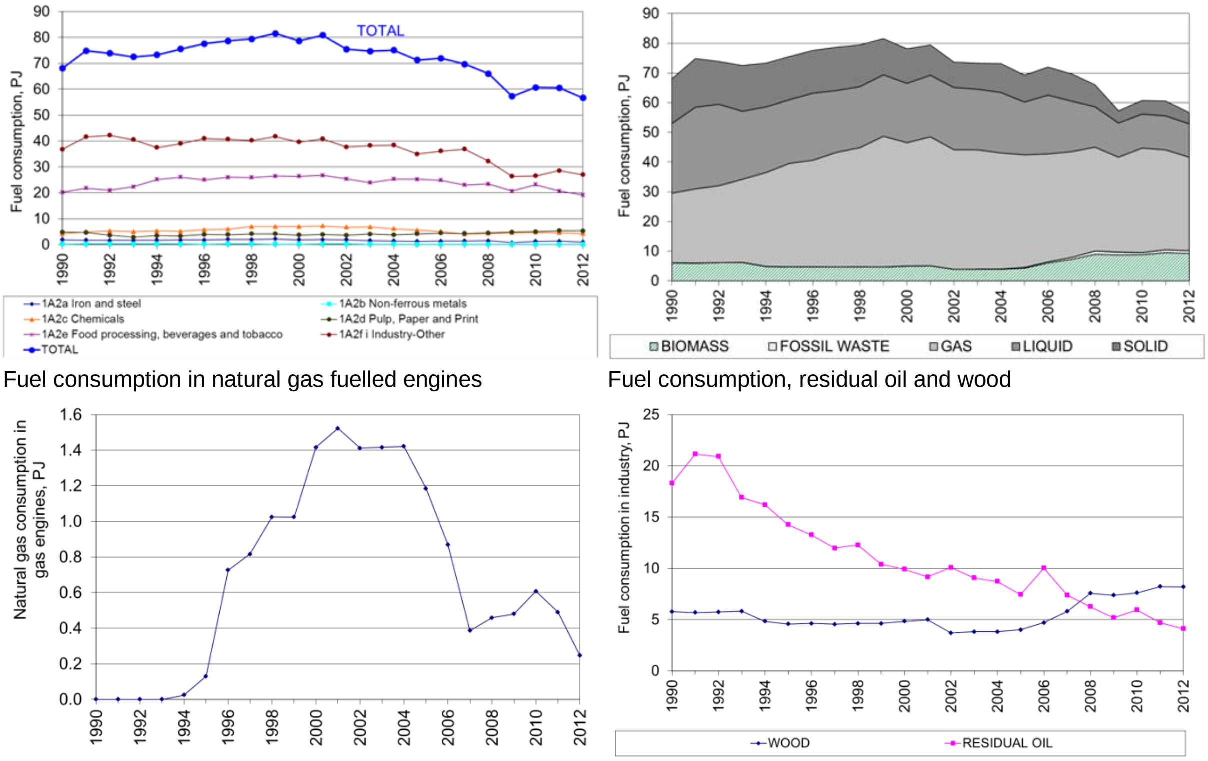


Figure 3.2.29 Time series for fuel consumption, 1A2 Industry.

[11] To meet emission limit.

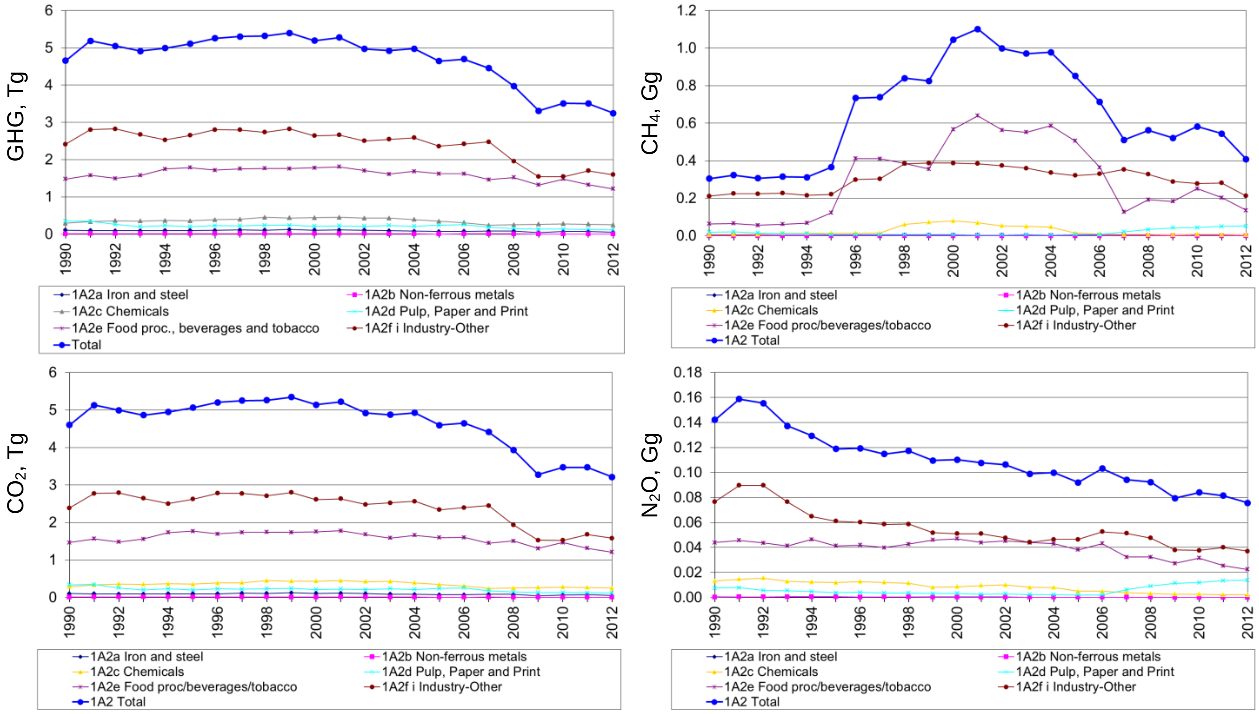


Figure 3.2.30 Time series for greenhouse gas emission, 1A2 Industry.

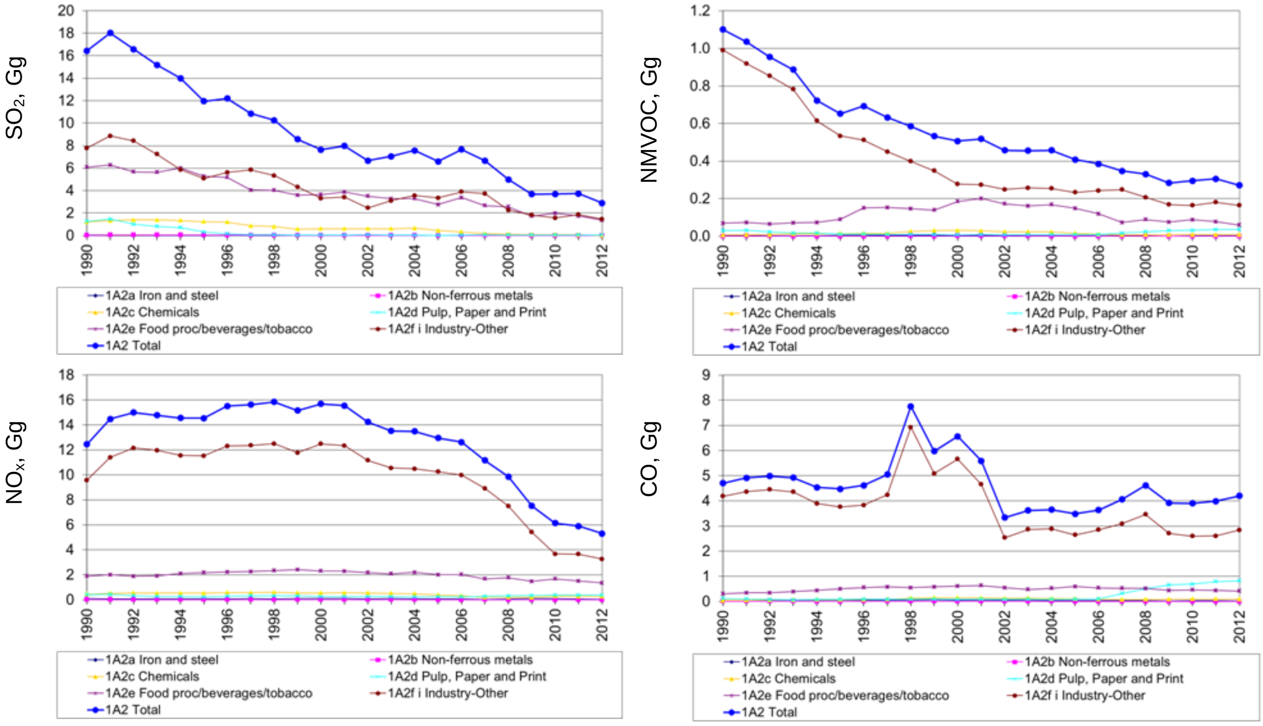


Figure 3.2.31 Time series for SO_2, NO_x, NMVOC and CO emission, 1A2 Industry.

1A2a Iron and steel

Iron and steel is a very small emission source category. Figure 3.2.32 shows the time series for fuel consumption and emissions.

Natural gas is the main fuel in the subsector.

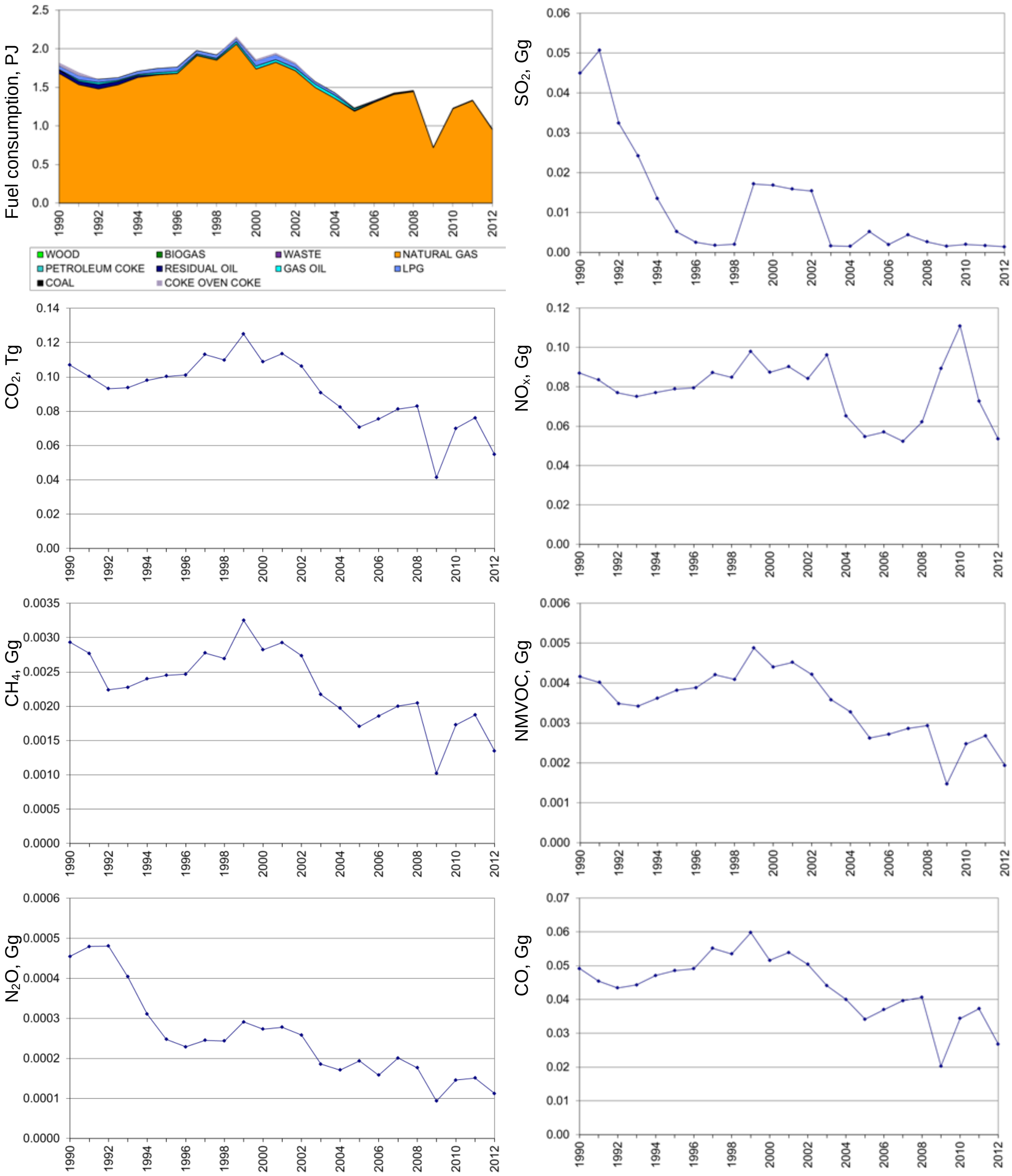


Figure 3.2.32 Time series for 1A2a Iron and steel.

1A2b Non-ferrous metals

Non-ferrous metals is a very small emission source category. Figure 3.2.33 shows the time series for fuel consumption and emissions.

Natural gas is the main fuel in the subsector. The consumption of residual oil has decreased and the SO_2 emission follows this fuel consumption. The emissions of NO_x, NMVOC and CO follow the fuel consumption.

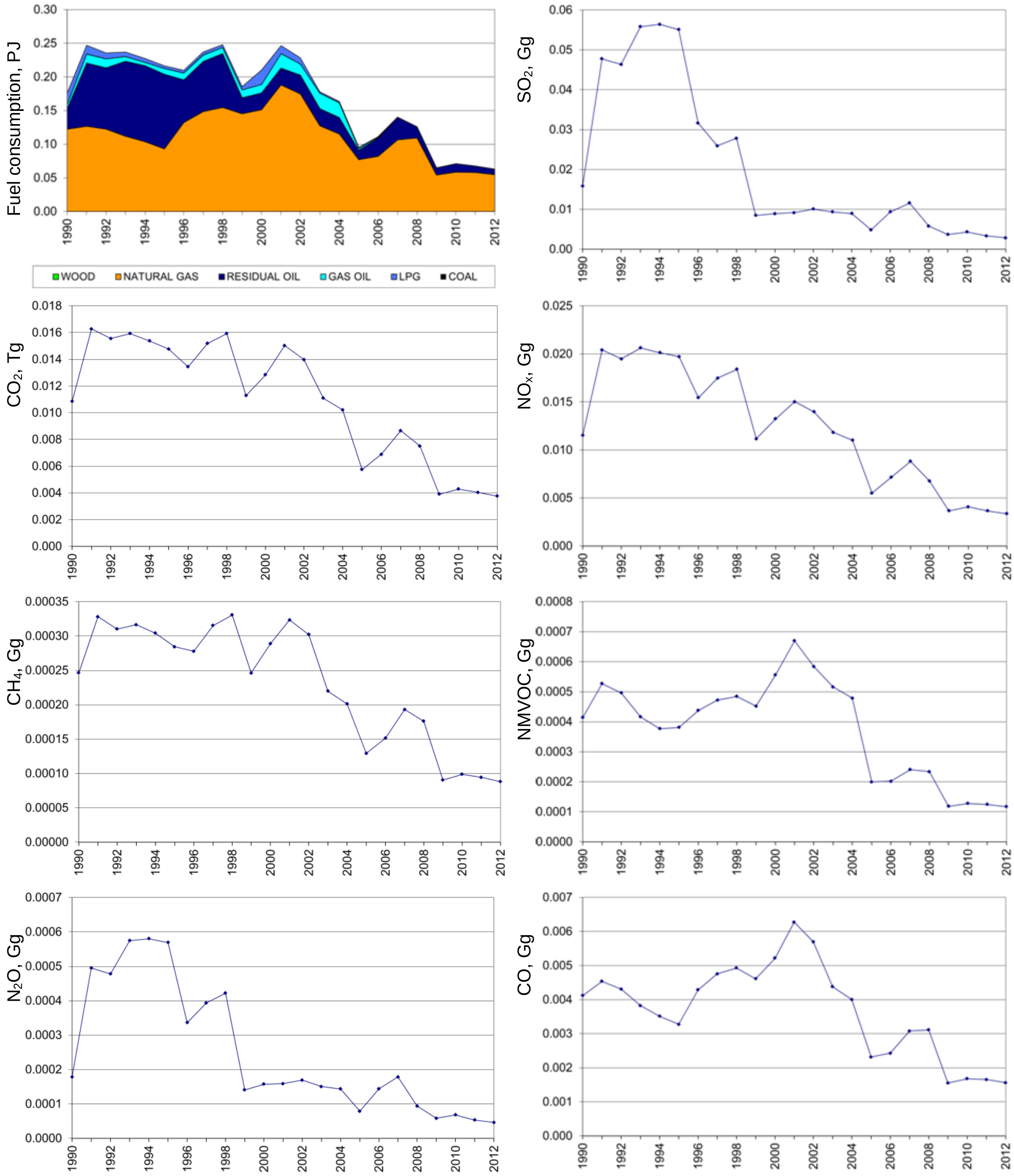


Figure 3.2.33 Time series for 1A2b Non-ferrous metals.

1A2c Chemicals

Chemicals is a minor emission source category. Figure 3.2.34 shows the time series for fuel consumption and emissions.

Natural gas is the main fuel in this subsector. The consumption of residual oil has decreased and the SO_2 emission follows this fuel consumption. The time series for CH_4, NMVOC and CO is related to consumption of natural gas in gas engines.

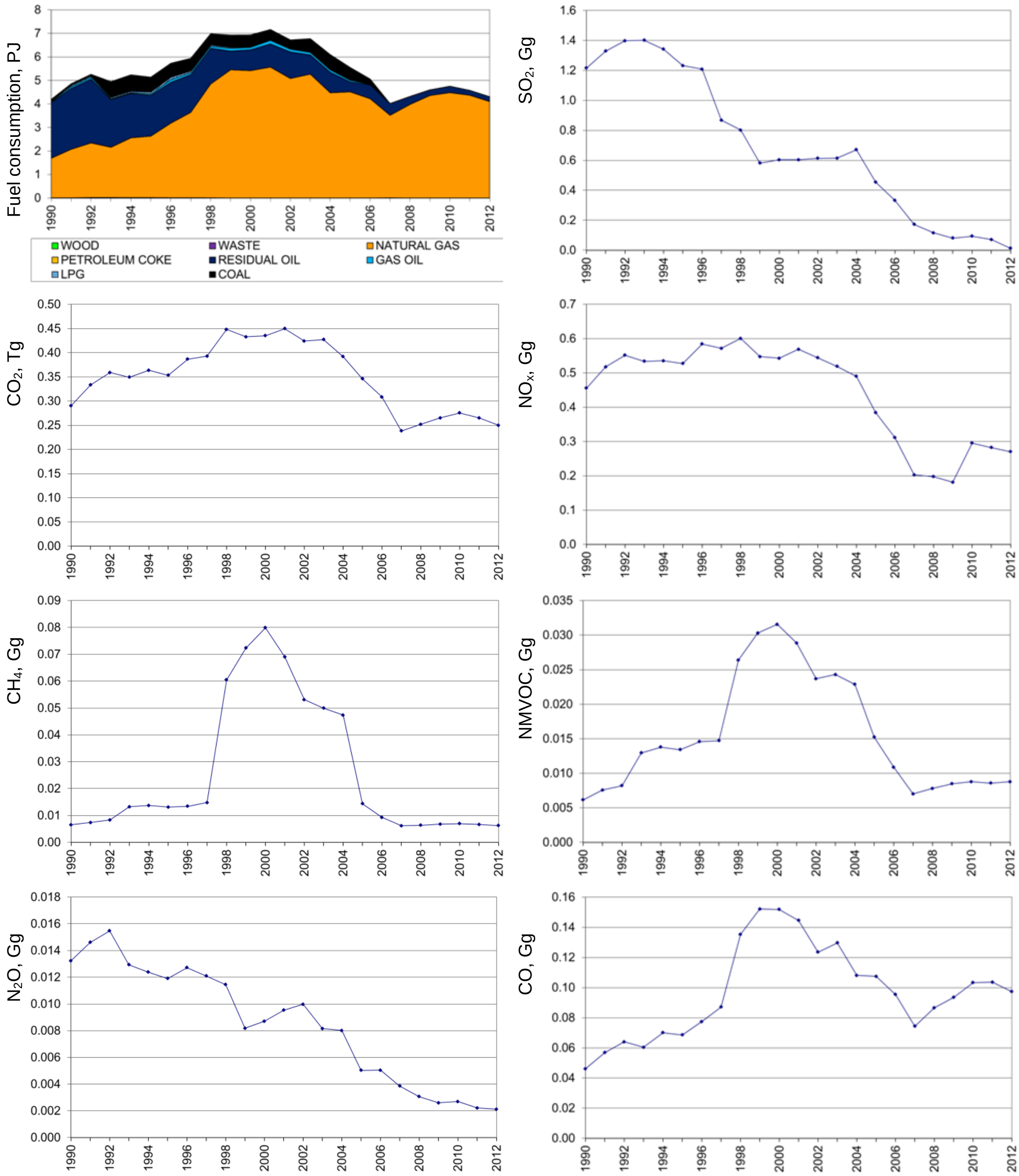


Figure 3.2.34 Time series for 1A2c Chemicals.

1A2d Pulp, paper and print

Pulp, paper and print is a minor emission source category. Figure 3.2.35 shows the time series for fuel consumption and emissions.

Natural gas and - since 2007 - also wood are the main fuels in the subsector. The increased consumption of wood in 2007 onwards is reflected in the CH_4, N_2O, NMVOC and CO emission time series.

The consumption of coal and residual oil has decreased and this is reflected in the SO_2 emission time series.

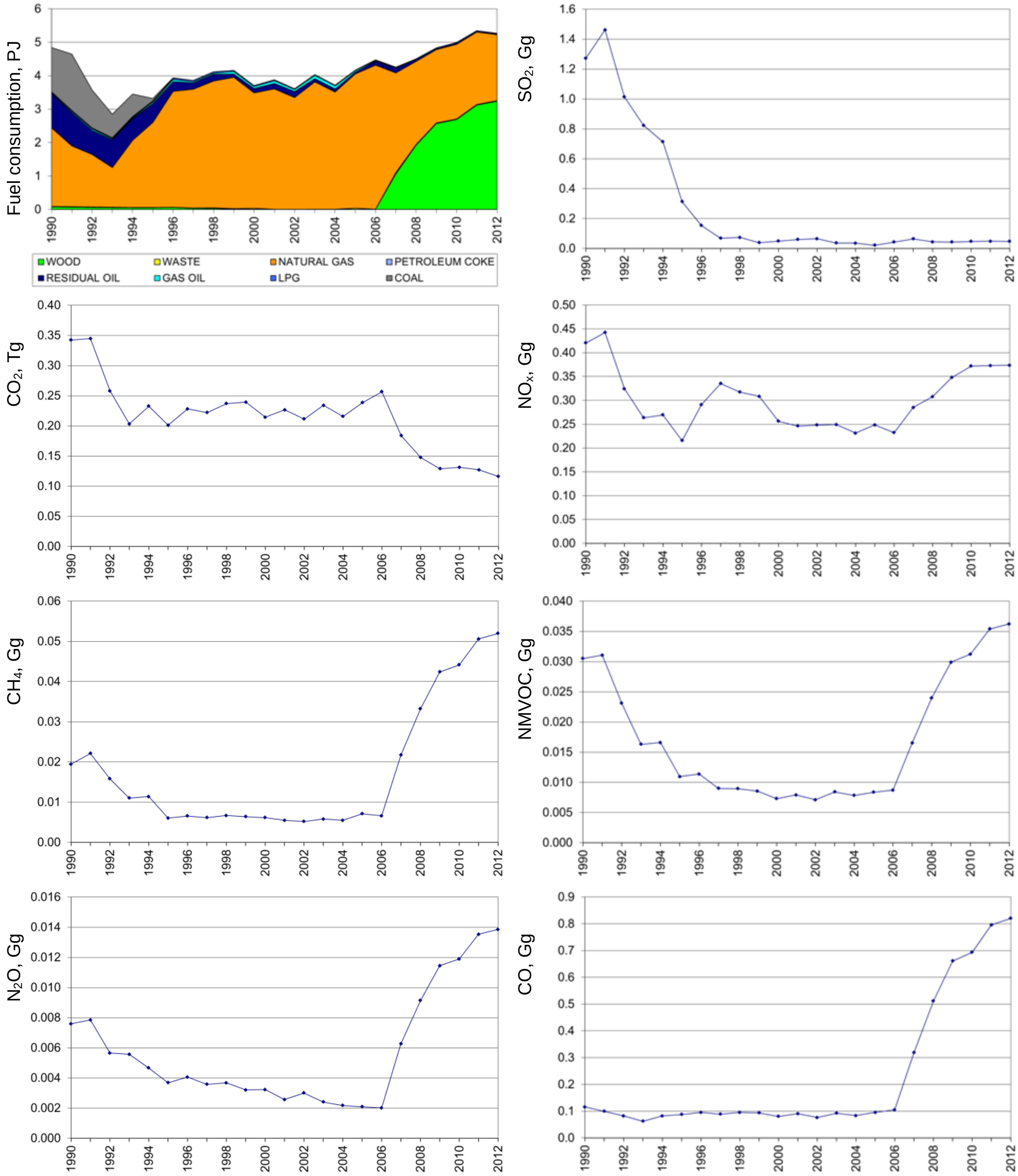


Figure 3.2.35 Time series for 1A2d Pulp, paper and print.

1A2e Food processing, beverages and tobacco

Food processing, beverages and tobacco is a considerable industrial subsector. Figure 3.2.36 shows the time series for fuel consumption and emissions.

Natural gas, residual oil and coal are the main fuels in the subsector. The consumption of coal and residual oil has decreased whereas the consumption of natural gas has increased. This is reflected in the SO_2 emission time series. The time series for CH_4 and NMVOC emission reflects the consumption of natural gas in gas engines.

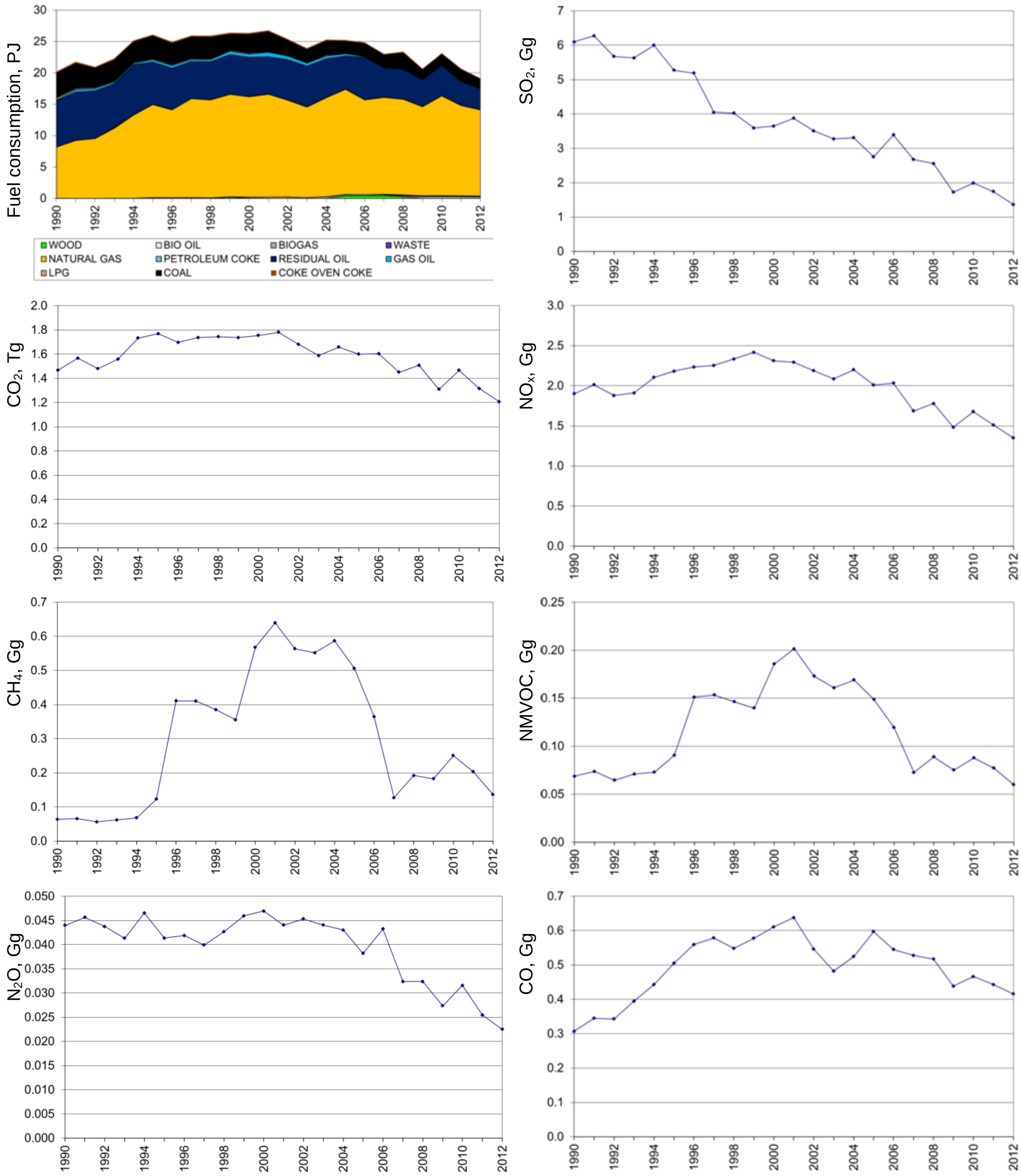


Figure 3.2.36 Time series for 1A2e Food processing, beverages and tobacco.

1A2f Industry – other

Industry - other is a considerable industrial subsector. Figure 3.2.37 shows the time series for fuel consumption and emissions. The subsector includes cement production that is a major industrial emission source in Denmark.

Natural gas is the main fuels in the subsector in recent years. The consumption of coal and residual oil has decreased.

The NO_x time series is discussed above.

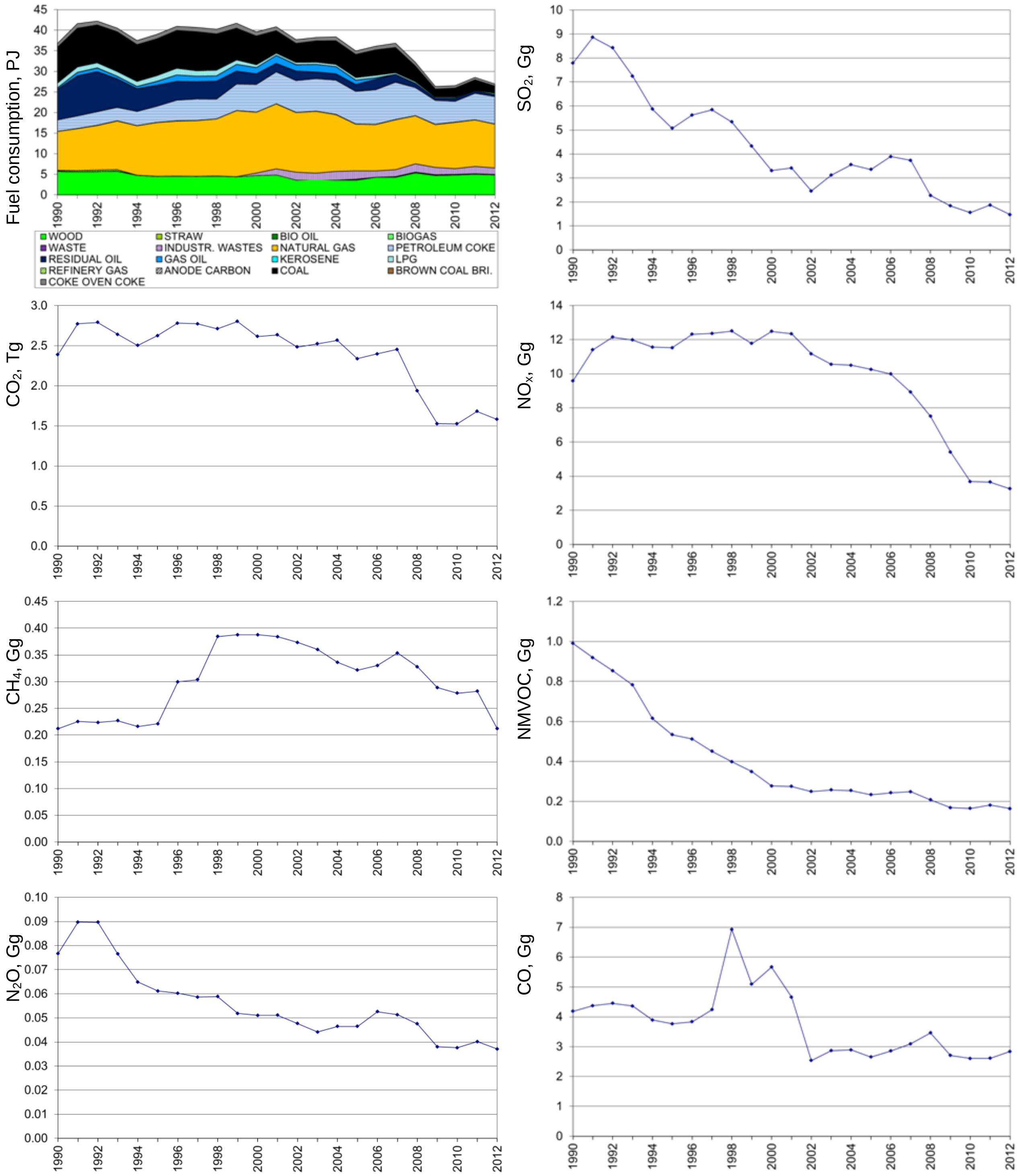


Figure 3.2.37 Time series for 1A2f Industry - other.

1A4 Other Sectors

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

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

Figure 3.2.38-40 present time series for this emission source category. Residential plants is the dominant subcategory accounting for the largest part of all emissions. Time series are discussed below for each subcategory.

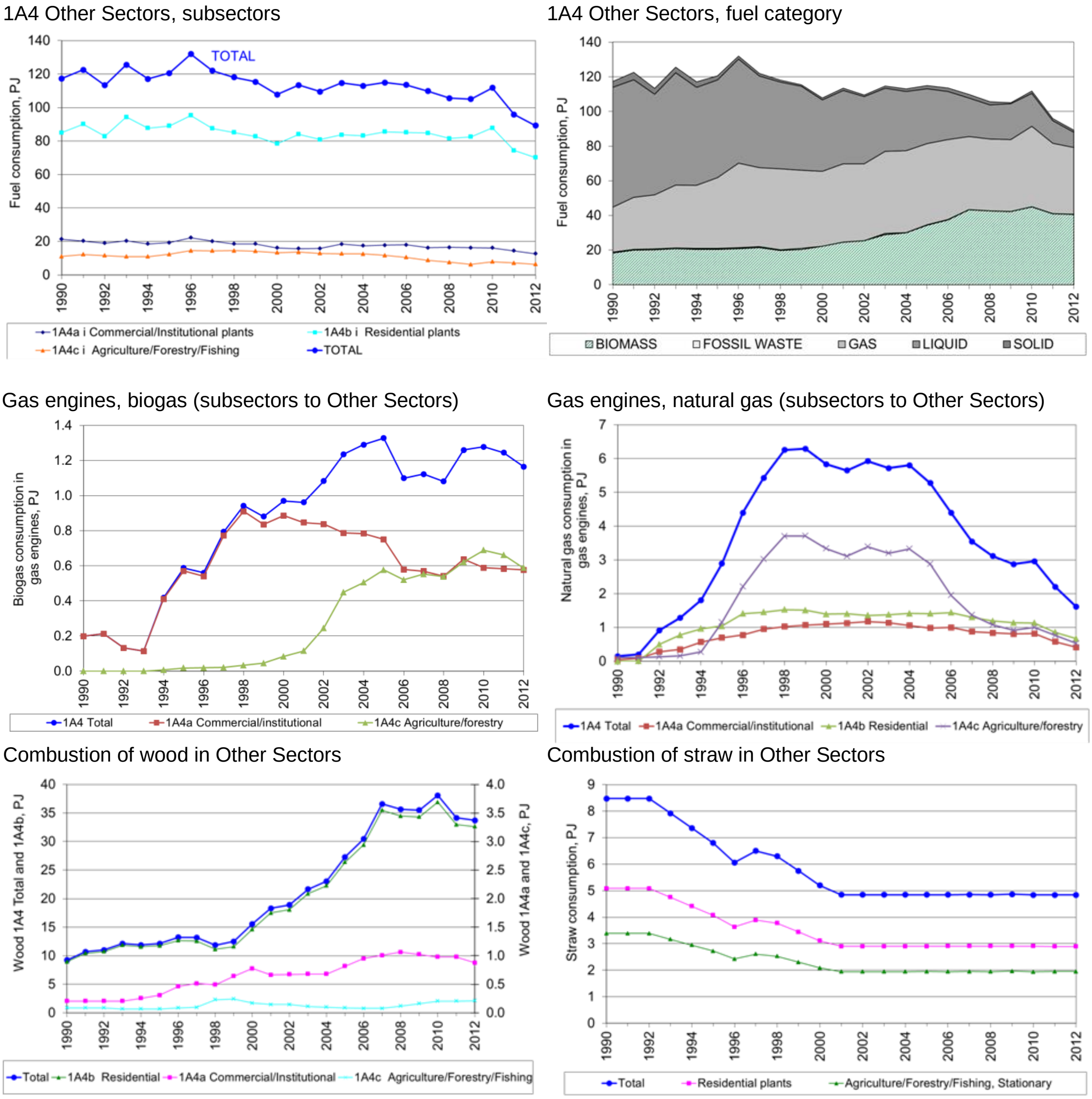


Figure 3.2.38 Time series for fuel consumption, 1A4 Other Sectors.

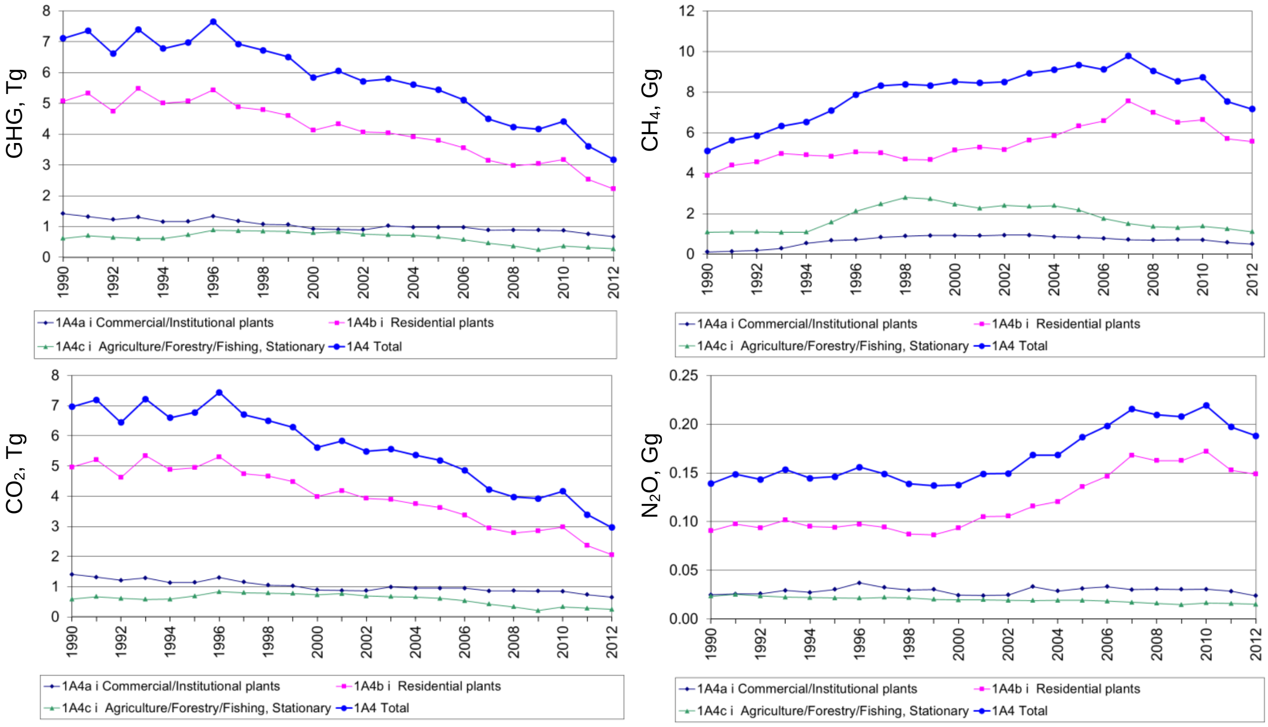


Figure 3.2.39 Time series for greenhouse gas emission, 1A4 Other Sectors.

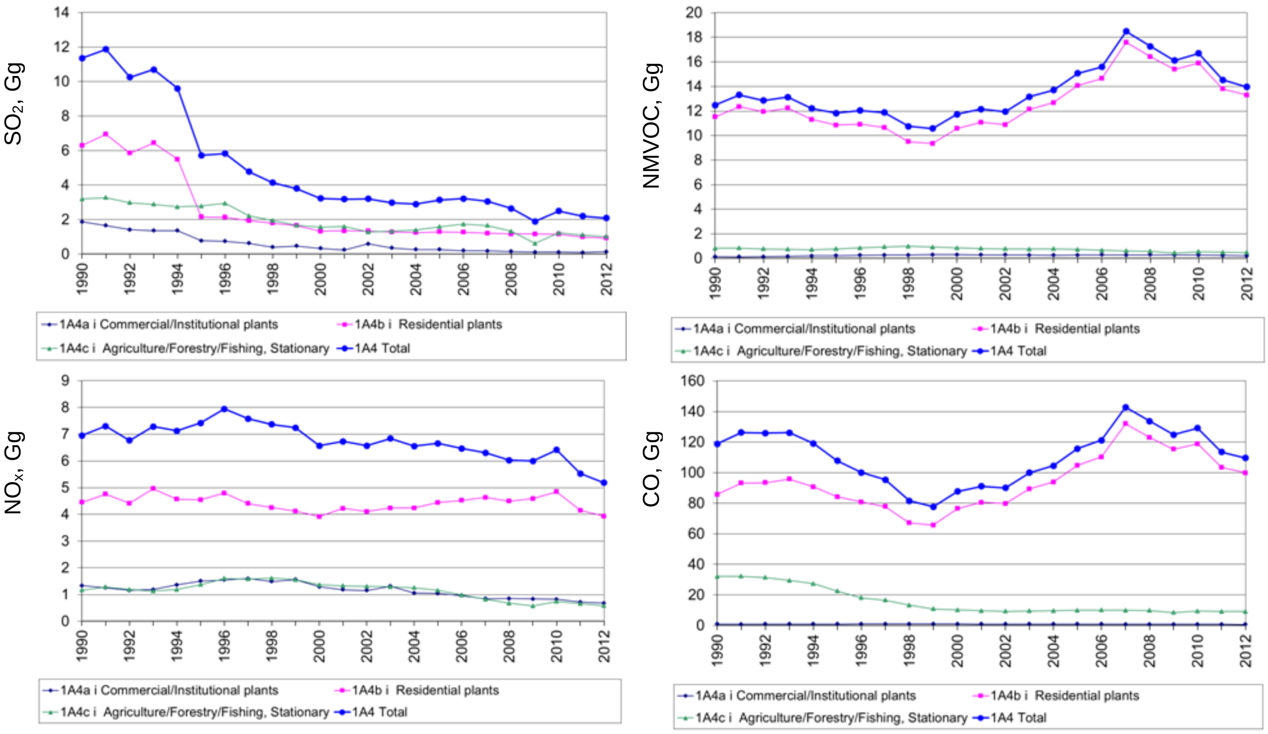


Figure 3.2.40 Time series for SO_2, NO_x, NMVOC and CO emission, 1A4 Other Sectors.

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 3.2.41 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. Figure 3.2.35 shows the time series for fuel consumption and emissions.

The fuel consumption in commercial/institutional plants has decreased 41 % since 1990 and there has been a change of fuel type. The fuel consumption consists mainly of gas oil and natural gas. The consumption of gas oil has decreased whereas the consumption of natural gas has increased since 1990. The consumption of wood and biogas has also increased. The wood consumption in 2012 was 4.3 times the consumption in 1990.

The CO_2 emission has decreased 53 % since 1990. Both the decrease of fuel consumption and the change of fuels – from gas oil to natural gas - contribute to the decreased CO_2 emission.

The CH_4 emission in 2012 was 4.4 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 3.2.32.

The N_2O emission in 2012 was 4 % lower than in 1990. The fluctuations of the N_2O emission follow the fuel consumption.

The SO_2 emission has decreased 92 % since 1990. The decrease is a result of both the change of fuel from gas oil to natural gas and of the lower sulphur content in gas oil and in residual oil. The lower sulphur content (0.05 % for gas oil since 1995 and 0.7 % for residual oil since 1997) is a result of Danish tax laws (DMT, 1998). New boilers and abatement equipment was installed in a large wastewater treatment plant in 2002, but the efficiency of the abatement equipment was not as expected in the first months. Thus, an increased emission from this plant has caused the increased SO_2 emission in 2002.

The NO_x emission was 49 % lower in 2012 than in 1990. The decrease is mainly a result of the lower fuel consumption but also the change from gas oil to natural gas has contributed to the decrease. The emission from gas engines and wood combustion has increased.

The NMVOC emission in 2012 was 54 % higher than the 1990 emission level. The large increase is a result of the increased combustion of wood that is the main source of emission. The increased consumption of natural gas in gas engines (Figure 3.2.32) also contribute to the increased NMVOC emission.

The CO emission has decreased 25 % since 1990. The emission from wood and from natural gas fuelled engines and boilers have increased, whereas the emission from gas oil has decreased. This is a result of the change of fuels applied in the sector.

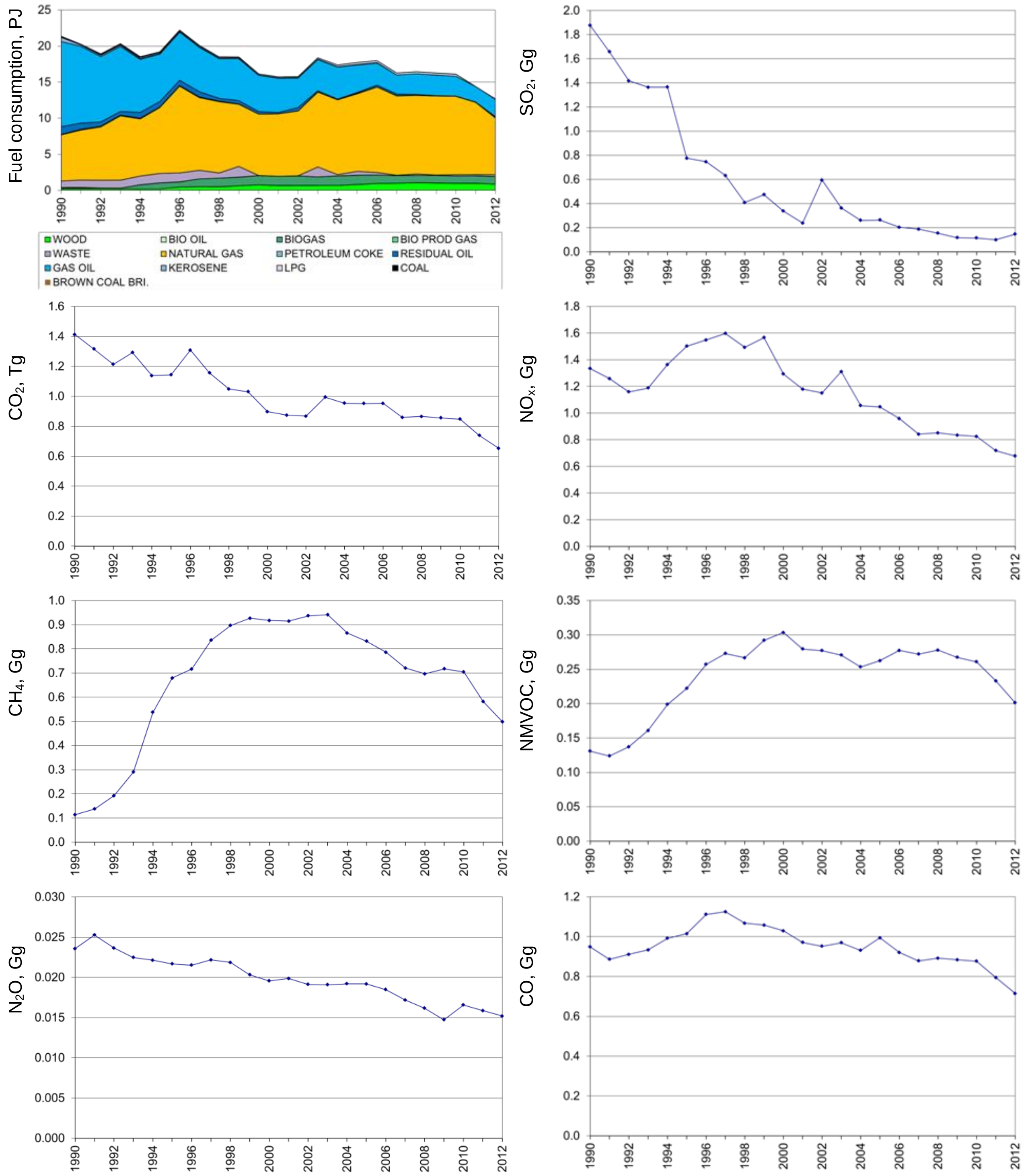


Figure 3.2.41 Time series for 1A4a Commercial/institutional.

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 3.2.42 shows the time series for fuel consumption and emissions.

For residential plants, the total fuel consumption was 17 % lower in 2012 than in 1990. The large decrease from 2010 to 2011 is caused by higher temperature in the winter season of 2012. The consumption of gas oil has decreased since 1990 whereas the consumption of wood has increased considerably (3.6 times the 1990 level). The consumption of natural gas has also increased since 1990.

The CO_2 emission has decreased by 58 % since 1990. This decrease is mainly a result of the considerable change in fuels used from gas oil to wood and natural gas.

The CH_4 emission from residential plants has increased 43 % since 1990 due to the increased combustion of wood in residential plants, which is the main source of emission. The increased emission from gas engines also contributes to the increased emission.

The change of fuel from gas oil to wood has resulted in a 64 % increase of N_2O emission since 1990 due to a higher emission factor for wood than for gas oil.

The large decrease (85 %) of SO_2 emission from residential plants is mainly a result of a change of sulphur content in gas oil since 1995. The lower sulphur content (0.05 %) is a result of Danish tax laws (DMT, 1998). In addition, the consumption of gas oil has decreased and the consumption of natural gas that results in very low SO_2 emissions has increased.

The NO_x emission has increased by 15 % since 1990 due to the increased emission from wood combustion. The emission factor for wood is higher than for gas oil.

The emission of NMVOC has increased 15 % since 1990 as a result of the increased combustion of wood. The emission factor for wood has decreased since 2000, due to improved technology, but not as much as the increase in consumption of wood. The emission factor for wood and straw is higher than for liquid or gaseous fuels.

The CO emission has increased 16 % due to the increased use of wood that is the main source of emission. The emission factor for wood has decreased since 2000, due to improved technology, but not as much as the increase in consumption of wood. The emission from combustion of straw has decreased since 1990.

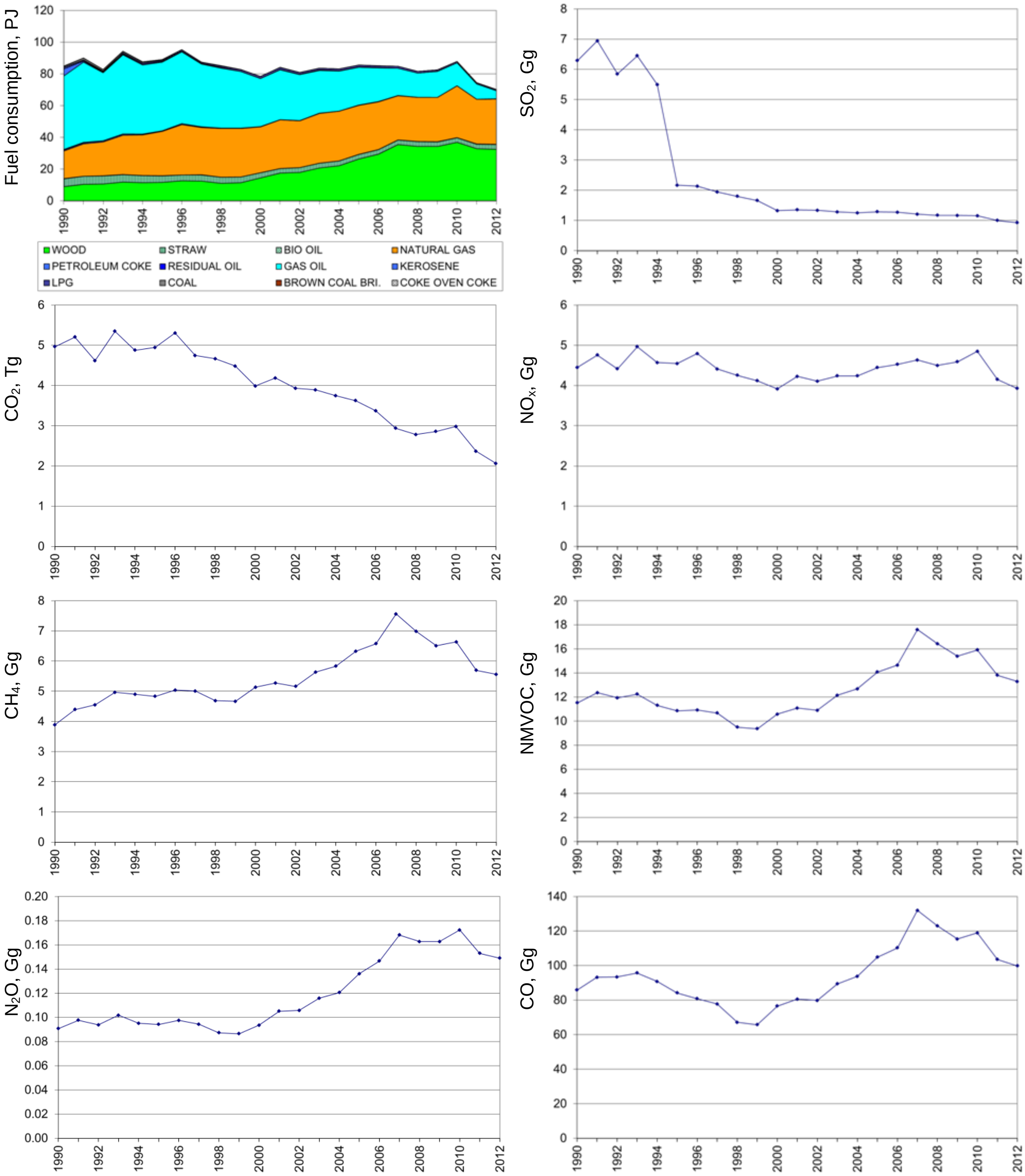


Figure 3.2.42 Time series for 1A4b Residential plants.

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 3.2.43 shows the time series for fuel consumption and emissions.

For plants in agriculture/forestry, the fuel consumption has decreased 42 % since 1990. A considerable decrease in the fuel consumption has taken place since year 2000.

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 in recent years, the consumption decreased again. A large part of the natural gas consumption has been applied in gas engines (Figure 3.2.32). Most CHP plants in agriculture/forestry based on gas engines came in operation in 1995-1999. The decrease in later years is a result of the liberalisation of the electricity market.

The consumption of straw has decreased since 1990. The consumption of both residual oil and gas oil has increased after 1990 but has decreased again in recent years.

The CO_2 emission in 2012 was 57 % 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 2012 was 2 % higher than the emission in 1990. The emission follows the time series for natural gas combusted in gas engines (Figure 3.2.32). 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 36 % 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.

The SO_2 emission was 68 % lower in 2012 than in 1990. The emission decreased mainly in the years 1996-2002. The main emission sources are coal, residual oil and straw.

The emission of NO_x was 50 % lower in 2012 than in 1990.

The emission of NMVOC has decreased 42 % since 1990. The major emission source is combustion of straw. The consumption of straw has decreased since 1990. The emission from gas engines has increased mainly due to increased fuel consumption.

The CO emission has decreased 72 % since 1990. The major emission source is combustion of straw. In addition to the decrease of straw consumption, the emission factor for straw has also decreased since 1990.

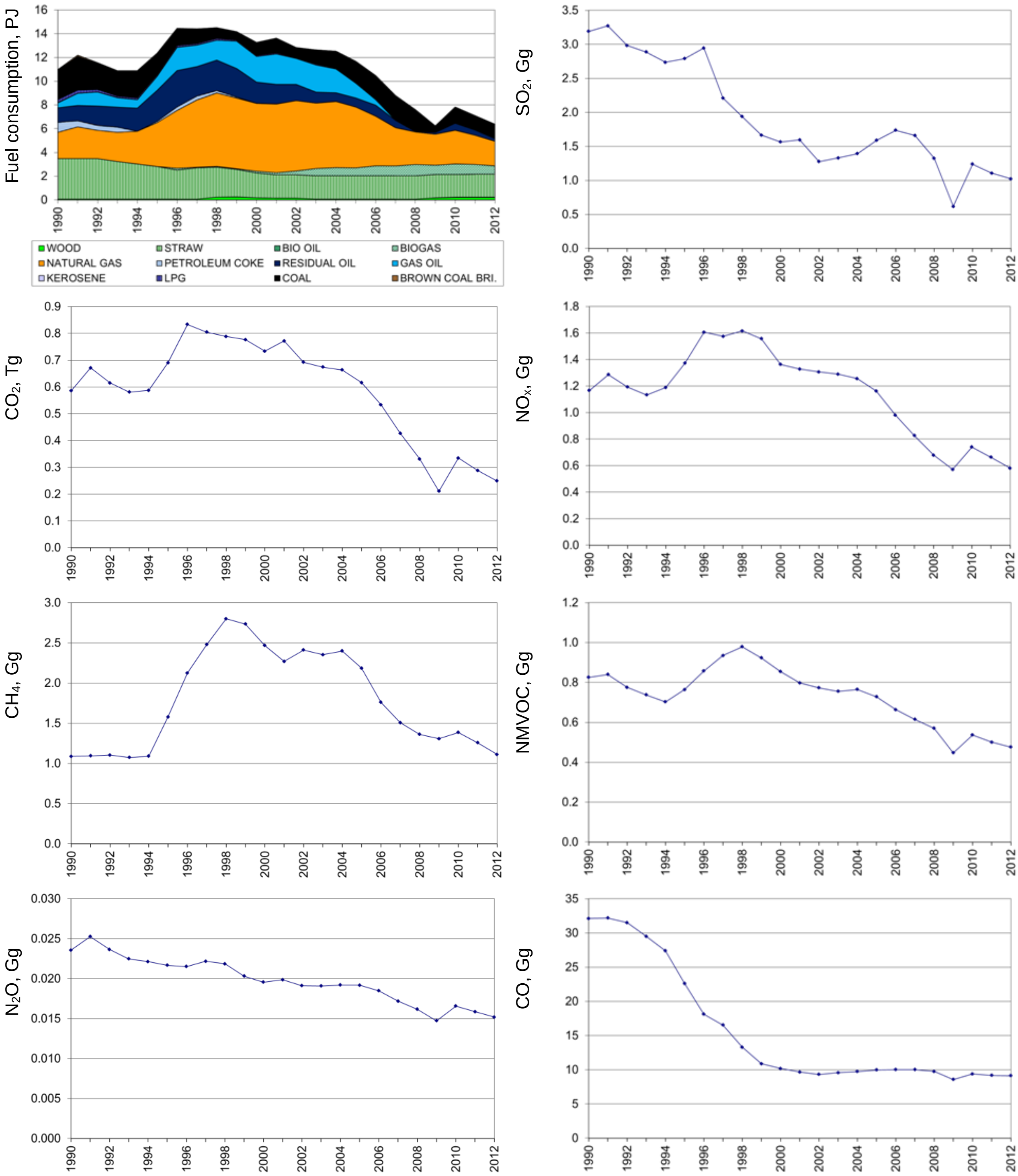


Figure 3.2.43 Time series for 1A4c Agriculture/Forestry.

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 EMEP/CORINAIR Emission Inventory Guidebook 2009 update, prepared by the UNECE/EMEP Task Force on Emissions Inventories and Projections (EEA, 2009). Emission data are stored in an Access database, 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.

Tiers

The type of emission factor and the applied tier level for each emission source are shown in Table 3.2.13 below. The tier levels have been determined based on the IPCC Guidelines (IPCC, 1997).

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 comsumption rates have been estimated.

Distinguishing between tier level 2 and tier 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 either a few emission measurements or IPCC tier 2 emission factors.
- Tier 3: Based on plant specific emission data or on a country specific emission factor based on a considerable number of plant specific emission measurements and detailed technology knowledge.

Table 3.2.13 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 source analysis[12].

[12] Key category according to the KCA tier 1 or tier 2 for Denmark (excluding Greenland and Faroe Islands), including LULUCF, level 1990/ level 2012/ trend.

Table 3.2.13 Methodology and type of emission factor.

		Tier	EMF[1)]	Key category[2)]
Stationary Combustion, Coal	CO_2	Tier 3[13] (Tier 3) /Tier 1[14]	PS (CS) / D	Yes
Stationary Combustion, BKB	CO_2	Tier 1	D	No
Stationary Combustion, Coke	CO_2	Tier 1	D	No
Stationary Combustion, Fossil waste	CO_2	Tier 3	CS	Yes
Stationary Combustion, Petroleum coke	CO_2	Tier 3	PS/CS	Yes
Stationary Combustion, Residual oil	CO_2	Tier 3 / Tier 3 / Tier 1	PS / CS / D[15]	Yes
Stationary Combustion, Gas oil	CO_2	Tier 2 / Tier 3	CR / PS	Yes
Stationary Combustion, Kerosene	CO_2	Tier 1	D	Yes
Stationary Combustion, LPG	CO_2	Tier 1	D	No
Stationary Combustion, Refinery gas	CO_2	Tier 3	PS / CS	Yes
Stationary Combustion, Natural gas	CO_2	Tier 3	CS / PS[16]	Yes
Stationary Combustion, SOLID	CH_4	Tier 2 / Tier 1	D(2) / D	No
Stationary Combustion, LIQUID	CH_4	Tier 2 / Tier 2 / Tier 1	D(2) / CS / D	No
Stationary Combustion, GAS	CH_4	Tier 2 / Tier 3	D(2) / CS	No
Natural gas fuelled engines, GAS	CH_4	Tier 3	CS	Yes
Stationary Combustion, WASTE	CH_4	Tier 2	CS	No
Stationary Combustion, BIOMASS	CH_4	Tier 2 / Tier 1	D(2) / CS / D	Yes
Biogas fuelled engines, BIOMASS	CH_4	Tier 3	CS	No
Stationary Combustion, SOLID	N_2O	Tier 2 / Tier 1	CS / D	Yes
Stationary Combustion, LIQUID	N_2O	Tier 2 / Tier 1	D(2) / D / CS	Yes
Stationary Combustion, GAS	N_2O	Tier 1 / Tier 2	D / CS / D(2)	Yes
Stationary Combustion, WASTE	N_2O	Tier 2	CS	No
Stationary Combustion, BIOMASS	N_2O	Tier 1 / Tier 2	D / CS / D(2)	Yes

1) D: IPCC tier 1, D(2): IPCC tier 2/3, CR: Corinair default, CS: Country specific, PS: Plant specific.

2) KCA tier 1 or tier 2 for Denmark (excluding Greenland and Faroe Islands), including LULUCF, level 1990/level 2012/ trend

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 2012, 62 stationary combustion plants are specified as large point sources. These point sources include:

- Power plants and decentralised CHP plants (combined heat and power plants).
- Waste incineration plants.
- Large industrial combustion plants.
- Petroleum refining plants.

The criteria for selection of point sources consist of the following:

- All centralized power plants, including smaller units.
- All units with a capacity 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, 2010a).

13 For 2006 onwards. Country specific emission factors and tier 2 have been applied for 1990-2005.

14 Tier 1 and IPCC default emission factor is only applied for 2 % of the coal consumption in 2012.

15 Residual oil not applied in source category 1A1a.

16 Off shore gas turbines and some power plants.

- 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 2012 inventory was 225 PJ. This corresponds to 51 % of the overall fuel consumption for stationary combustion.

A list of the large point sources for 2012 and the fuel consumption rates is provided in Annex 3A-5. The number of large point sources registered in the databases increased from 1990 to 2012.

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. Annex 3A-5 shows which of the emission data for large point sources are plant-specific and the corresponding share of the emission from stationary combustion.

The emission shares from point sources with plant specific data are shown in Table 3.2.14.

Table 3.2.14 Emission share, plant specific data.

Pollutant	Share from plant specific data
CO_2	63 %
CH_4	0 %
N_2O	0 %
SO_2	52%
NO_x	43%
NMVOC	0.02%
CO	2.7%

CO_2 emission factors are plant specific for the major power plants, refineries, off shore gas turbines and for cement production. SO_2 and NO_x emissions from large point sources are often plant-specific based on emission measurements. Emissions of CO and NMVOC are also plant-specific for some plants. Plant-specific emission data are obtained from:

- CO_2 data reported under the EU Emission Trading Scheme (ETS).
- Annual environmental reports / environmental reporting available on the Danish EPA home page[17]
- Annual plant-specific reporting of SO_2 and NO_x from power plants >25MW_e prepared for the Danish Energy Agency and Energinet.dk.
- Emission data reported by DONG Energy and Vattenfall, the two major electricity suppliers.
- Emission data reported from industrial plants.

The EU ETS data are discussed in the chapter Emission factors.

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

[17] http://www3.mst.dk/Miljoeoplysninger/PrtrPublicering/Index

If plant-specific emission factors are not available, general area source emission factors are used.

Emissions of the greenhouse gases CH_4 and N_2O from the large point sources are all based on the area source emission factors.

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 (see page 157).

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 3A-9.

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, 2013c).

The fuel consumption data flow is shown in Figure 3.2.44.

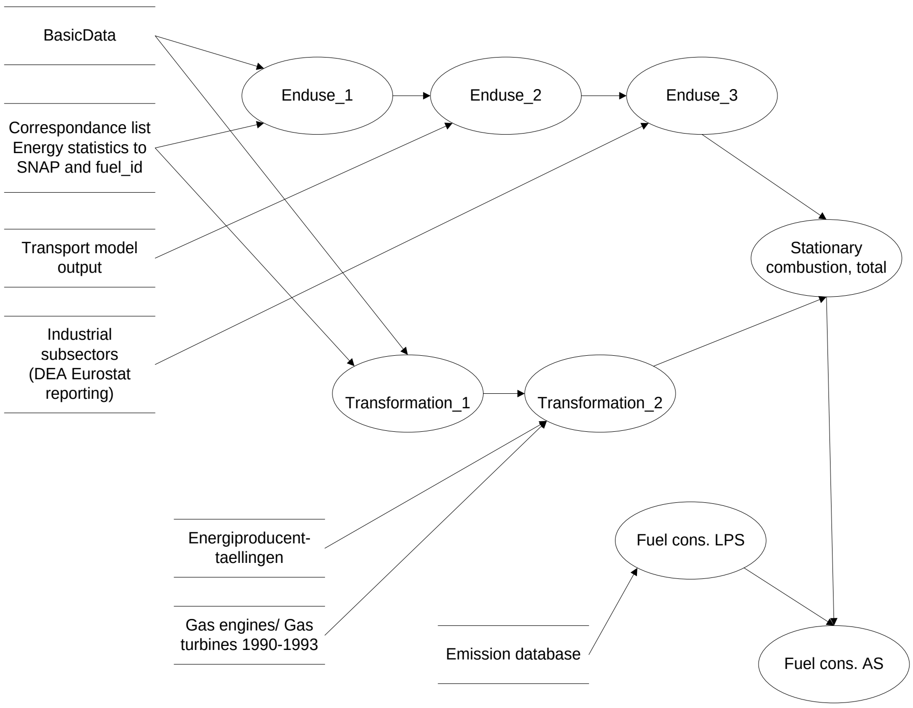


Figure 3.2.44 Fuel consumption data flow.

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 628 TJ in 2012) is not included in the Danish inventory. This is in agreement with the IPCC Guidelines (IPCC, 1997).

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 157.

For all other large point sources, the fuel consumption refers to a DEA database (DEA, 2013b). The DEA compiles a database for 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 DEA database (DEA, 2013b) is checked by the DEA and any 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 of large point sources.

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. 11.5 PJ in 2012. The use of white spirit is included in the inventory in *Solvent and other product use*. The emissions associated with the use of bitumen and lubricants are included in *Industrial Processes.* The non-energy use of fuels is included in the reference approach for Climate Convention reporting and appropriately corrected in line with the Revised 1996 IPCC Guidelines (IPCC, 1997).

In Denmark, all waste incineration are 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.

Town gas

Town gas 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 2012. 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. The use of coal for town gas production ceased in the early 1980s.

An indicative composition of town gas according to the largest supplier of town gas in Denmark is shown in Table 3.2.15 (KE, 2014).

Table 3.2.15 Composition of town gas, 2012 (KE, 2014).

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 currently used is 19.3 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 of 56.97 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 3.2.16 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, 2008; Kristensen, 2007). The data refer to three measurements performed several years apart; the first in 2000 and the latest in 2005.

Table 3.2.16 Composition of town gas, information from the period 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

The lower calorific value has 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 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.

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 3.2.45. In 2009[18], 3 % of the incinerated waste was hazardous waste[19].

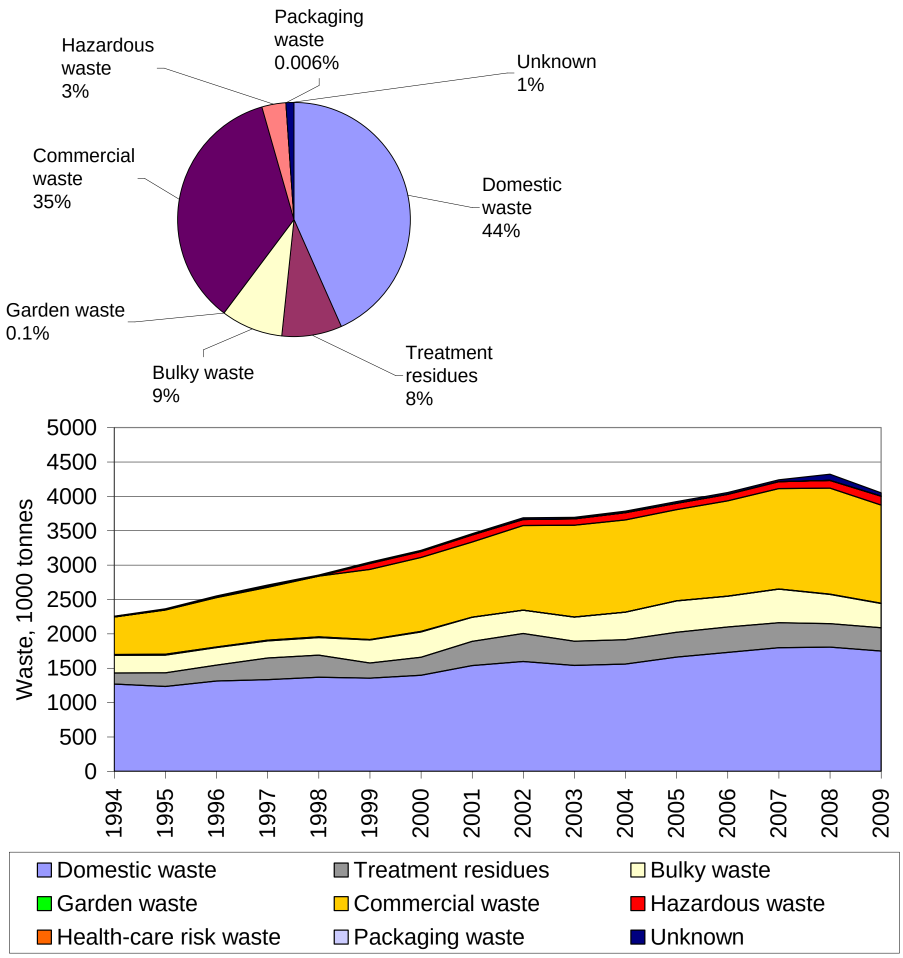


Figure 3.2.45 Waste fractions (weight) for incinerated waste in 2009 and the corresponding time series 1994-2009 (ISAG, 2012).

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[20]. The Danish energy statistics specifies production and consumption of each of the biogas types. In 2012, 75 % of the applied biogas was based on manure /organic waste.

[18] Currently, data are only available for 1994-2009.
[19] In 2001 onwards, health-care risk waste is included in hazardous waste in the ISAG database.
[20] Based on manure with addition of other organic waste.

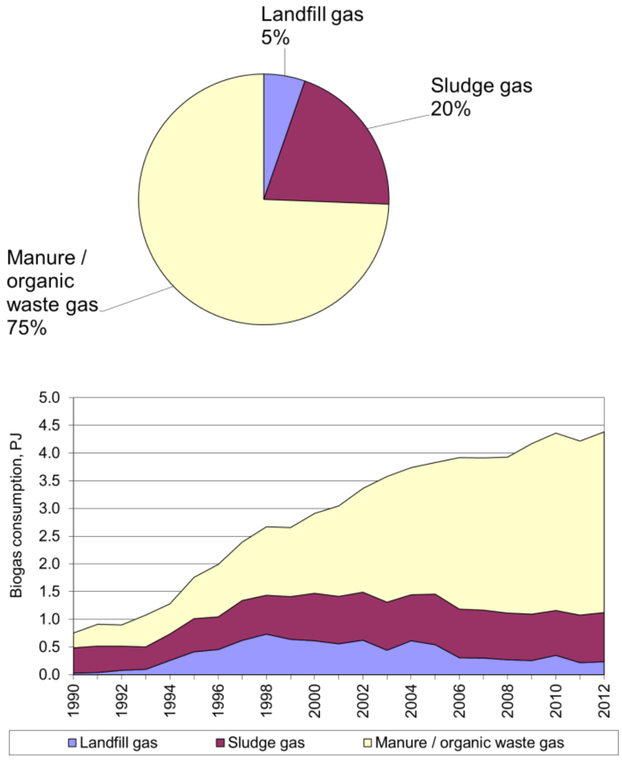


Figure 3.2.46 Biogas types 2012 and the corresponding time series 1990-2012 (DEA, 2013a).

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 emission factors are either nationally referenced or based on the international guidebooks: EMEP/EEA Guidebook (EEA, 2013)[21] and IPCC Guidelines (IPCC, 1997).

An overview of the type of CO_2 emission factor is shown in Table 3.2.13. 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 is based on EU ETS data[22]. The EU ETS data have been applied for the years 2006 - 2012.

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

ETS data, methodology, criteria for implementation and QA/QC

The Danish emission inventory for stationary combustion only includes data from plants using higher tier methods as defined in the EU decision (EU Commission, 2007), 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.

[21] And former editions of the EMEP/EEA and EMEP/Corinair Guidebook.
[22] See page 134 and 134.

For each of the plants included individually 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 plants/fuels included individually in the Danish inventory all apply the Tier 3 methodology for calculating the CO_2 emission factor. This selection criteria results in a dataset for which the emission factor values are based on fuel quality measurements[23], not default values from the Danish UNFCCC reporting. All fuel analyses are performed according to ISO 17025.

The power plants/fuels selected based on emission factor methodology apply the tiers for activity data, net calorific value (NCV), emission factor and oxidation factor listed below.

Coal

The CO_2 emission factor for coal is based on analysis of C content of the coal (g C per kg) and coal weight measurements. However, NCV values are also measured according to high tier methods in spite of the fact that this value is not input data for the calculation of total CO_2 emission.

- Fuel flow: Tier 4 methodology (± 1.5 %). For coal, the activity data (weight) is based on measurements on belt conveyor scale. The uncertainty is below the required ± 1.5 %.
- NCV: Tier 3 methodology. Data are based on measurements according to ISO 13909 / ISO 18283 (sampling) and ISO 1928 (NCV). The uncertainty for data is below ± 0.5 %.
- Emission factor: The emission factor is C-content of the coal. Tier 3 methodology (± 0.5 %) is applied and the measurements are performed according to ISO 13909 (sampling) and ISO/TS 12902 (C-content).
- Oxidation factor: Based on Tier 3 methodology except for one plant that applies Tier 1 methodology[24]. The Tier 3 methodology is based on measurements of C-content in bottom ash and fly ash according to ISO/TS 12902 or on burning loss measurements according to ISO 1171. The uncertainty has been estimated to 0.5 %. For Tier 1 the oxidation factor is assumed to be 1.

Residual oil

- Fuel flow: Tier 4 methodology (± 1.5 %) for most plants. However, a few of the included plants apply Tier 3 methodology (± 2.5 %).
- NCV: Tier 3 methodology. Data are based on sampling according to API Manual of Petroleum Measurement Standards / ASTM D 270 and fuel analysis (NCV) according to ASTM D 240 / ISO 1928 / data stated by the fuel supplier.
- Emission factor: Tier 3 methodology according to API Manual of Petroleum Measurement Standards / ASTM D 4057 (sampling) and ISO 12902 / ASTM D 5291 (C-content).
- Oxidation factor: Based on Tier 2 or Tier 3 methodology, both resulting in the oxidation factor 1 with an uncertainty of 0.8 %.

[23] Applying specific methods defined in the EU decision
[24] In addition, DCE have assumed the oxidation factor to be 1 for a plant for which the stated oxidation factor was rejected in the QC work.

For coal and residual oil fuel analyses are required for each 20,000 tonnes or at least six times each year. The fuel analyses are performed by accredited laboratories[25].

QC of EU ETS data

DCE performs QC checks on the reported emission data, see Chapter 1.4.10. Based on the QC checking DCE excluded the oxidation factor for coal for one stationary combustion plant for 2012.

EU ETS data presentation

The EU ETS data include plant specific emission factors for coal, residual oil, gas oil, natural gas, refinery gas, petroleum coke and fossil waste. The EU ETS data account for 63 % of the CO_2 emission from stationary combustion.

EU ETS data for coal

EU ETS data for 2012 were available from 15 coal fired plants. The plant specific information accounts for 98 % of the Danish coal consumption and 43 % of the total (fossil) CO_2 emission from stationary combustion plants. The average CO_2 emission factor for coal for these 15 units was 94.25 kg per GJ (Table 3.2.17. The plants all apply bituminous coal.

Data from two plants have been excluded in the calculation of the implied emission factor for coal because the coal applied in those plants is not representative for the coal applied in Denmark. However, both data sets have been included in the inventories and in Table 3.2.17 below. The estimated IEF for CO_2 is however 94.25 kg/GJ in both cases.

Table 3.2.17 EU ETS data for 15 coal fired plants, 2012.

	Average	Min	Max
Heating value, GJ per tonne[26]	24.11	23.5	26.6
CO_2 implied emission factor, kg per GJ[1)]	94.25	91.4	96.4
Oxidation factor	0.996	0.988	1.000

[1)] Including oxidation factor.

Table 3.2.18 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	94.3

[1)] Including oxidation factor.

EU ETS data for residual oil

EU ETS data for 2012 based on higher tier methodologies were available from 13 plants combusting residual oil. Aggregated data and time series are shown in Table 3.2.19 and Table 3.2.20. The EU ETS data accounts for 53 % of the residual oil consumption in stationary combustion.

[25] EN ISO 17025.

[26] One data set has been excluded as part of the QC work.

Table 3.2.19 EU ETS data for 13 plants combusting residual oil.

	Average	Min	Max
Heating value, GJ per tonne	40.5	40.2	40.7
CO_2 implied emission factor, kg per GJ	79.21	77.30	80.48
Oxidation factor	1.000	1.000	1.000

Table 3.2.20 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

[1)] Including oxidation factor

EU ETS data for gas oil combusted in power plants or refineries

EU ETS data for 2012 based on higher tier methodologies were included from 4 plants combusting gas oil. Aggregated data and time series are shown in Table 3.2.21 and Table 3.2.22. The EU ETS data accounts for 10 % of the gas oil consumption in stationary combustion.

Table 3.2.21 EU ETS data for gas oil applied in power plants/refineries.

	Average	Min	Max
Heating value, GJ per tonne	35.9	34.1	35.9
CO_2 implied emission factor, kg per GJ	73.92	73.73	75.15
Oxidation factor	1.000	1.000	1.000

Table 3.2.22 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

[1)] Including oxidation factor.

EU ETS data for petroleum coke and waste applied in industrial plants

Plant specific CO_2 emission factors from EU ETS have also been applied for the some industrial plants including cement industry, sugar production, glass wood production, lime production, and vegetable oil production. The implemented EU ETS data set also includes CO_2 emission factors for petroleum coke and waste applied in industrial plants.

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 applied in offshore gas turbines, see page 166.

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 165.

CO_2, other 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 37 % of the fossil CO_2 emission.

The CO_2 emission factors applied for 2012 are presented in Table 3.2.23. Time series have been estimated for:

- Coal applied for production of electricity and district heating
- Residual oil applied for production of electricity and district heating
- Refinery gas
- Natural gas applied in off shore gas turbines
- Natural gas, other
- Industrial waste, biomass part

For all other fuels, the same emission factor has been applied for 1990-2012.

In the reporting to the UNFCCC, the CO_2 emission is aggregated to five fuel types: Solid fuels, Liquid fuels, Gaseous fuels, Biomass and Other fuels. The correspondence list between the DCE fuel categories and the IPCC fuel categories is also provided in Table 3.2.23.

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 (37 + 75.1 kg per GJ) 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. In the IPCC reporting, the fuel consumption and emissions from the fossil content of the waste is reported in the fuel category, *Other fuels*.

Table 3.2.23 CO_2 emission factors, 2012.

Fuel	Emission factor kg per GJ Bio-mass	Fossil fuel	Reference type	IPCC fuel category
Coal, source category 1A1a Public electricity and heat production		94.25 1)	Country specific	Solid
Coal, Other source categories		94.6 3)	IPCC (1997)	Solid
Brown coal briquettes		94.6	IPCC (1997)	Solid
Coke oven coke		108	IPCC (1997)	Solid
Other solid fossil fuels 6)		108 1)	IPCC (1997)	Solid
Fly ash fossil (from coal)		93.6	Country specific	Solid
Petroleum coke		93 3)	Country specific	Liquid
Residual oil, source category 1A1a Public electricity and heat production		79.21 1)	Country specific	Liquid
Residual oil, other source categories		77.4 3)	IPCC (1997)	Liquid
Gas oil		74 1)	EEA (2007)	Liquid
Kerosene		71.9	IPCC (1997)	Liquid
Orimulsion		80 2)	Country specific	Liquid
LPG		63.1	IPCC (1997)	Liquid
Refinery gas		58.099	Country specific	Liquid
Natural gas, off shore gas turbines		57.423	Country specific	Gas
Natural gas, other		57.03	Country specific	Gas
Waste	75.1 3)4)	+ 37 3)4)	Country specific	Biomass and Other fuels
Straw	110		IPCC (1997)	Biomass
Wood	110		IPCC (1997)	Biomass
Bio oil	74		Country specific	Biomass
Biogas	83.6		Country specific	Biomass
Biomass producer gas	142.9 5)		Country specific	Biomass

1) Plant specific data from EU ETS incorporated for individual plants.
2) Not applied in 2012. Orimulsion was applied in Denmark in 1995 – 2004.
3) Plant specific data from EU ETS incorporated for cement industry and sugar, lime and glass wool production.
4) The emission factor for waste is (37+75.1) 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 fuels* in CRF. The IEF[27] for CO_2, Other fuels is 82.22 kg CO_2 per GJ fossil waste.
5) Includes a high content of CO_2 in the gas.
6) Anodic carbon.

Coal

As mentioned above[28], EU ETS data have been utilised for the years 2006 - 2012 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. Data from two plants have been excluded in the calculation of the implied emission factor for coal because the coal applied in those plants is not representative for the coal applied in Denmark. However, it turns out that the consumption in these two plants is sufficiently low to not influence the resulting implied emission factor. In 2012, the implied emission factor (including oxidation factor) was 94.25 kg per GJ. The implied emission factor values were between 92.81 and 96.36 kg per GJ.

In 2012, only 2 % of the CO_2 emission from coal consumption was based on the emission factor, whereas 98 % of the coal consumption was covered by EU ETS data. All coal applied in Denmark is bituminous coal (DEA, 2013c).

[27] Not including cement production.
[28] EU ETS data for CO2 on page 60.

The emission factors for coal combustion in *Public electricity and heat production* in the years 2006-2012 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 in *Public electricity and heat production* refer to the average IEF for 2006-2009.

Time series for net calorific value (NCV) of coal are available in the Danish energy statistics. NCV for *Electricity plant coal* fluctuates in the interval 24.23-25.8 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-10. 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-10. 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.

As mentioned above all coal applied in Denmark is bituminous coal and within the range of coal qualities applied in the plants reporting data to EU ETS a correlation could not be documented.

For other sectors apart from 1A1a, the applied emission factor 94.6 kg per GJ refers to IPCC Guidelines (IPCC, 1997). This emission factor has been applied for all years.

Time series for the CO_2 emission factor are shown in Table 3.2.24.

Table 3.2.24 CO_2 emission factors for coal, time series.

Year	1A1a Public electricity and heat production kg per GJ	Other source categories kg per GJ
1990-2005	94.0	94.6
2006	94.4	94.6
2007	94.3	94.6
2008	94.0	94.6
2009	93.6	94.6
2010	93.6	94.6
2011	93.73	94.6
2012	93.25	94.6

Brown coal briquettes

The emission factor for brown coal briquettes, 94.6 kg per GJ, is based on a default value from the IPCC Guidelines (IPCC, 1997) assuming full oxidation. The default value in the IPCC Guidelines is 25.8 t C per TJ, corresponding to $25.8 \cdot (12+2 \cdot 16)/12$ = 94.6 kg CO_2 per GJ assuming full oxidation. The same emission factor has been applied for 1990-2012.

Coke oven coke

The emission factor for coke oven coke, 108 kg per GJ, is based on a default value from the IPCC Guidelines (IPCC, 1997) assuming full oxidation. The default value in the IPCC guidelines is 29.5 t C per TJ, corresponding to $29.5 \cdot (12+2 \cdot 16)/12$ = 108 kg CO_2 per GJ assuming full oxidation. The same emission factor has been applied for 1990-2012.

Other solid fossil fuels (Anodic carbon)

Anodic carbon has been applied in Denmark in 2009-2012 in two mineral wool production units. EU ETS data are available for both plants and thus the area source emission factor (108 kg/GJ) have not been applied.

Fly ash fossil (from coal)

Fly ash from coal combustion is applied in some power plants. The emission factor 93.6 kg/GJ have been applied. This is the emission factor for coal consumption in power plants in 2009-2010. The emission factor for 1990-2005 will be applied in future inventories (94 kg/GJ).

The emission factor have however not been applied due to the fact that plant specific data are available from the EU ETS dataset.

Petroleum coke

The emission factor for petroleum coke has been recalculated in this inventory. The improved 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 - 2012. This consumption represents more than 98 % of the consumption of petroleum coke in Denmark.

Residual oil

The emission factor for residual oil applied in public electricity and heat production is based on EU ETS data.

As mentioned above[29] EU ETS data have been utilised for the 2006 - 2012 emission inventories. In 2012, the implied emission factor (including oxidation factor) for the power plants and refineries combusting residual oil was 79.21 kg per GJ. The implied emission factor values were between 77.30 and 80.48 kg per GJ.

In 2012, 47 % of the CO_2 emission from residual oil consumption was based on the emission factor, whereas 53 % of the residual oil consumption was covered by EU ETS data[30].

The emission factors for residual oil combustion in *Public electricity and heat production* in the years 2006-2012 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 in *Public electricity and heat production* refer to the average IEF for 2006-2009.

For other source categories apart from 1A1a, the applied emission factor 77.4 kg per GJ refers to the IPCC Guidelines (IPCC, 1997). This emission factor has been applied for all years.

Time series for the CO_2 emission factor are shown in Table 3.2.25.

[29] EU ETS data for CO2 on page 61
[30] Including EU ETS data for cement production.

Table 3.2.25 CO_2 emission factors for residual oil, time series.

Year	Source category 1A1a Public electricity and heat production kg per GJ	Other source categories kg per GJ
1990-2005	78.4	77.4
2006	78.2	77.4
2007	78.1	77.4
2008	78.5	77.4
2009	78.9	77.4
2010	79.2	77.4
2011	79.25	77.4
2012	79.21	77.4

Gas oil

The emission factor for gas oil, 74 kg per GJ, refers to EEA (2007). The emission factor is consistent with the IPCC default emission factor for gas oil (74.1 kg per GJ assuming full oxidation). The CO_2 emission factor has been confirmed by the two major power plant operators in 1996 (Christiansen, 1996 and Andersen, 1996). The same emission factor has been applied for 1990-2012.

Plant specific EU ETS data have been utilised for a few plants in the 2006 - 2012 emission inventories. In 2012, the implied emission factor for the power plants using gas oil was 73.9 kg per GJ. The EU ETS CO_2 emission factors were in the interval 73.7 - 75.1 kg per GJ. In 2012, 10 % of the CO_2 emission from gas oil consumption was based on EU ETS data.

Kerosene

The emission factor for kerosene, 71.9 kg per GJ, refers to IPCC Guidelines (IPCC, 1997). The same emission factor has been applied for 1990-2012. CO_2 emission from combustion of kerosene is a key category and thus a country specific emission factor should be implemented in future inventories.

Orimulsion

The emission factor for orimulsion, 80 kg per GJ, refers to the Danish Energy Agency (DEA, 2013a). 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

The emission factor for LPG, 63.1 kg per GJ, refers to IPCC Guidelines (IPCC, 1997). The same emission factor has been applied for 1990-2012.

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 (57.6 kg per GJ) for 2006-2009 have been applied for the years 1990-2005. This emission factor is consistent to the emission factor stated in the 2006 IPCC Guidelines (IPCC, 2006). The time series is shown in Table 3.2.26.

Table 3.2.26 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	56.814
2010	57.134
2011	57.881
2012	58.099

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 2006-2012. Based on data for each oilfield implied emission factors have been estimated for 2006-2012. The average value for 2006-2009 has been applied for the years 1990-2005. The time series is shown in Table 3.2.27.

Table 3.2.27 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

Natural gas, other source categories

The emission factor for natural gas is estimated by the Danish gas transmission company, Energinet.dk[31]. The calculation is based on gas analysis carried out daily by Energinet.dk at Egtved.

In 2012, the natural gas import was 33 PJ, the natural gas export 112 PJ and a consumption that added up to 145 PJ. Before 2010, only natural gas from the Danish gas fields was utilised in Denmark. If the import of natural gas increases further, the methodology for estimating the CO_2 emission factor might be revised based on an on-going dialog with the Danish Energy Agency and Energinet.dk. However, 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 2000-2012. The emission factor applied for 1990-1999 refers to Fenhann & Kilde (1994). This emission factor was confirmed by the two major power plant operators in 1996 (Christiansen, 1996 and Andersen, 1996). The time series for the CO_2 emission factor is provided in Table 3.2.28.

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

Table 3.2.28 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

Waste

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.

The CO_2 emission factor 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 fossil emission factors for waste have estimated to be 37 kg/GJ waste and the interval for the five plants was 25 – 51 kg/GJ. The five plants represent 44 % of the incinerated waste in 2010. The emission factor 37 kg/ GJ waste corresponds to 82.22 kg/GJ fossil waste.

The total CO_2 emission factor for waste refers to a Danish study (Jørgensen & Johansen, 2003). Based on emission measurements on five waste incineration plants the total CO_2 emission factor for waste incineration has been determined to 112.1 kg per GJ. Thus, the biomass emission factor has been determined to 75.1 kg/GJ waste.

Plant specific EU ETS data have been utilised for cement production in the 2006 - 2012 emission inventories.

Wood

The emission factor for wood, 110 kg per GJ, refers IPCC (1997). The same emission factor has been applied for 1990-2012.

Straw

The emission factor for wood, 110 kg per GJ, refers IPCC (1997). The same emission factor has been applied for 1990-2012.

Bio oil

The emission factor is assumed to be the same as for gas oil – 74 kg per GJ. The consumption of bio oil is below 2 PJ.

Biogas

In Denmark, 3 different types of biogas are applied: Manure/organic waste based biogas, landfill based biogas and wastewater treatment biogas (sludge gas). Manure / organic waste based biogas represent 75 % of the consumption, see page 156.

The emission factor for biogas, 83.6 kg per GJ, is based on a biogas with 65 % (vol.) CH_4 and 35 % (vol.) CO_2. Danish Gas Technology Centre has stated that this is a typical manure-based biogas as utilised in stationary combustion plants (Kristensen, 2001). The same emission factor has been applied for 1990-2012.

Biomass producer gas

Biomass producer gas applied in Denmark is based on wood. The gas composition is known for three different plants and the applied emission factor have been estimated by Danish Gas Technology Centre (Kristensen, 2010) based on the gas composition measured on the plant that with the highest consumption.

The consumption of biomass producer gas is below 0.4 PJ for all years.

CH_4

The CH_4 emission factors applied for 2012 are presented in Table 3.2.29. In general, the same emission factors have been applied for 1990-2012. However, time series have been estimated for both natural gas fuelled engines and biogas fuelled engines, residential wood combustion, natural gas fuelled gas turbines[32] and waste incineration plants[32].

Emission factors for CHP plants < 25 MW_e refer to emission measurements carried out on Danish plants (Nielsen et al., 2010; 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, 1997).

Gas engines combusting natural gas or biogas account for more than half the CH_4 emission from stationary combustion plants. The relatively high emission factor for gas engines is well-documented and further discussed below.

[32] A minor emission source.

Table 3.2.29 CH_4 emission factors, 2012.

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g pr GJ	Reference
SOLID	COAL	1A1a	Public electricity and heat production	0101 0102	0.9	IPCC (1997), Tier 2, Table 1-15, Utility Boiler, Pulverised Bituminous Combustion, Wet bottom.
		1A2 a-f	Industry	03	10	IPCC (1997), Tier 2, Table 1-19, Commercial coal boilers.
		1A4b i	Residential	0202	300	IPCC (1997), Tier 1, Table 1-7, Residential, coal.
		1A4c i	Agriculture/ Forestry	0203	10	IPCC (1997), Tier 2, Table 1-19, Commercial coal boilers.[1)]
	BROWN COAL BRI.	1A4b i	Residential	0202	300	IPCC (1997), Tier 1, Table 1-7, Residential, coal.
	COKE OVEN COKE	1A2 A-f	Industry	03	10	IPCC (1997), Tier 2, Table 1-19, Commercial coal boilers.
		1A4b i	Residential	0202	300	IPCC (1997), Tier 1, Table 1-7, Residential, coal.
	ANODIC CARBON	1A2a-f	Industry	03	10	IPCC (1997), Tier 2, Table 1-19, Commercial coal boilers.
	FOSSIL FLY ASH	1A1a	Public electricity and heat production	0101	0.9	IPCC (1997), Tier 2, Table 1-15, Utility Boiler, Pulverised Bituminous Combustion, Wet bottom.
LIQUID	PETROLEUM COKE	1A2a-f	Industry	03	2	IPCC (1997), Tier 1, Table 1-7, Industry, oil.
	RESIDUAL OIL	1A1a	Public electricity and heat production	010101	0.9	IPCC (1997), Tier 2, Table 1-15, Utility Boiler, Residual fuel oil.
				010102 010103	1.3	Nielsen et al. (2010)
				010104	3	IPCC (1997), Tier 1, Table 1-7, Energy industries, oil.
				010203	0.9	IPCC (1997), Tier 2, Table 1-15, Utility Boiler, Residual fuel oil.
		1A1b	Petroleum refining	010306	3	IPCC (1997), Tier 1, Table 1-7, Energy industries, oil.
		1A2 a-f	Industry	03	1.3	Nielsen et al. (2010)
				En-gines	4	IPCC (1997), Tier 2, Table 1-15, Utility, Large diesel engines
		1A4a	Commercial/ Institutional	0201	1.4	IPCC (1997), Tier 2, Table 1-19, Commercial, residual fuel oil[1)].
		1A4b	Residential	0202	1.4	IPCC (1997), Tier 2, Table 1-19, Commercial, residual fuel oil[1)].
		1A4c	Agriculture/ Forestry	0203	1.4	IPCC (1997), Tier 2, Table 1-19, Commercial, residual fuel oil[1)].
	GAS OIL	1A1a	Public electricity and heat production	010101 010102 010103	0.9	IPCC (1997), Tier 2, Table 1-15, Utility Boiler, distillate fuel oil.
				010104	3	IPCC (1997), Tier 1, Table 1-7, Energy industries, oil.
				010105	24	Nielsen et al. (2010)
				010202 010203	0.9	IPCC (1997), Tier 2, Table 1-15, Utility Boiler, distillate fuel oil.
		1A1b	Petroleum refining	010306	3	IPCC (1997), Tier 1, Table 1-7, Energy industries, oil.
		1A1c	Other energy industries	010504	3	IPCC (1997), Tier 1, Table 1-7, Energy industries, oil
		1A2 a-f	Industry	03	0.2	IPCC (1997), Tier 2, Table 1-16, Industry, distillate fuel oil.
				Tur-bines	2	IPCC (1997), Tier 1, Table 1-7, Industry, oil.
				En-gines	24	Nielsen et al. (2010)
		1A4a	Commercial/ Institutional	0201	0.7	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil.
				020105	24	Nielsen et al. (2010)
		1A4b i	Residential	0202	0.7	IPCC (1997), Tier 2, Table 1-18,

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g pr GJ	Reference
						Residential, distillate fuel oil.
		1A4c	Agriculture/ Forestry	0203	0.7	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil.
	KEROSENE	1A2 a-f	Industry	all	0.2	IPCC (1997), Tier 2, Table 1-16, Industry, distillate fuel oil.
		1A4a	Commercial/ Institutional	0201	0.7	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil.
		1A4b i	Residential	0202	0.7	IPCC (1997), Tier 2, Table 1-18, Residential, distillate fuel oil.
		1A4c i	Agriculture/ Forestry	0203	0.7	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil[1].
	LPG	1A1a	Public electricity and heat production	0101 0102	3	IPCC (1997), Tier 1, Table 1-7, Energy Industries, oil.
		1A1b	Petroleum refining	0103	3	IPCC (1997), Tier 1, Table 1-7, Energy Industries, oil.
		1A2 a-f	Industry	03	2	IPCC (1997), Tier 1, Table 1-7, Industry, oil
		1A4a	Commercial/ Institutional	0201	10	IPCC (1997), Tier 1, Table 1-7, Commercial, oil.
		1A4b i	Residential	0202	1.1	IPCC (1997), Tier 2, Table 1-18, Residential propane/butane furnaces.
		1A4c i	Agriculture/ Forestry	0203	10	IPCC (1997), Tier 1, Table 1-7, Agriculture, oil.
	REFINERY GAS	1A1b	Petroleum refining	010304	1.7	Assumed equal to natural gas fuelled gas turbines. Nielsen et al. (2010)
				010306	1	Assumed equal to natural gas fuelled plants. IPCC (1997), Tier 1, Table 1-7, Natural gas
GAS	NATURAL GAS	1A1a	Public electricity and heat production	010101 010102 010103	0.1	IPCC (1997), Tier 2, Table 1-15, Utility Boiler, natural gas.
				010104	1.7	Nielsen et al. (2010)
				010105	481	Nielsen et al. (2010)
				010202 010203	0.1	IPCC (1997), Tier 2, Table 1-15, Utility Boiler, natural gas.
		1A1c	Other energy industries	010504	1.7	Nielsen et al. (2010)
		1A2 a-f	Industry	Other	1.4	IPCC (1997), Tier 2, Table 1-16, Industry, natural gas boilers.
				Gas turbines	1.7	Nielsen et al. (2010)
				En-gines	481	Nielsen et al. (2010)
		1A4a	Commercial/ Institutional	0201	1.2	IPCC (1997), Tier 2, Table 1-19, Commercial, natural gas boilers.
				020105	481	Nielsen et al. (2010)
		1A4b i	Residential	0202	5	IPCC (1997), Tier 1, Table 1-7, Residential, natural gas.
				020204	481	Nielsen et al. (2010)
		1A4c i	Agriculture/ Forestry	0203	1.2	IPCC (1997), Tier 2, Table 1-19, Commercial, natural gas boilers[1].
				020304	481	Nielsen et al. (2010)
WASTE	WASTE	1A1a	Public electricity and heat production	0101 0102	0.34	Nielsen et al. (2010)
		1A2a-f	Industry	03	30	IPCC (1997), Tier 1, Table 1-7, Industry, wastes.
		1A4a	Commercial/ Institutional	0201	30	IPCC (1997), Tier 1, Table 1-7, Industry, wastes.
	INDUSTRIAL WASTE	1A2f	Industry	0316	30	IPCC (1997), Tier 1, Table 1-7, Industry, wastes.
BIO-MASS	WOOD	1A1a	Public electricity and heat production	0101	3.1	Nielsen et al. (2010)
				0102	30	IPCC (1997), Tier 1, Table 1-7, Energy industries, wood
		1A2 a-f	Industry	03	15	IPCC (1997), Tier 2, Table 1-16, Industry, wood stoker boilers.

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g pr GJ	Reference
		1A4a	Commercial/ Institutional	0201	30	IPCC (1997), Tier 1, Table 1-7, Industry, wood[2].
		1A4b i	Residential	0202	129.3	DCE estimate based on technology distribution [3]
		1A4c i	Agriculture/ Forestry	0203	30	IPCC (1997), Tier 1, Table 1-7, Industry, wood[2].
	STRAW	1A1a	Public electricity and heat production	0101	0.47	Nielsen et al. (2010)
				0102	30	IPCC (1997), Tier 1, Table 1-7, Energy industries, other biomass
		1A4b i	Residential	0202	300	IPCC (1997), Tier 1, Table 1-7, Residential, other biomass.
		1A4c i	Agriculture/ Forestry	020300	300	IPCC (1997), Tier 1, Table 1-7, Agriculture, other biomass.
				020302	30	IPCC (1997), Tier 1, Table 1-7, Energy industries, other biomass
	BIO OIL	1A1a	Public electricity and heat production	010102	0.9	IPCC (1997), Tier 2, Table 1-15, Utility Boiler, distillate fuel oil.
				010105	24	Nielsen et al. (2010) assumed same emission factor as for gas oil fuelled engines.
				0102	0.7	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil.
		1A2 a-f	Industry	03	0.7	Assumed equal to district heating plants.
		1A4b i	Residential	0202	0.7	IPCC (1997), Tier 2, Table 1-18, Residential, distillate fuel oil.
	BIOGAS	1A1a	Public electricity and heat production	0101	1	IPCC (1997), Tier 1, Table 1-7, Energy industries, natural gas. Assumed similar to natural gas (DCE assumption).
				010105	434	Nielsen et al. (2010)
				0102	1	IPCC (1997), Tier 1, Table 1-7, Energy industries, natural gas. Assumed similar to natural gas (DCE assumption).
		1A2 a-f	Industry	03	5	IPCC (1997), Tier 1, Table 1-7, Industry, natural gas. Assumed similar to natural gas (DCE assumption).
				Engines	434	Nielsen et al. (2010)
		1A4a	Commercial/ Institutional	0201	5	IPCC (1997), Tier 1, Table 1-7, Commercial, natural gas. Assumed similar to natural gas (DCE assumption).
				020105	434	Nielsen et al. (2010)
		1A4c i	Agriculture/ Forestry	0203	5	IPCC (1997), Tier 1, Table 1-7, Agriculture, natural gas. Assumed similar to natural gas (DCE assumption).
				020304	434	Nielsen et al. (2010)
	BIO PROD GAS	1A1a	Public electricity and heat production	010105	13	Nielsen et al. (2010)
		1A4a	Commercial/Institutional	020105	13	Nielsen et al. (2010)

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 (DEPA, 2013) and technology specific emission factors that refer to: Paulrud et al. (2005), Johansson et al. (2004) and Olsson & Kjällstrand (2005).

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., 2010).

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 producer gas. CH_4 emission factors for these plants all refer to Nielsen et al. (2010). 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 factor for different gas engine types has been 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

SNAP 010105, 030905, 030705, 031005, 031205, 031305, 031405, 031605, 020105, 020204 and 020304

The emission factor for natural gas engines refers to the Nielsen et al. (2010). 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. (2010):

> *CH_4 emission factors for gas engines were estimated for 2003-2006 and for 2007-2012. The dataset was split in two due to new emission limits for the 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. (2010).*

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 2007-2012 (Nielsen et al., 2010).
- 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 3.2.30 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
2007-2012	481

Gas engines, biogas

SNAP 010105, 030905, 020105 and 020304

The emission factor for biogas engines was estimated to 434 g per GJ in 2012. 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. (2010) and Nielsen & Illerup (2003). The two references are discussed below. The time series are shown in Table 3.2.31.

Nielsen et al. (2010):

> *CH_4 emission factors for gas engines were estimated for 2006 based on emission measurements performed in 2003-2012. 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 3.2.31 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
2007-2012	434

Gas turbines, natural gas

SNAP 010104, 010504, 030604 and 031104

The emission factor for gas turbines was estimated to be below 1.7 g per GJ in 2005 (Nielsen et al., 2010). 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 have been estimated.

CHP, wood

SNAP 010101, 010102, 010103 and 010104

The emission factor for CHP plants combusting wood was estimated to be below 3.1 g per GJ (Nielsen et al., 2010) 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

SNAP 010101, 010102, 010103 and 010104

The emission factor for CHP plants combusting straw was estimated to be below 0.47 g per GJ (Nielsen et al., 2010) 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

SNAP 010102, 010103, 010104 and 010203

The emission factor for CHP plants combusting waste was estimated to be below 0.34 g per GJ in 2006 (Nielsen et al., 2010) and 0.59 g per GJ in year 2000 (Nielsen & Illerup, 2003). A time series have 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 wood combustion

SNAP 020200, 020202 and 020204

The emission factor for residential wood combustion is based on technology specific data. The emission factor time series is shown in Table 3.2.32.

Table 3.2.32 CH_4 emission factor time series for residential wood combustion.

Year	Emission factor, g per GJ
1990-2000	224.0
2001	199.3
2002	189.6
2003	187.2
2004	184.5
2005	175.5
2006	165.2
2007	166.5
2008	156.5
2009	143.8
2010	136.6
2011	129.3
2012	123.7

The emission factors for each technology and the corresponding reference are shown in Table 3.2.33. The emission factor time series are estimated based on time series (2000-2012) for wood consumption in each technology (DEPA, 2013). The time series for wood consumption in the ten different technologies are illustrated in Figure 3.2.47. The consumption in pellet boilers and new stoves has increased.

Table 3.2.33 Technology specific CH_4 emission factors for residential wood combustion.

Technology	Emission factor, g per GJ	Reference
Old stove	430	Methane emissions from residential biomass combustion, Paulrud et al. (2005) (SMED report, Sweden)
New stove	215	Assumed ½ the emission factor for old stoves.
Stove according to resent Danish legislation (2008)	125	Estimated based on the emission factor for new stoves and the emission factors for NMVOC.
Eco labelled stove	2	Low emissions from wood burning in an ecolabelled residential boiler. Olsson & Kjällstrand (2005).
Other stove	430	Assumed equal to old stove.
Old boilers with hot water storage	211	Methane emissions from residential biomass combustion, Paulrud et al., 2005 (SMED report, Sweden)
Old boilers without hot water storage	256	Methane emissions from residential biomass combustion, Paulrud et al., 2005 (SMED report, Sweden)
New boilers with hot water storage	50	Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Johansson et al. (2004)
New boilers without hot water storage	50	Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Johansson et al. (2004)
Pellet boilers/stoves	3	Methane emissions from residential biomass combustion, Paulrud et al., 2005 (SMED report, Sweden)

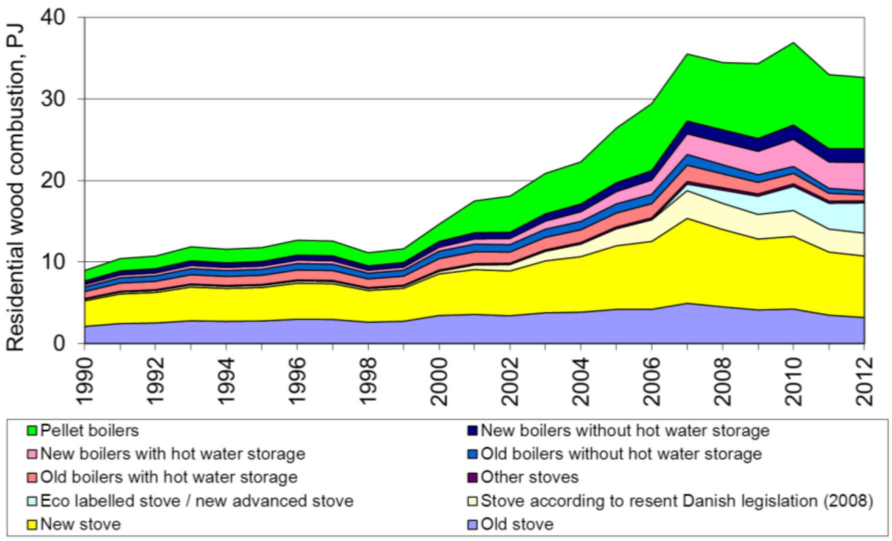


Figure 3.2.47 Technology specific wood consumption in residential plants.

Other stationary combustion plants

Emission factors for other plants refer to the IPCC Guidelines (IPCC, 1997).

N_2O

The N_2O emission factors applied for the 2012 inventory are listed in Table 3.2.34. 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 1990-2012.

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 producer gas all refer to emission measurements carried out on Danish plants, Nielsen et al. (2010).

The emission factor for coal-powered plants in public power plants refers to research conducted by Elsam (now part of DONG Energy).

The emission factor for natural gas has been applied for refinery gas. Denmark uses two different N_2O emission factors for refinery gas, one when the gas is utilised in gas turbines and one for use in boilers. The emission factor for gas turbines is nationally referenced while the emission factor for boilers is based on the Revised 1996 IPCC Guidelines (IPCC, 1997). 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. This is the reasoning behind choosing the emission factor for natural gas rather than for liquid fuel for both turbines and boilers.

All emission factors that are not nationally referenced refer to the IPCC Guidelines (IPCC, 1997).

Table 3.2.34 N_2O emission factors 2012.

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	Elsam (2005)
				0102	1.6	IPCC (1997), Tier 2, Table 1-15, Utility boiler, pulverised bituminous coal.
		1A2 a-f	Industry	03	1.4	IPCC (1997), Tier 1, Table 1-8, Industry, coal
		1A4b i	Residential	0202	1.4	IPCC (1997), Tier 1, Table 1-8, Residential, coal
		1A4c i	Agriculture/ Forestry	0203	1.4	IPCC (1997), Tier 1, Table 1-8, Commercial, coal
	BROWN COAL BRI.	1A4b i	Residential	0202	1.4	IPCC (1997), Tier 1, Table 1-8, Residential, coal
	COKE OVEN COKE	1A2 a-f	Industry	03	1.4	IPCC (1997), Tier 1, Table 1-8, Industry, coal
		1A4b i	Residential	020200	1.4	IPCC (1997), Tier 1, Table 1-8, Residential, coal
	ANODIC CARBON	1A2 a-f	Industry	03	1.4	IPCC (1997), Tier 1, Table 1-8, Industry, coal
LIQUID	PETROLEUM COKE	1A2a-f	Industry – other	03	0.6	IPCC (1997), Tier 1, Table 1-8, Industry, oil
	RESIDUAL OIL	1A1a	Public electricity and heat production	010101	0.3	IPCC (1997), Tier 2, Table 1-15, Utility, residual fuel oil
				010102 010103	5	Nielsen et al. (2010)
				010104	0.6	IPCC (1997), Tier 1, Table 1-8, Energy industries, oil
				010203	0.3	IPCC (1997), Tier 2, Table 1-15, Utility, residual fuel oil
		1A1b	Petroleum refining	010306	0.6	IPCC (1997), Tier 1, Table 1-8, Energy industries, oil
		1A2 a-f	Industry	03	5	Nielsen et al. (2010)
				Engines	0.6	IPCC (1997), Tier 2, Table 1-15, Utility, residual fuel oil
		1A4a	Commercial/ Institutional	0201	0.3	IPCC (1997), Tier 2, Table 1-19, Commercial, fuel oil
		1A4b i	Residential	0202	0.6	IPCC (1997), Tier 1, Table 1-8, Residential, oil
		1A4c i	Agriculture/ Forestry	0203	0.3	IPCC (1997), Tier 2, Table 1-19, Commercial, fuel oil
	GAS OIL	1A1a	Public electricity and heat production	010101 010102 010103	0.4	IPCC (1997), Tier 2, Table 1-15, Utility, distillate fuel oil
				010104	0.6	IPCC (1997), Tier 1, Table 1-8, Energy industries, oil
				010105	2.1	Nielsen et al. (2010)
				0102	0.4	IPCC (1997), Tier 2, Table 1-15, Utility, distillate fuel oil
		1A1b	Petroleum refining	010306	0.6	IPCC (1997), Tier 1, Table 1-8, Energy industries, oil
		1A2 a-f	Industry	03	0.4	IPCC (1997), Tier 2, Table 1-16, Industry, distillate fuel oil boilers
				Turbines	0.6	IPCC (1997), Tier 1, Table 1-8, Industry, oil
				Engines	2.1	Nielsen et al. (2010)
		1A4a	Commercial/ Institutional	0201	0.4	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil
				Engines	2.1	Nielsen et al. (2010)
		1A4b i	Residential	0202	0.6	IPCC (1997), Tier 1, Table 1-8, Residential,

Fuel group	Fuel	CRF source catego-ry	CRF source category	SNAP	Emis-sion factor, g per GJ	Reference
						oil
		1A4c	Agriculture/ Forestry	0203	0.4	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil
	KEROSENE	1A2 a-f	Industry	03	0.4	IPCC (1997), Tier 2, Table 1-16, Industry, distillate fuel oil boilers
		1A4a	Commercial/ Institutional	0201	0.4	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil
		1A4b i	Residential	0202	0.6	IPCC (1997), Tier 1, Table 1-8, Residential, oil
		1A4c i	Agriculture/ Forestry	0203	0.4	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil[1)]
	LPG	1A1a	Public electricity and heat production	0101 0102	0.6	IPCC (1997), Tier 1, Table 1-8, Energy industries, oil
		1A1b	Petroleum refining	010306	0.6	IPCC (1997), Tier 1, Table 1-8, Energy industries, oil
		1A2 a-f	Industry	03	0.6	IPCC (1997), Tier 1, Table 1-8, Industry, oil
		1A4a	Commercial/ Institutional	0201	0.6	IPCC (1997), Tier 1, Table 1-8, Commercial, oil
		1A4b i	Residential	0202	0.6	IPCC (1997), Tier 1, Table 1-8, Residential, oil
		1A4c i	Agriculture/ Forestry	0203	0.6	IPCC (1997), Tier 1, Table 1-8, Agriculture, oil
	REFINERY GAS	1A1b	Petroleum refining	010304	1	Assumed equal to natural gas fuelled tur-bines. Based on Nielsen et al. (2010).
				010306	0.1	IPCC (1997), Tier 1, Table 1-8, Energy industries, natural gas
GAS	NATURAL GAS	1A1a	Public electricity and heat production	010101 010102 010103	0.1	IPCC (1997), Tier 1, Table 1-8, Energy industries, natural gas
				010104	1	Nielsen et al. (2010)
				010105	0.58	Nielsen et al. (2010)
				0102	0.1	IPCC (1997), Tier 1, Table 1-8, Energy industries, natural gas
		1A1c	Other energy industries	010504	1	Nielsen et al. (2010)
		1A2 a-f	Industry	03	0.1	IPCC (1997), Tier 1, Table 1-8, Industry, natural gas
				Gas turbines	1	Nielsen et al. (2010)
				Engines	0.58	Nielsen et al. (2010)
		1A4a	Commercial/ Institutional	020100 020103	2.3	IPCC (1997), Tier 2, Table 1-19, Commercial, natural gas boilers
				Engines	0.58	Nielsen et al. (2010)
		1A4b i	Residential	0202	0.1	IPCC (1997), Tier 1, Table 1-8, Residential, natural gas
				Engines	0.58	Nielsen et al. (2010)
		1A4c i	Agriculture/ Forestry	0203	2.3	IPCC (1997), Tier 2, Table 1-19, Commercial, natural gas boilers[1)]
				Engines	0.58	Nielsen et al. (2010)
WAST E	WASTE	1A1a	Public electricity and heat production	0101 0102	1.2	Nielsen et al. (2010)
		1A2 a-f	Industry	03	4	IPCC (1997), Tier 1, Table 1-8, Industry, wastes
		1A4a	Commercial/ Institutional	0201	4	IPCC (1997), Tier 1, Table 1-8, Commercial, wastes
	INDUSTR. WASTE	1A2a-f	Industry	03	4	IPCC (1997), Tier 1, Table 1-8, Industry, waste
BIO-MASS	WOOD	1A1a	Public electricity and heat production	0101	0.8	Nielsen et al. (2010)

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
				0102	4	IPCC (1997), Tier 1, Table 1-8, Energy industries, wood
		1A2 a-f	Industry	03	4	IPCC (1997), Tier 1, Table 1-8, Industry, wood
		1A4a	Commercial/ Institutional	0201	4	IPCC (1997), Tier 1, Table 1-8, Commercial, wood
		1A4b i	Residential	0202	4	IPCC (1997), Tier 1, Table 1-8, Residential, wood
		1A4c i	Agriculture/ Forestry	0203	4	IPCC (1997), Tier 1, Table 1-8, Agriculture, wood
	STRAW	1A1a	Public electricity and heat production	0101	1.1	Nielsen et al. (2010)
				0102	4	IPCC (1997), Tier 1, Table 1-8, Energy industries, other biomass
		1A4b i	Residential	0202	4	IPCC (1997), Tier 1, Table 1-8, Residential, other biomass
		1A4c i	Agriculture/ Forestry	0203	4	IPCC (1997), Tier 1, Table 1-8, Agriculture, other biomass
	BIO OIL	1A1a	Public electricity and heat production	0101 0102	0.4	IPCC (1997), Tier 2, Table 1-15, Utility, distillate fuel oil
				Engines	2.1	Assumed equal to gas oil. Based on Nielsen et al. (2010)
		1A2 a-f	Industry	03	0.4	IPCC (1997), Tier 1, Table 1-8, Industry, oil
		1A4b i	Residential	0202	0.6	IPCC (1997), Tier 1, Table 1-8, Residential, oil
	BIOGAS	1A1a	Public electricity and heat production	0101 0102	0.1	IPCC (1997), Tier 1, Table 1-8, Energy industries, natural gas
				Engines	1.6	Nielsen et al. (2010)
		1A2 a-f	Industry	03	0.1	IPCC (1997), Tier 1, Table 1-8, Industry, natural gas
				Engines	1.6	Nielsen et al. (2010)
		1A4a	Commercial/ Institutional	0201	0.1	IPCC (1997), Tier 1, Table 1-8, Commercial, natural gas
				Engines	1.6	Nielsen et al. (2010)
		1A4c i	Agriculture/ Forestry	0203	0.1	IPCC (1997), Tier 1, Table 1-8, Agriculture, natural gas
				Engines	1.6	Nielsen et al. (2010)
	BIO PROD GAS	1A1a	Public electricity and heat production	010105	2.7	Nielsen et al. (2010)
		1A4a	Commercial/ Institutional	020105	2.7	Nielsen et al. (2010)

1) In Denmark, plants in Agriculture/Forestry are similar to Commercial plants.

SO_2 and NO_x emission factors

Emission factors for SO_2 and NO_x listed in Annex 3A-4. The appendix includes references and time series. Further details about the references, additional references, assumptions and discussions are included in Nielsen et al. (2014).

The emission factors refer to:

- The EMEP/EEA Guidebook: EEA (2013) and former editions.
- The IPCC Guidelines, Reference Manual (IPCC, 1997).
- Danish legislation
- Danish research reports including:
  - Two emission measurement programs for decentralised CHP plants (Nielsen et al. 2010; Nielsen & Illerup, 2003).

- Research and emission measurements programs for biomass fuels:
- Research and environmental data from the gas sector:

- Aggregated emission factors for residential wood combustion based on technology distribution (DEPA, 2013) and technology specific emission factors (EEA, 2013; DEPA, 2010b).
- Calculations based on plant-specific emissions from a considerable number of power plants.
- Calculations based on plant-specific emission data from a considerable number of waste incineration plants. These data refer to annual environmental reports published by plant operators.
- Sulphur content data from oil companies and the Danish gas transmission company, Energinet.dk.
- Additional personal communication.

Emission factor time series have been estimated for a considerable number of the emission factors. These are provided in Annex 3A-4.

NMVOC emission factors

Emission factors for NMVOC are listed in Annex 3A-4. The annex includes references and time series. The emission factors for NMVOC refer to:

- An emission measurement program for decentralised CHP plants (Nielsen et al., 2010).
- The EMEP/EEA Guidebook (EEA, 2009).
- Aggregated emission factor based on the technology distribution for residential wood combustion and guidebook (EEA, 2013) emission factors. Technology distribution refers to DEPA (2013).
- DGC Danish Gas Technology Centre 2001, Naturgas – Energi og miljø (DGC, 2001).
- Gruijthuijsen L.v. & Jensen J.K., 2000. Energi- og miljøoversigt, Danish Gas Technology Centre 2000 (In Danish).

CO emission factors

Emission factors for CO are listed in Annex 3A-4. The annex includes references and time series. The emission factors for CO refer to:

- The EMEP/EEA Guidebook (EEA, 2009) and the former update (EEA, 2007).
- IPCC Guidelines (IPCC, 1997)
- An emission measurement program for decentralised CHP plants (Nielsen et al., 2010).
- Danish legislation (DEPA, 2001)
- Aggregated emission factor based on the technology distribution for residential wood combustion and guidebook (EEA, 2013) emission factors. The technology distribution refer to DEPA (2013).
- DCE estimate based on annual environmental reports for Danish waste incineration plants without power production, year 2000.
- Nikolaisen et al. (1998)
- Jensen & Nielsen (1990)
- Bjerrum (2002)
- Sander (2002)
- Gruijthuijsen & Jensen (2000)

Technology specific emission factors for residential wood combustion, NO_x, NMVOC and CO

For the pollutants NO_x, NMVOC and CO emission factors have been based on fuel consumption data and emission factors for 10 different technologies. Technology categories, emission factors and implied emission factors for 2012 are shown in Table 3.2.35. References for the technology specific emission factors are included in Annex 3A-4.

Technology specific emission factors for CH_4 including references are shown on page 175.

For SO_2, time series have not been estimated and the emission factors are shown in Annex 3A-4.

Table 3.2.35 Technology specific emission factors for residential wood combustion.

Technology	NOx, g/GJ	NMVOC, g/GJ	CO, g/GJ
Old stove	50	1200	8000
New stove	50	600	4000
Stove according to resent Danish legislation (2008)	80	350	4000
Eco labelled stove	95	175	1117
Other stove	50	600	4000
Old boilers with hot water storage	80	350	4000
Old boilers without hot water storage	80	350	4000
New boilers with hot water storage	95	175	1117
New boilers without hot water storage	95	350	2234
Pellet boilers/stoves	80	1200	8000
IEF residential wood combustion, 2012	74	363	2676

3.2.6 Uncertainty

Uncertainty estimates include uncertainty with regard to the total emission inventory as well as uncertainty with regard to trends.

Methodology

Greenhouse gases

The uncertainty for greenhouse gas emissions have been estimated according to the IPCC Good Practice Guidance (IPCC, 2000). The uncertainty has been estimated by two approaches; tier 1 and tier 2. Both approaches are further described in Chapter 1.7.

The **tier 1** approach is based on a normal distribution and a confidence interval of 95 %.

The input data for the tier 1 approach 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 3.2.36.

The **tier 2** approach is a Monte Carlo approach based on a lognormal distribution. The input data for the model is also based on 95 % confidence interval. The input data for the tier 2 approach are:

- Fuel consumption data for the base year and the latest year.

- Emission factors or implied emission factors (IEF) for the base year and the latest year
- Uncertainties for emission factors for the base year and the latest year. If the same uncertainty is applied for both years, the data can be indicated as statistically dependent or independent.
- Uncertainties for fuel consumption rates in the base year and the latest year. If the same uncertainty is applied for both years, the data can be indicated as statistically dependent or independent.

The same emission source categories and emission data have been applied for both approaches. The separate uncertainty estimation for gas engine CH_4 emission and CH_4 emission from other plants does not follow the recommendations in the IPCC Good Practice Guidance. Disaggregation 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.

In general, the same uncertainty levels have been applied for both approaches. However, the tier 2 approach allows different uncertainty levels for 1990 and 2012 and this is relevant to a few uncertainties as discussed below. The 2012 uncertainty levels have been applied in the tier 1 approach.

Most of the applied uncertainty estimates for activity rates and emission factors are default values from the IPCC Reference Manual or aggregated by DCE based on the default values. Some of the uncertainty estimates are, however, based on national estimates.

In general, the uncertainty of the fuel consumption data has been assumed to be the same in 1990 and 2012 and the uncertainty has been assumed to be statistically independent. However, a considerable part of the residential wood consumption is non-traded and the uncertainty of biomass consumption has been assumed statistically dependent.

Fuel consumption data for waste are more uncertain for 1990 than for 2012.

For coal and refinery gas combustion, the uncertainty of the CO_2 emission factor is lower in 2012 than in 1990 due to availability of EU ETS data. Further, the CO_2 emission factor for the fossil part of waste is less uncertain for 2012 than for 1990.

The uncertainty of the CH_4 emission factors for gas engines have been assumed higher in 1990 than in 2012 due to the emission measurement programmes on which the emission factors in later years are based.

All other uncertainty levels for emission factors have been assumed equal in 1990 and 2012 and statistically dependent.

Table 3.2.36 Uncertainty rates for fuel consumption and emission factors, 2012.

IPCC Source category	Gas	Fuel consumption uncertainty, %		Emission factor uncertainty, %	
		1990	2012	1990	2012
Stationary Combustion, Coal, CO_2	CO_2	0.9[2)]	0.9[7)]	4[10)]	0.5[7)]
Stationary Combustion, BKB, CO_2	CO_2	2.9[2)]	3.0[2)]		5[1)]
Stationary Combustion, Coke[33], CO_2	CO_2	1.8[2)]	1.8[2)]		5[1)]
Stationary Combustion, Fossil waste, CO_2	CO_2	10.0[2)]	5.0[2)]	20[5)]	10[5)]
Stationary Combustion, Petroleum coke, CO_2	CO_2	1.7[2)]	2.0[2)]		5[1)]
Stationary Combustion, Residual oil, CO_2	CO_2	1.2[2)]	1.2[2)]	2[4)]	2[7)]
Stationary Combustion, Gas oil, CO_2	CO_2	2.9[2)]	2.2[2)]		4[10)]
Stationary Combustion, Kerosene, CO_2	CO_2	3.0[2)]	2.0[2)]		5[1)]
Stationary Combustion, LPG, CO_2	CO_2	1.7[2)]	1.8[2)]		5[1)]
Stationary Combustion, Refinery gas, CO_2	CO_2	1.0[2)]	1.0[2)]	5[1)]	2[12)]
Stationary Combustion, Natural gas, CO_2	CO_2	1.2[2)]	1.0[2)]		0.4[8)]
Stationary Combustion, SOLID, CH_4	CH_4	0.9[2)]	1.0[2)]		100[1)]
Stationary Combustion, LIQUID, CH_4	CH_4	1.5[2)]	0.8[2)]		100[1)]
Stationary Combustion, GAS, CH_4	CH_4	1.0[8)]	1.0[8)]		100[1)]
Natural gas fuelled engines, GAS, CH_4	CH_4	1.0[9)]	1.0[9)]	10[11)]	2[3)]
Stationary Combustion, WASTE, CH_4	CH_4	10.0[5)]	5.0[5)]		100[1)]
Stationary Combustion, BIOMASS, CH_4	CH_4	14.9[2)]	15.7[2)]		100[1)]
Biogas fuelled engines, BIOMASS, CH_4	CH_4	6.8[2)]	3.9[2)]	20[11)]	10[11)]
Stationary Combustion, SOLID, N_2O	N_2O	0.9[2)]	1.0[2)]		400[6) 13)]
Stationary Combustion, LIQUID, N_2O	N_2O	1.5[2)]	0.8[2)]		1000[1) 13)]
Stationary Combustion, GAS, N_2O	N_2O	1.0[8)]	1.0[8)]		750[6) 13)]
Stationary Combustion, WASTE, N_2O	N_2O	10.0[5)]	5.0[5)]		400[6) 13)]
Stationary Combustion, BIOMASS, N_2O	N_2O	14.7[2)]	15.3[2)]		400[6) 13)]

1) IPCC Good Practice Guidance, default value (IPCC, 2000).
2) Estimated by DCE based on default uncertainty levels in IPCC Good Practice Guidance, Table 2.6 (IPCC, 2000).
3) Jørgensen et al. (2010). Uncertainty data for NMVOC + CH_4.
4) Jensen & Lindroth (2002).
5) Estimated by DCE based on Astrup et al. (2012).
6) DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark.
7) Emission data based on EU ETS data.
8) Lindgren (2010). Personal communication, Tine Lindgren, Energinet.dk, e-mail 2010-03-16.
9) Equal to natural gas total. DCE assumption.
10) DCE assumption based on EU ETS data interval and IPCC Guidelines (IPCC, 1997) data interval.
11) DCE estimate based on Nielsen et al. (2010).
12) DCE assumption based on the fact that data are based on EU ETS data.
13) With a truncation of twice the uncertainty rate. The truncation is relevant for the very large uncertainty rates for N_2O emission factors due to the log-normal distribution applied in the tier 2 model.

Other pollutants

With regard to other pollutants, IPCC methodologies for uncertainty estimates have been adopted for the LRTAP Convention reporting activities (Pulles & Aardenne, 2004). The Danish uncertainty estimates are based on the simple Tier 1 approach.

The uncertainty estimates are based on emission data for the base year and year 2012 as well as on uncertainties for fuel consumption and emission factors for each of the main SNAP source categories. The applied uncer-

[33] Including anodic carbon.

tainties for activity rates and emission factors are default values referring to Pulles & Aardenne (2004). The default uncertainties for emission factors are given in letter codes representing an uncertainty range. It has been assumed that the uncertainties were in the lower end of the range for all sources and pollutants. The applied uncertainties for emission factors are listed in Table 3.2.37. The uncertainty for fuel consumption in stationary combustion plants is assumed to be 2 %.

Table 3.2.37 Uncertainty rates for emission factors, %.

SNAP source category	SO_2	NO_x	NMVOC	CO
01	10	20	50	20
02	20	50	50	50
03	10	20	50	20

Results

The tier 1 uncertainty estimates for stationary combustion emission inventories are shown in Table 3.2.38. Detailed calculation sheets are provided in Annex 3A-7. The tier 2 uncertainty estimates are shown in Table 3.2.39 and detailed results are provided in Annex 3A-7.

The tier 1 uncertainty interval for greenhouse gas is estimated to be ±2.2 % and trend in greenhouse gas emission is -39 % ± 1.1 %-age points. The main sources of uncertainty for greenhouse gas emission 2012 are the N_2O emission from combustion of biomass and gaseous fuels, CH_4 emission from biomass combustion and CO_2 emission from fossil waste combustion. The main sources of uncertainty in the trend in greenhouse gas emission are the CO_2 emission from coal and fossil waste combustion and the N_2O emission from combustion of biomass and liquid fuels.

The total emission uncertainty is 7.5 % for SO_2, 16 % for NO_x, 45 % for NMVOC and 44 % for CO.

The tier 2 approach points out N_2O and CH_4 emissions from combustion of biomass and CO_2 from fossil waste combustion as the main contributors to the total uncertainty for greenhouse gas emission from stationary combustion.

Table 3.2.38 Danish uncertainty estimates, tier 1 approach, 2012.

Pollutant	Uncertainty Total emission, %	Trend 1990-2012, %	Uncertainty trend, %-age points
GHG	±2.2%	-39%	±1.1%
CO_2	±0.9%	-40%	±0.7%
CH_4	±46%	134%	±86%
N_2O	±260%	-2.0%	±244%
SO_2	±7.5%	-95%	±0.3%
NO_x	±16%	-72%	±1.8%
NMVOC	±45%	12%	±6%
CO	±44%	-5.2%	±2.7%

Table 3.2.39 Danish uncertainty estimates, tier 2 approach, 2012.

Pollutant	Uncertainty of total emission, %		Trend 1990-2012, %	Uncertainty of trend, %-age points	
GHG	-1.4	+3.9	-38.9	-2.9	+2.7
CO_2	-0.9	+1.9	-39.8	-2.8	+2.6
CH_4	-28	+138	131	-19	+41
N_2O	-73	+1096	-2.8	-171	+119

The results are illustrated and compared in figure 3.2.48. The uncertainties are in the same level for each pollutant. The emission data shown for the tier 1 approach are the CRF emission data. The tier 2 emission levels are median values based on the Monte Carlo approach.

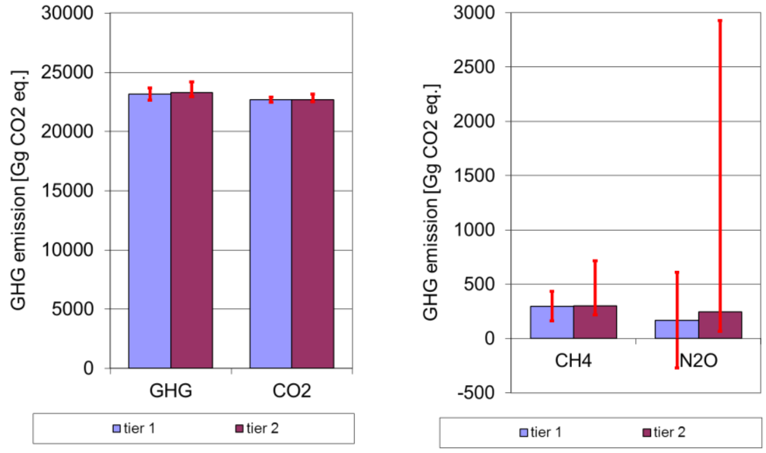


Figure 3.2.48 Uncertainty level, the two approaches are compared for 2012.

3.2.7 Source specific QA/QC and verification

An updated quality manual for the Danish emission inventories has been published in 2013 (Nielsen et al., 2013). The quality manual describes the concepts of quality work and definitions of sufficient quality, critical control points and a list of Point for Measuring (PM).

Documentation concerning verification of the Danish GHG emission inventories has been published by (Fauser et al., 2013). In addition, the IPCC reference approach for CO_2 emission is an important verification of the CO_2 emission from the energy sector. The reference approach for the energy sector is shown in Chapter 3.4.

Information on the Danish QA/QC plan is included in Chapter 1.6. Source specific QA/QC and PM's are shown below.

National external review

The 2004, 2006 and 2009 updates of the sector report for stationary combustion has been reviewed by external experts (Nielsen & Illerup, 2004; Nielsen & Illerup, 2006; Nielsen et al., 2009). An updated sector report for stationary combustion will be published in 2014 (Nielsen et al., 2014). The national external review forms a vital part of the QA activities for stationary combustion.

The 2004, 2006 and 2009 updates of this report were reviewed by Jan Erik Johnsson from the Technical University of Denmark, Bo Sander from Elsam Engineering and Annemette Geertinger from FORCE Technology.

Data storage, level 1

Table 3.2.40 lists the sector specific PM's for data storage level 1.

Table 3.2.40 List of PM, data storage level 1.

Level	CCP	Id	Description	Sectoral/general	Stationary combustion
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/EEA Guidebook 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 are shown and discussed below.
	4.Consistency	DS.1.4.1	The original external data has to be archived with proper reference.	Sectoral	It is ensured that all external data are archived at DCE. 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.
	6.Robustness	DS.1.6.1	Explicit agreements between the external institution holding the data and DCE about the conditions of delivery	Sectoral	For stationary combustion, a data delivery agreement is made with the DEA. NERI (now DCE) and DEA have renewed the data delivery agreement in 2010. An update of the data delivery agreement will be signed in 2014. Most of the other external data sources are available due to legislatory requirements. See Table 3.2.41.
	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 3.2.41 below.

Table 3.2.41 List of external data sources.

Dataset	Description	AD or Emf.	Reference	Contact(s)	Data agreement/ Comment
Energiproducenttællingen.xls	Data set for all electricity and heat producing plants.	Activity data	The Danish Energy Agency (DEA)	Kaj Stærkind	Data agreement 2010. An updated data agreement will be signed in 2014.
Gas consumption for gas engines and gas turbines 1990-1994	Historical data set for gas engines and gas turbines.	Activity data	The Danish Energy Agency (DEA)	Kaj Stærkind	No data agreement. Historical data
Basic data (Grunddata.xls)	The Danish energy statistics. Data set applied for both the reference approach and the national approach.	Activity data	The Danish Energy Agency (DEA)	Jane Rusbjerg	Data agreement 2010. However, the data set is also published as part of national energy statistics An updated data agreement will be signed in 2014.
Energy statistics for industrial subsectors	Disaggregation of the industrial fuel consumption.	Activity data	The Danish Energy Agency (DEA)	Jane Rusbjerg	Only informal data delivery agreement. The data set will be included in the next update of the data delivery agreement with DEA.
SO_2 & NO_x data, plants>25 MW_e	Annual emission data for all power plants > 25 MW_e. Includes information on methodology: measurements or emission factor.	Emissions	Energinet.dk	Christian F.B. Nielsen	No data agreement.
Emission factors	Emission factors refer to a large number of sources.	Emission factors	See chapter regarding emission factors		Some of the annually updated CO_2 emission factors are based on EU ETS data, see below. For the other emission factors no formal data delivery agreement.
Annual environmental reports / environmental data	Emissions from plants defined as large point sources	Emissions	Various plants		No data agreement necessary. Plants are obligated by law (DEPA 2010a) and data published on the Danish EPA homepage.
EU ETS data	Plant specific CO_2 emission factors	Emission factors and fuel consumption	The Danish Energy Agency (DEA)	Dorte Maimann Helen Falster	Plants are obligated by law. The availability of detailed information is part of the renewed data agreement with DEA.

Energiproducenttaellingen - statistic on fuel consumption from district heating and power plants (DEA)
The data set includes all plants producing power or district heating. The spreadsheet from DEA is listing fuel consumption of all plants included as large point sources in the emission inventory. The statistic on fuel consumption from district heating and power plants is regarded as complete and with no significant uncertainty since the plants are bound by law to report their fuel consumption and other information.

Gas consumption for gas engines and gas turbines 1990-1994 (DEA)
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. DCE assesses that the DEA estimate is the best available data.

Basic data (DEA)
The Danish Energy statistics. The spreadsheet from DEA is used for the CO_2 emission calculation in accordance with the IPCC reference approach and is also the first data set applied in the national approach. The data set is included in the data delivery agreement with DEA, but it is also published annually on DEA's homepage.

Energy statistics for industrial subsectors (DEA)
The data includes disaggregation of the fuel consumption for industrial plants. The data set is estimated for the reporting to Eurostat. The data delivery agreement is informal at this time, but the dataset will be included in the 2014 update of the agreement with DEA.

SO_2 and NO_x emission data from electricity producing plants > 25MW$_e$ (Energinet.dk)
Plants larger than 25 MW$_e$ are obligated to report emission data for SO_2 and NO_x to the DEA annually. Data are collected by Energinet.dk and forwarded to DEA. Data are on production unit level and classified. The data on plant level are part of the plants annually environmental reports. DCE's QC of the data consists of a comparison with data from previous years and with data from the plants' annual environmental reports.

Emission factors
For specific references, see the Chapter 3.2.5 regarding emission factors. Some of the annually updated CO_2 emission factors are based on EU ETS data, se below.

Annual environmental reports (DEPA)
A large number of plants are obligated by law to report annual environmental data including emission data. DCE compares the data with those from previous years and large discrepancies are checked.

EU ETS data (DEA)
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. The data delivery agreement is informal at this

time, but the dataset will be included in the 2014 update of the agreement with DEA.

Data processing, level 1

Table 3.2.42 lists the sector specific PM's for data processing level 1.

Table 3.2.42 List of PM, data processing level 1.

Level	CCP	Id	Description	Sectoral / general	Stationary combustion
Data Pro-cessing 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.
	2.Comparability	DP.1.2.1	The methodologies have to follow the inter-national guidelines suggested by UNFCCC and IPCC.	Sectoral	The methodological approach is consistent with international guide-lines. An overview of tiers is given in NIR Chapter 3.2.5
	3.Completenes s	DP.1.3.1	Identification of data gaps with regard to data sources that could improve quantitative knowledge.	Sectoral	The energy statistics is considered complete.
	4.Consistency	DP.1.4.1	Documentation and reasoning of methodo-logical 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; imple-mentation of Energiproducenttael-lingen (plant specific fuel consump-tion 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 vali-dates the fuel consumption rates and CO_2 emission. Both differ less than 2.0 % (1990-2012). The refer-ence approach is further discussed in NIR Chapter 3.4.
	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	-

Data storage, level 2

Table 3.2.43 lists the sector specific PM's for data storage level 2.

Table 3.2.43 List of PM, data storage level 2.

Level	CCP	Id	Description	Sectoral / general	Stationary combustion
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

Table 3.2.44 lists the sector specific PM's for data storage level 4.

Table 3.2.44 List of PM, data storage level 4.

Level	CCP	Id	Description	Sectoral / general	Stationary combustion
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.

Other QC procedures

Some automated checks have been prepared for the emission databases:

- 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 this report (Chapter 3.2.5 and Appendix 3A-4).
- Annual environmental reports are kept for subsequent control of plant-specific emission data.
- QC checks of the country-specific emission factors have not been performed, but most factors are based on input from companies that have implemented some QA/QC work. The major power plant owner/operators in Denmark, DONG Energy and Vattenfall have 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.
- The emission from each large point source is compared with the emission reported the previous year.

3.2.8 Source specific recalculations and improvements

Recalculations for stationary combustion 2011 are shown in Table 3.2.45. The main calculations are discussed below.

Table 3.2.45 Recalculations for stationary combustion, 2011.

	CO_2 , Gg CO_2	CH_4, Gg CO_2 eqv.	N_2O Gg CO_2 eqv.	CO_2 , %	CH_4, %	N_2O %
1.A.1. Energy Industries	**7.72**	**2.13**	**0.02**	**0%**	**1%**	**0%**
Liquid Fuels	0.41	0.03	0.03	0%	6%	2%
Solid Fuels	9.95	0.00	0.05	0%	0%	0%
Gaseous Fuels	-2.63	1.59	-0.08	0%	1%	0%
Biomass	4.43	0.50	0.02	0%	2%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
a. Public Electricity and Heat Production	28.79	2.14	0.14	0%	1%	0%
Liquid Fuels	0.10	0.03	0.03	0%	29%	3%
Solid Fuels	9.95	0.00	0.05	0%	0%	0%
Gaseous Fuels	18.74	1.61	0.03	1%	1%	0%
Biomass	4.43	0.50	0.02	0%	2%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
b. Petroleum Refining	0.30	0.00	0.00	0%	0%	0%
Liquid Fuels	0.30	0.00	0.00	0%	0%	0%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	0.00	0.00	0.00	0%	0%	0%
Biomass	0.00	0.00	0.00	0%	0%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
c. Manufacture of Solid Fuels and Other Energy Industries	-21.37	-0.01	-0.12	-1%	-1%	-1%
Liquid Fuels	0.00	0.00	0.00	0%	0%	0%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	-21.37	-0.01	-0.12	-1%	-1%	-1%
Biomass	0.00	0.00	0.00	0%	0%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
1.A.2 Manufacturing Industries and Construction	**132.50**	**-0.76**	**3.26**	**3%**	**-6%**	**9%**
Liquid Fuels	127.36	0.05	2.46	7%	4%	13%
Solid Fuels	3.32	0.01	0.02	1%	1%	1%
Gaseous Fuels	5.80	-0.99	-0.01	0%	-14%	-1%
Biomass	72.48	0.20	0.86	8%	6%	8%
Other Fuels	-3.98	-0.03	-0.06	-5%	-5%	-5%
a. Iron and Steel	-11.35	-0.01	0.00	-13%	-13%	-3%
Liquid Fuels	0.23	0.00	0.00	86%	43%	608%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	-11.60	-0.01	-0.01	-13%	-13%	-13%
Biomass	0.00	0.00	0.00	0%	0%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
b. Non-Ferrous Metals	-2.57	0.00	0.01	-39%	-42%	355%
Liquid Fuels	0.73	0.00	0.01	17180%	9090%	116882%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	-3.30	0.00	0.00	-50%	-50%	-50%
Biomass	0.00	0.00	0.00	0%	0%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
c. Chemicals	97.74	0.04	0.34	58%	38%	100%
Liquid Fuels	15.84	0.01	0.32	10570%	6489%	80732%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	82.45	0.04	0.04	49%	47%	14%
Biomass	0.00	0.00	0.00	0%	0%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
d. Pulp, Paper and Print	-14.01	0.55	2.30	-10%	108%	121%
Liquid Fuels	2.40	0.00	0.05	358%	163%	2763%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	-14.88	-0.01	-0.01	-11%	-10%	-3%
Biomass	201.02	0.57	2.27	140%	136%	141%
Other Fuels	-1.53	-0.01	-0.02	-74%	-74%	-74%
e. Food Processing, Beverages and Tobacco	106.81	-0.14	1.31	9%	-3%	20%

	CO_2, Gg CO_2	CH_4, Gg CO_2 eqv.	N_2O Gg CO_2 eqv.	CO_2, %	CH_4, %	N_2O %
Liquid Fuels	68.42	0.02	1.38	30%	29%	31%
Solid Fuels	-40.85	-0.09	-0.19	-18%	-18%	-18%
Gaseous Fuels	77.09	0.05	0.04	10%	1%	5%
Biomass	1.37	-0.14	0.04	4%	-60%	23%
Other Fuels	2.16	0.02	0.03	80%	80%	80%
f. Other (please specify)(4)	-44.13	-1.21	-0.69	-2%	-15%	-3%
Cement production	0.00	0.00	0.00	0%	0%	0%
Liquid Fuels	0.00	0.00	0.00	0%	0%	0%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	0.00	0.00	0.00	0%	0%	0%
Biomass	0.00	0.00	0.00	0%	0%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
Non-road machinery	0.00	0.00	0.00	0%	0%	0%
Liquid Fuels	12.19	0.00	0.16	1%	1%	1%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	0.00	0.00	0.00	0%	0%	0%
Biomass	0.00	0.00	0.00	0%	0%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
Other non-specified	0.00	0.00	0.00	0%	0%	0%
Liquid Fuels	27.55	0.01	0.53	120%	81%	929%
Solid Fuels	44.15	0.10	0.20	39%	42%	42%
Gaseous Fuels	-123.38	-0.96	-0.08	-16%	-32%	-18%
Biomass	-128.79	-0.22	-1.44	-19%	-11%	-19%
Other Fuels	-4.06	-0.03	-0.06	-39%	-39%	-39%
1.A.4 Other Sectors	**17.66**	**15.25**	**-1.00**	**0%**	**10%**	**-1%**
Liquid Fuels	-56.21	0.07	-1.39	-2%	1%	-4%
Solid Fuels	3.31	0.01	0.02	3%	2%	3%
Gaseous Fuels	66.65	0.17	0.28	3%	1%	3%
Biomass	5.53	14.97	0.04	0%	13%	0%
Other Fuels	3.90	0.03	0.06	140%	140%	140%
a. Commercial/Institutional	-5.87	-0.19	0.09	-1%	-1%	1%
Liquid Fuels	-15.57	-0.06	-0.05	-4%	-2%	-4%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	5.80	0.02	0.07	1%	0%	1%
Biomass	3.03	-0.19	0.01	1%	-3%	0%
Other Fuels	3.90	0.03	0.06	140%	140%	140%
b. Residential	57.75	15.15	0.05	2%	14%	0%
Liquid Fuels	11.72	0.01	0.04	1%	0%	2%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	46.03	0.12	0.03	3%	1%	3%
Biomass	-1.58	15.03	-0.02	0%	16%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
c. Agriculture/Forestry/Fisheries	-34.22	0.29	-1.13	-2%	1%	-3%
Liquid Fuels	-52.36	0.12	-1.38	-3%	5%	-5%
Solid Fuels	3.31	0.01	0.02	3%	3%	3%
Gaseous Fuels	14.82	0.03	0.18	12%	0%	16%
Biomass	4.08	0.13	0.05	1%	1%	2%
Other Fuels	0.00	0.00	0.00	0%	0%	0%

For stationary combustion plants, the emission estimates for the years 1990-2011 have been updated according to the latest energy statistics published by the Danish Energy Agency. The update included both end use and transformation sectors as well as a source category update. The changes in the energy statistics are largest for the years 2009, 2010 and 2011.

For CO_2 the largest recalculation is in source category Manufacturing industries and constructions. The recalculation is related to liquid fuels and is a result of correction of an error. The consumption of residual oil was underestimated in the former inventories. The CO_2 emission from liquid fuels applied in manufacturing industries and constructions 2011 is 7% higher in the 2014 reporting than in the 2013 reporting.

The CH_4 emission from residential wood combustion has been recalculated based on improved emission factors for stoves. This has caused a 16 % increase of the CH4 emission reported for biomass fuels in residential plants for 2011.

For N_2O the largest recalculation is in source category Manufacturing industries and constructions. This recalculation is also related to the former underestimate for residual oil. The N_2O emission from liquid fuels applied in manufacturing industries and constructions 2011 is 13% higher in the 2014 reporting than in the 2013 reporting.

Improvements related to reviews

The text in the CRF documentation box in Table 1.A(c) has been improved and a reference to the relevant NIR chapter have been added.

Data for lubricants have been added in Table 1.C.

3.2.9 Source specific planned improvements

The next emission inventory will implement the 2006 IPCC Guidelines (IPCC, 2006).

3.2.10 References for chapter 3.2 and Annex 3A

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3.3 Transport and other mobile sources (CRF sector 1A2, 1A3, 1A4 and 1A5)

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) 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, 2013). 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
07 Road transport	1A3b Transport-Road
0801 Military	1A5 Other
0802 Railways	1A3c Railways
0803 Inland waterways	1A3d Transport-Navigation
080402 National sea traffic	1A3d Transport-Navigation
080403 National fishing	1A4c Agriculture/forestry/fisheries
080404 International sea traffic	1A3d Transport-Navigation (international)
080501 Dom. airport traffic (LTO < 1000 m)	1A3a Transport-Civil aviation
080502 Int. airport traffic (LTO < 1000 m)	1A3a Transport-Civil aviation (international)
080503 Dom. cruise traffic (> 1000 m)	1A3a Transport-Civil aviation
080504 Int. cruise traffic (> 1000 m)	1A3a Transport-Civil aviation (international)
0806 Agriculture	1A4c Agriculture/forestry/fisheries
0807 Forestry	1A4c Agriculture/forestry/fisheries
0808 Industry	1A2f Industry-Other
0809 Household and gardening	1A4b Residential
0811 Commercial and institutional	1A4a Commercial and institutional

Military transport activities (land and air) refer to the CRF/NFR sector Other (1A5), while the Transport-Navigation sector (1A3d) comprises national sea transport (SNAP code 080402, ship movements between two Danish ports) and recreational craft (SNAP code 0803).

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

[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.

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/fisheries (1A4c) sector together with fishing activities (SNAP code 080403).

For mobile sources, internal database models for road transport, air traffic, sea transport and non road machinery have been set up at Department of Environmental Science (ENVS)/Danish Centre for Environment and Energy (DCE), Aarhus University (former NERI), in order to produce the emission inventories. The output results from the DCE models 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 DCE models are used also as a calculation tool in research projects, environmental impact assessment studies, and to produce basic emission information which requires various aggregation levels.

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.

Fuel consumption

Table 3.3.2 Fuel consumption (PJ) for domestic transport in 2012 in CRF sectors.

CRF ID	Fuel consumption (PJ)
Industry-Other (1A2f)	13,9
Civil Aviation (1A3a)	1,8
Road (1A3b)	160,9
Railways (1A3c)	3,4
Navigation (1A3d)	6,6
Comm./Inst. (1A4a)	2,3
Residential (1A4b)	0,9
Agri./for./fish. (1A4c)	24,9
Military (1A5)	1,6
Total	216.4

Table 3.3.2 shows the fuel consumption for domestic transport based on DEA statistics for 2012 in CRF sectors. The fuel consumption figures in time series 1990-2012 are given in Annex 3.B.16 (CRF format) and are shown for 1990 and 2012 in Annex 3.B.15 (CollectER format). Road transport has a major share of the fuel consumption for domestic transport. In 2012 this sector's fuel consumption share is 74 %, while the fuel consumption shares for Agriculture/forestry/fisheries and Industry-Other are 11 and 6 %, respectively. For the remaining sectors the total fuel consumption share is 9 %.

From 1990 to 2012, diesel (sum of diesel and biodiesel) and gasoline (sum of gasoline and E5) fuel consumption has changed by 43 % and - 12 %, respectively (Figure 3.3.1), and in 2012 the fuel consumption shares for diesel and gasoline were 66 % and 28 %, respectively. Other fuels only have a 6 % share of the domestic transport 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 transport 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[2].

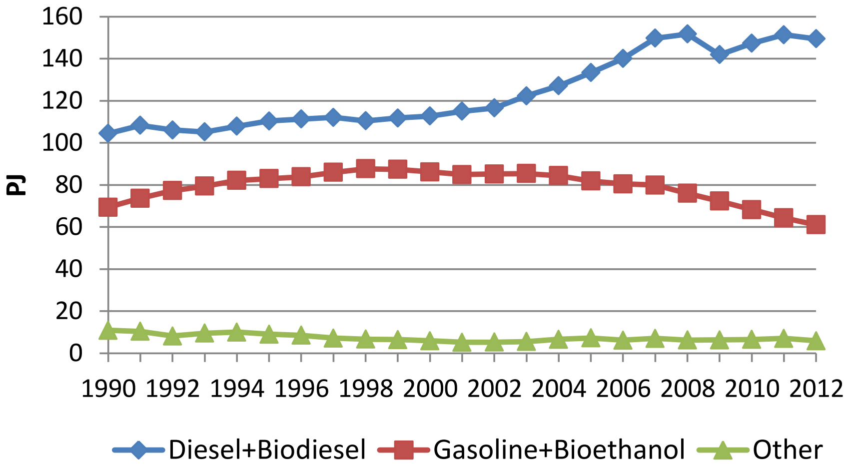

Figure 3.3.1 Fuel consumption pr fuel type for domestic transport 1990-2012.

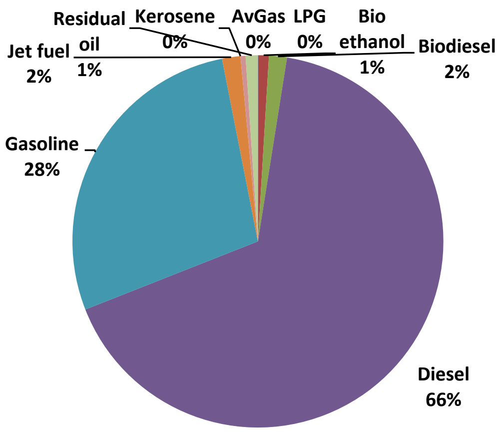

Figure 3.3.2 Fuel consumption share pr fuel type for domestic transport in 2012.

Road transport

As shown in Figure 3.3.3, the fuel consumption for road transport[3] has generally increased until 2007, except from a small fuel consumption decline noted in 2000. The impact of the global financial crisis on fuel consumption for road transport becomes visible for 2008 and 2009. The fuel consumption development is due to a decreasing trend in the use of gasoline fuels from 1999 onwards combined with a steady growth in the use of diesel until 2007. 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).

[2] Biofuels are sold at gas filling stations and are assumed to be used by road transport vehicles.
[3] The sum share of bioethanol and biodiesel in the gasoline and diesel fuel blends for road transport is 5.3 %, in 2012.

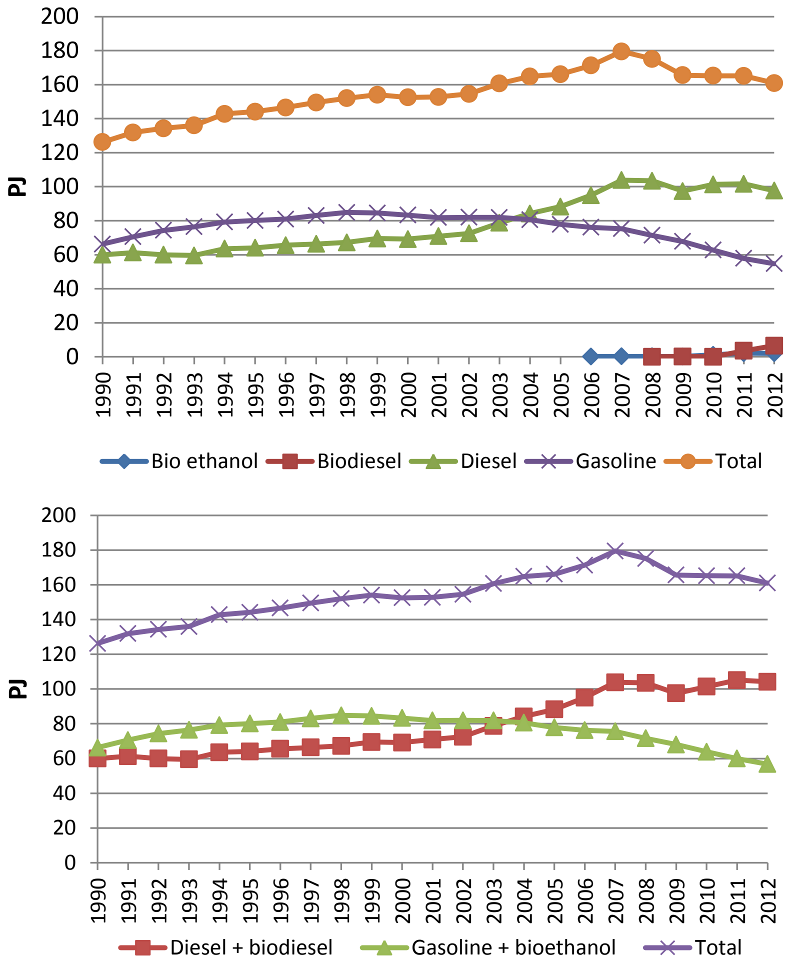

Figure 3.3.3 Fuel consumption pr fuel type and as totals for road transport 1990-2012.

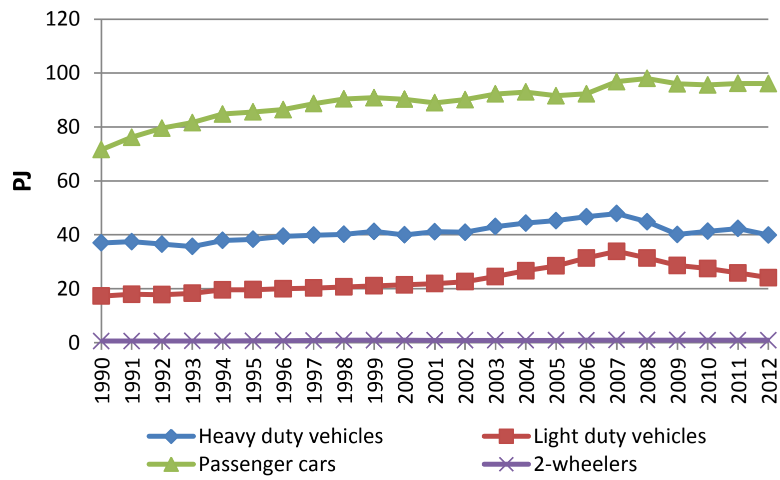

Figure 3.3.4 Total fuel consumption pr vehicle type for road transport 1990-2012.

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, while declines in the fuel consumption for trucks and buses (heavy-duty vehicles) and light duty vehicles are noted for 2008- 2009, 2012, and 2008-2012, respectively.

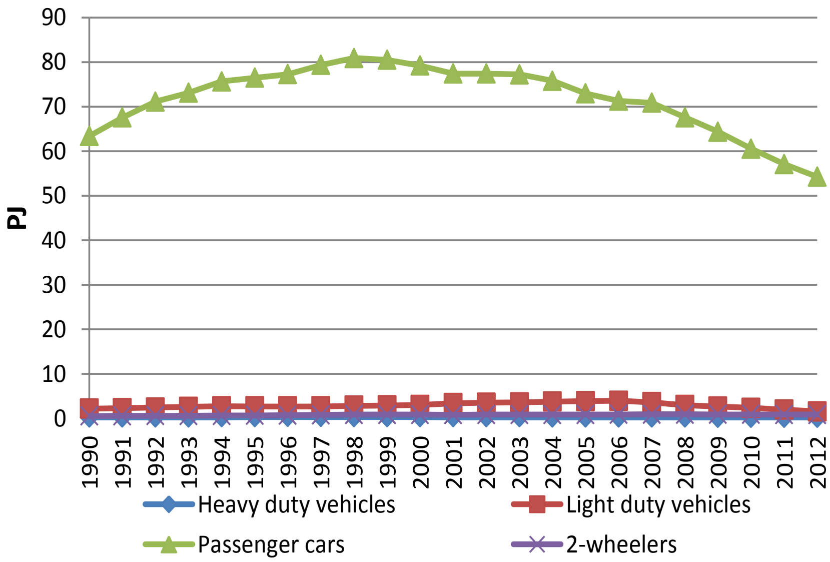

Figure 3.3.5 Gasoline fuel consumption pr vehicle type for road transport 1990-2012.

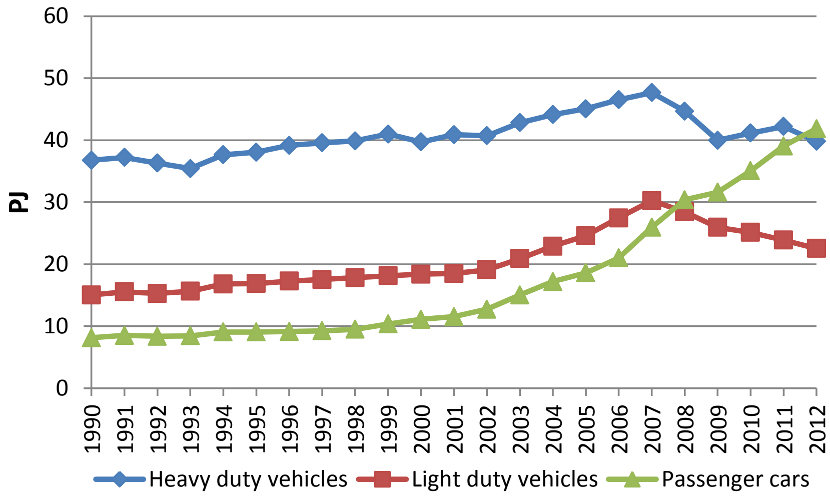

Figure 3.3.6 Diesel fuel consumption pr vehicle type for road transport 1990-2012.

In 2012, fuel consumption shares for gasoline passenger cars, heavy-duty vehicles, diesel passenger cars, diesel light duty vehicles and gasoline light duty vehicles were 34, 26, 25, 14 and 1 %, respectively (Figure 3.3.7).

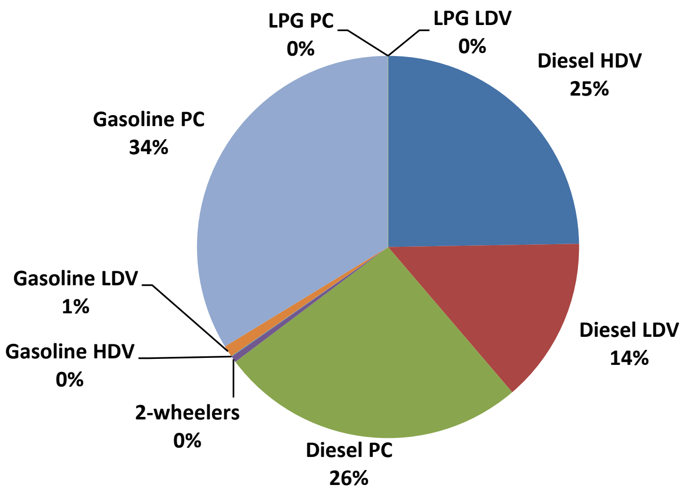

Figure 3.3.7 Fuel consumption share (PJ) pr vehicle type for road transport in 2012.

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 1A2f) and Navigation (1A3d). Minor fuel consuming sectors are Civil Aviation (1A3a), Railways (1A3c), Other (military mobile fuel consumption: 1A5), Commercial/institutional (1A4a) and Residential (1A4b).

The 1990-2012 time series are shown per fuel type in Figures 3.3.9-3.3.12 for diesel, gasoline and jet fuel, respectively.

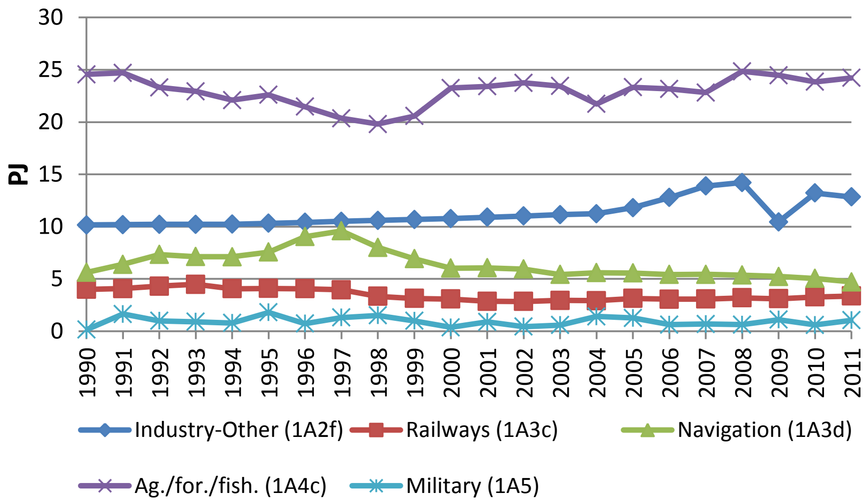

Figure 3.3.8 Total fuel consumption in CRF sectors for other mobile sources 1990-2012.

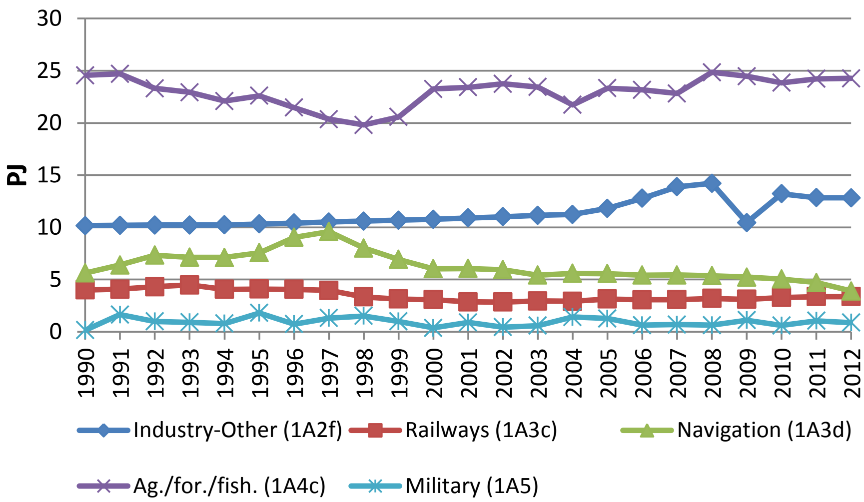

Figure 3.3.9 Diesel fuel consumption in CRF sectors for other mobile sources 1990-2012.

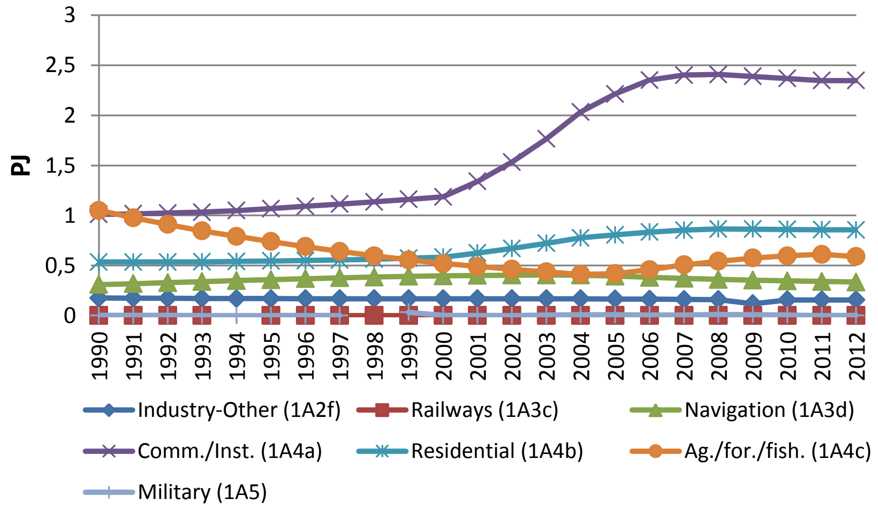

Figure 3.3.10 Gasoline fuel consumption in CRF sectors for other mobile source 1990-2012.

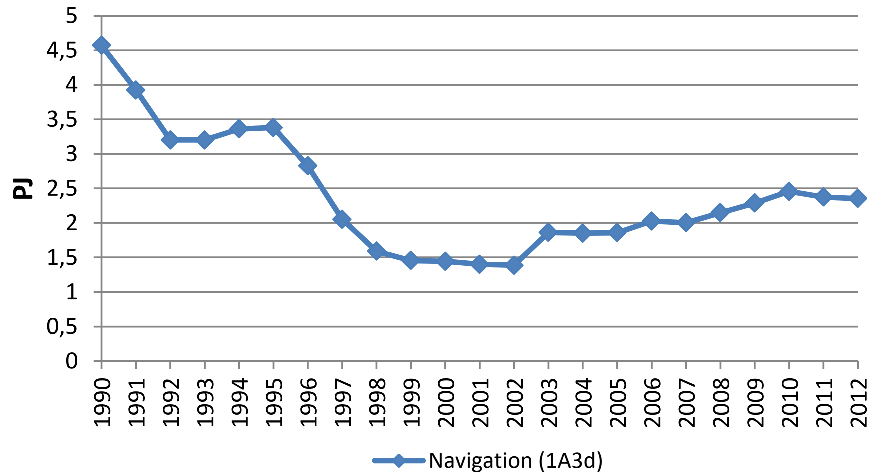

Figure 3.3.11 Residual oil fuel consumption in CRF sectors for other mobile sources 1990-2012.

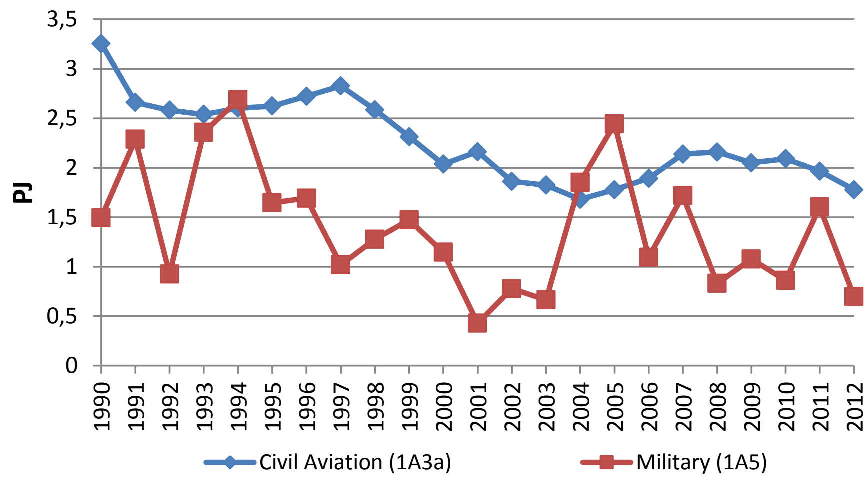

Figure 3.3.12 Jet fuel consumption in CRF sectors for other mobile sources 1990-2012.

In terms of diesel, the fuel consumption decreases for agricultural machines until 2000, due to fewer numbers of tractors and harvesters. After that, the increase in the engine sizes of new sold machines has more than outbalanced the trend towards smaller total stock numbers. 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. 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) and recreational craft. For the latter category, fuel consumption has increased significantly from 1990 to 2004 due to the rising number diesel-fuelled private boats. For national sea transport, the diesel fuel consumption curve reflects the combination of traffic and ferries in use for regional ferries. From 1998 to 2000, 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. The fuel consumption decreases in 2011 and 2012 are due to reductions in the number of round trips made by regional ferries. 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 found for household and gardening machinery in the Commercial/Institutional (1A4a) and Residential (1A4b) sectors. Especially from 2001-2006, a significant fuel consumption increase is apparent due to considerable growth in the machinery stock. The decline in gasoline fuel consumption for Agriculture/forestry/fisheries (1A4c) is due to the gradual phasing out of gasoline-fuelled agricultural tractors.

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 1990-1992 and from 1997-1999.

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. After 2004 an increase in the consumption of jet fuel is noted until 2007/2008.

Bunkers

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, tank vessels and foreign fishing boats. For jet petrol, the sudden fuel consumption drop in 2002 is explained by the recession in the air traffic 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.

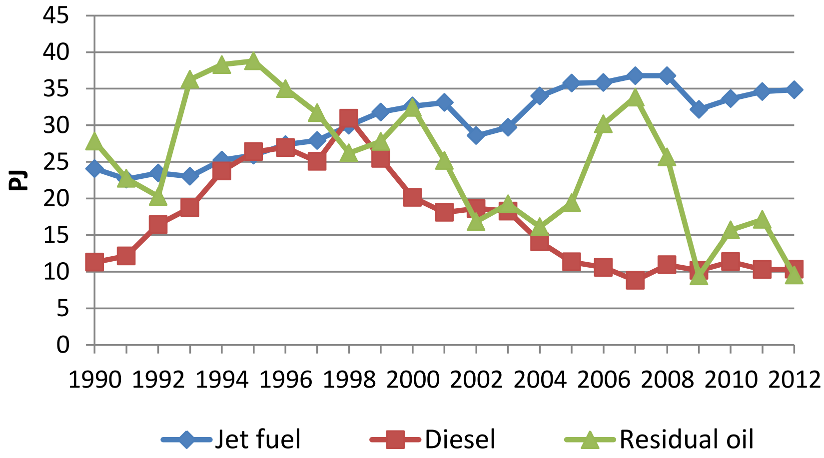

Figure 3.3.13 Bunker fuel consumption 1990-2012.

Emissions of CO_2, CH_4 and N_2O

In Table 3.3.3 the CO_2, CH_4 and N_2O emissions for road transport and other mobile sources are shown for 2012 in CRF sectors. The emission figures in time series 1990-2012 are given in Annex 3.B.16 (CRF format) and are shown for 1990 and 2012 in Annex 3.B.15 (CollectER format).

From 1990 to 2012 the road transport emissions of CO_2 and N_2O have increased by 21 and 28 %, respectively, whereas the emissions of CH_4 have decreased by 76 % (from Figures 3.3.14 - 3.3.16). From 1990 to 2012 the other mobile CO_2 emissions have decreased by 5 %, (from Figures 3.3.18 - 3.3.20).

Table 3.3.3 Emissions of CO_2, CH_4 and N_2O in 2012 for road transport and other mobile sources.

CRF Sector	CH_4 Tonnes	CO_2 Tonnes	N_2O Tonnes
Industry-Other (1A2f)	36	1 021	43
Civil Aviation (1A3a)	2	133	7
Railways (1A3c)	7	249	7
Navigation (1A3d)	34	498	29
Comm./Inst. (1A4a)	151	171	3
Residential (1A4b)	65	62	1
Ag./for./fish. (1A4c)	111	1 839	88
Military (1A5)	3	116	4
Total other mobile	409	4 090	181
Road (1A3b)	538	11 224	376
Total mobile	947	15 314	557

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 2012, the respective emission shares were 60, 25, 15 and 0 %, 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 2012 emission shares for CH_4 were 62, 18, 17 and 3 % for passenger cars, heavy-duty vehicles, 2-wheelers and light-duty vehicles, respectively (Figure 3.3.17).

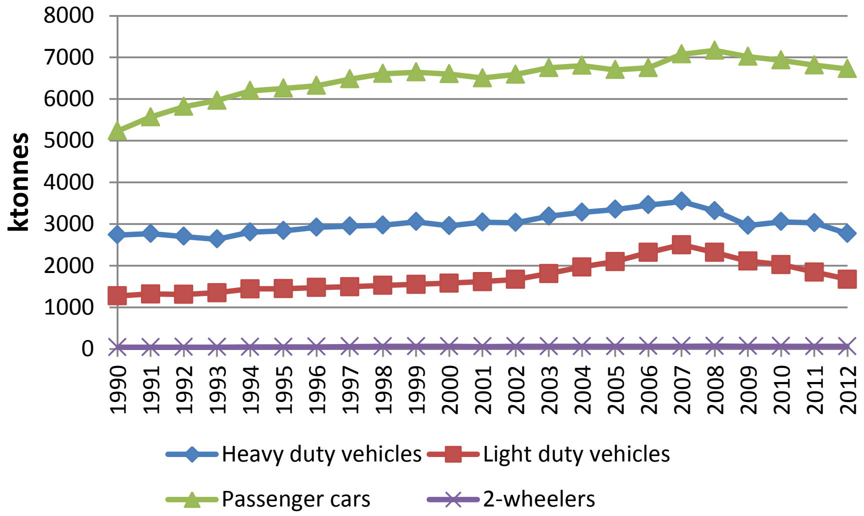

Figure 3.3.14 CO_2 emissions (k-tonnes) pr vehicle type for road transport 1990-2012.

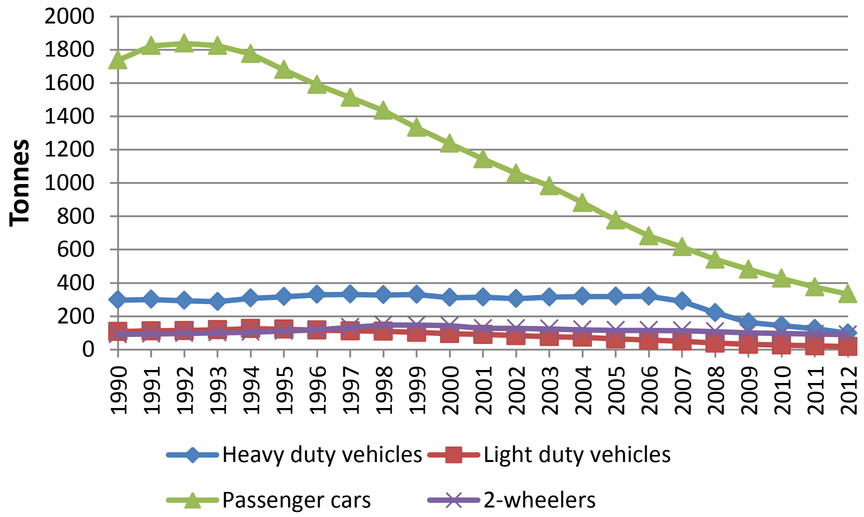

Figure 3.3.15 CH_4 emissions (tonnes) pr vehicle type for road transport 1990-2012.

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 2012, emission shares for passenger cars, heavy and light-duty vehicles were 54, 31 and 14 %, of the total road transport N_2O, respectively (Figure 3.3.17).

Referring to the second IPCC assessment report, 1 g CH_4 and 1 g N_2O has the greenhouse effect of 21 and 310 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.

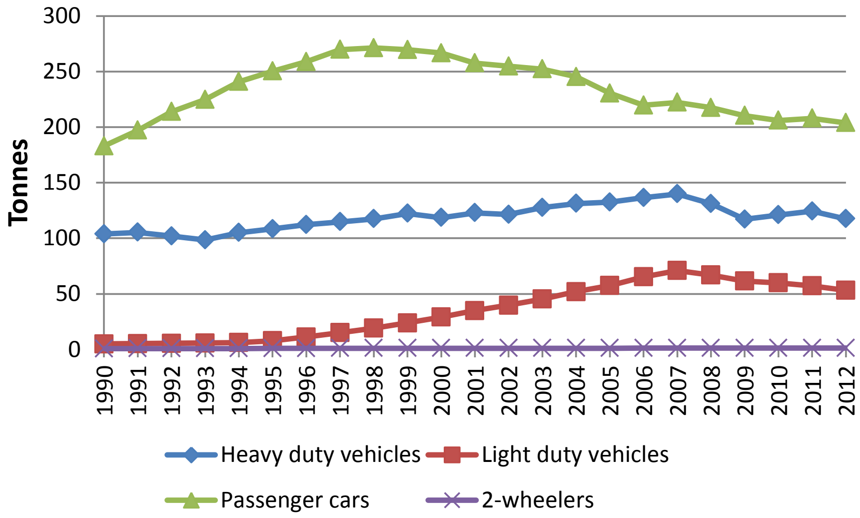

Figure 3.3.16 N_2O emissions (tonnes) pr vehicle type for road transport 1990-2012.

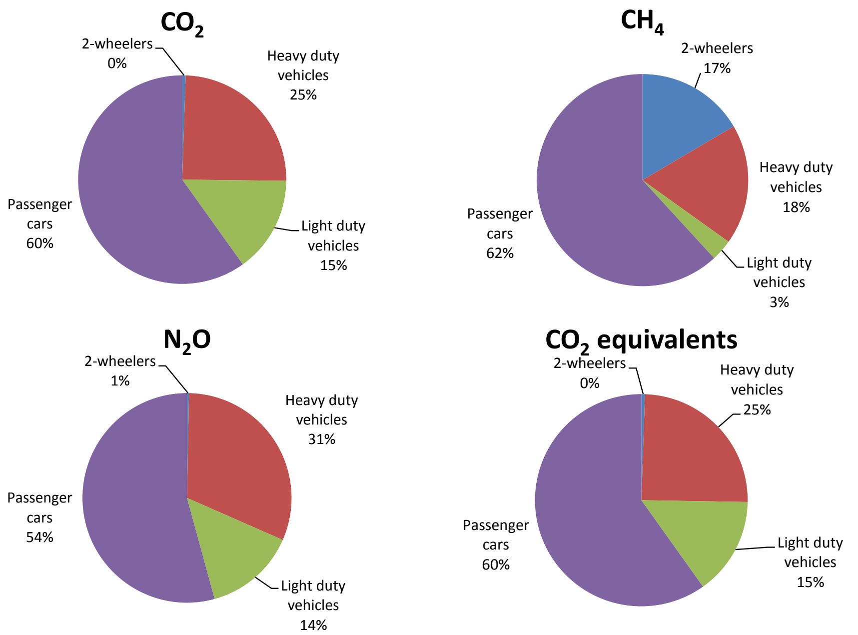

Figure 3.3.17 CO_2, CH_4 and N_2O emission shares and GHG equivalent emission distribution for road transport in 2012.

Other mobile sources

For other mobile sources, the highest CO_2 emissions in 2012 come from Agriculture/forestry/fisheries (1A4c), Industry-other (1A2f) and Navigation (1A3d), with shares of 49, 25 and 12 %, respectively (Figure 3.3.21). The 1990-2012 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 Military (1A5).

For CH_4, far the most important sources are the gasoline fuelled gardening machinery in the Commercial/Institutional (1A4a) and Residential (1A4b) sectors, see Figure 3.3.21. The emission shares are 37 % and 16 %, respectively in 2012. The 2012 emission shares for Agriculture/forestry/fisheries (1A4c), Industry (1A2f) and Navigation (1A3d) are 27, 9 and 8 %, respectively, whereas the remaining sectors have emission shares of 3 % or less.

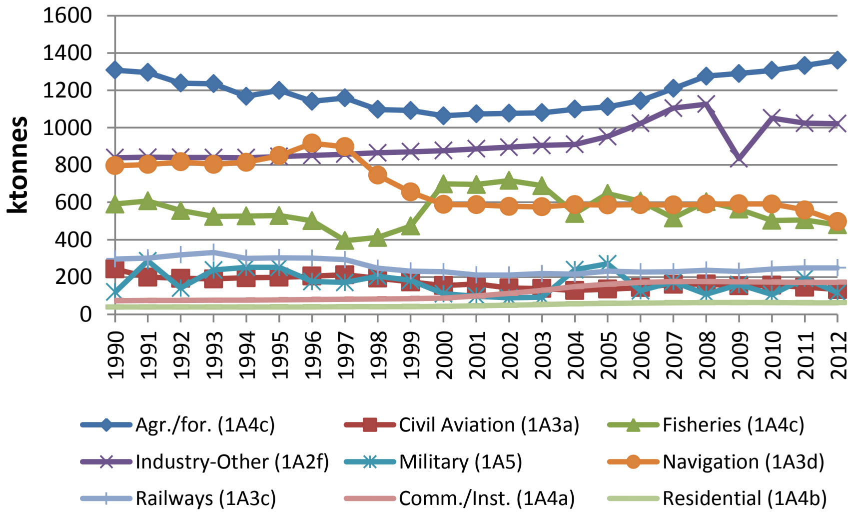

Figure 3.3.18 CO_2 emissions (ktonnes) in CRF sectors for other mobile sources 1990-2012.

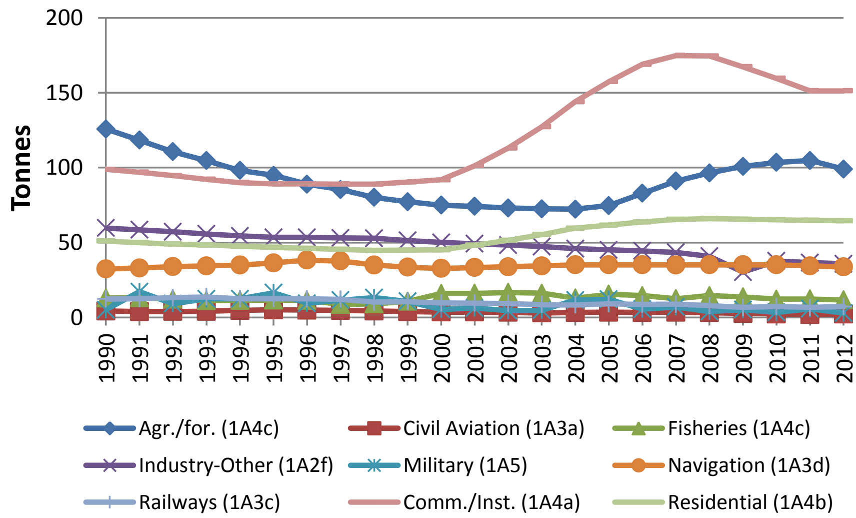

Figure 3.3.19 CH_4 emissions (tonnes) in CRF sectors for other mobile sources 1990-2012.

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).

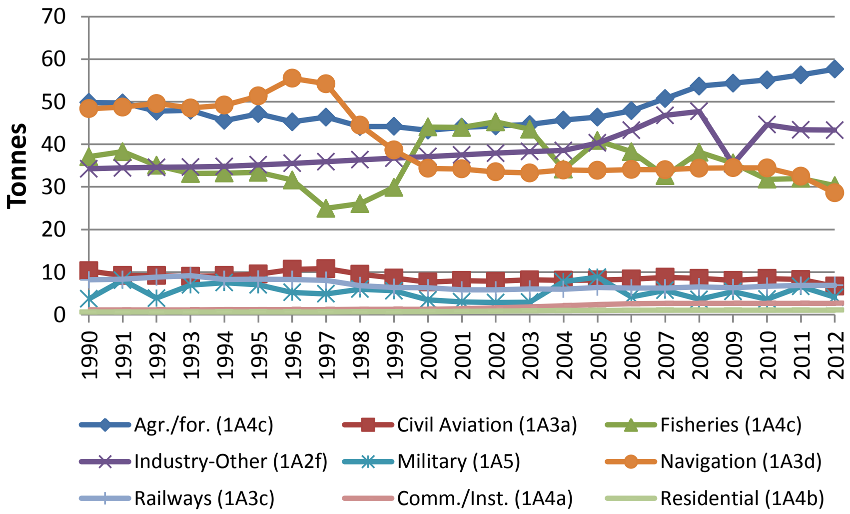

Figure 3.3.20 N_2O emissions (tonnes) in CRF sectors for other mobile sources 1990-2012.

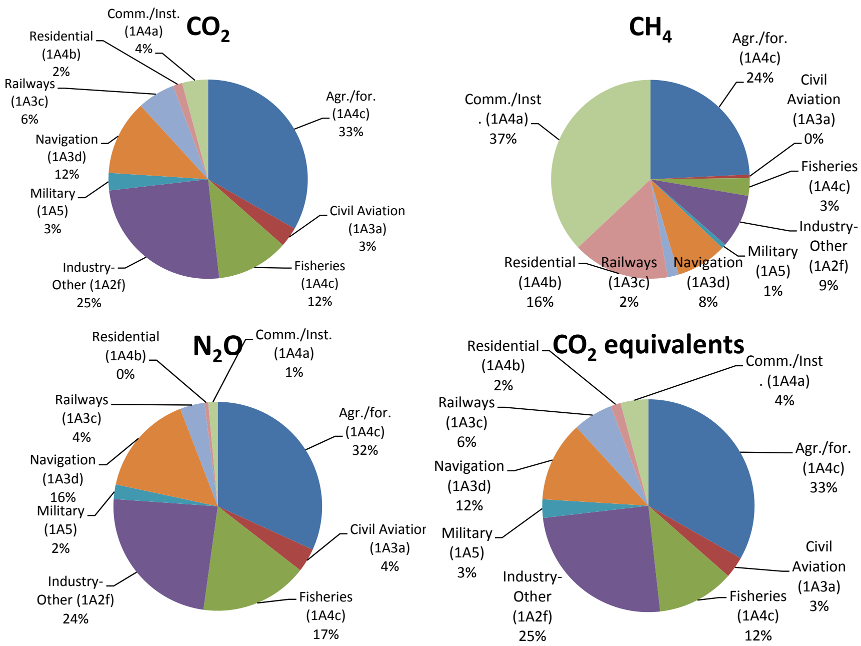

Figure 3.3.21 CO_2, CH_4 and N_2O emission shares and GHG equivalent emission distribution for other mobile sources in 2012.

Emissions of SO_2, NO_X, NMVOC and CO

In Table 3.3.4 the SO_2, NO_X, NMVOC and CO emissions for road transport and other mobile sources are shown for 2011 in CRF sectors. The emission figures in the time series 1990-2011 are given in Annex 3.B.16 (CRF format) and are shown for 1990 and 2011 in Annex 3.B.15 (CollectER format).

From 1990 to 2011, the road transport emissions of NMVOC, CO and NO_X emissions have decreased by 84, 77 and 58 %, respectively (Figures 3.3.23-3.3.25).

For other mobile sources, the emissions of NO_X decreased by 21 % from 1990 to 2011 and for SO_2 the emission drop is as much as 82 %. In the same period, the emissions of NMVOC have declined by 31 %, whereas the CO emissions have increased by 11 % (Figures 3.3.27-3.3.30).

Table 3.3.4 Emissions of SO_2, NO_X, NMVOC and CO in 2012 for road transport and other mobile sources.

CRF ID	SO_2	NO_x	NMVOC	CO
	Tonnes	Tonnes	Tonnes	Tonnes
Industry-Other (1A2f)	6	7 597	1 076	6 239
Civil Aviation (1A3a)	42	579	98	607
Railways (1A3c)	2	2 531	190	425
Navigation (1A3d)	1 334	8 692	749	5 030
Comm./Inst. (1A4a)	1	219	3 636	72 587
Residential (1A4b)	0	92	1 953	26 236
Ag./for./fish. (1A4c)	311	18 163	2 137	19 246
Military (1A5)	17	492	33	270
Total other mobile	1 713	38 366	9 873	130 639
Road (1A3b)	71	44 316	10 439	96 022
Total mobile	1 784	82 682	20 312	226 661

Road transport

The step-wise lowering of the sulphur content in diesel fuel has given rise to a substantial decrease in the road transport emissions of SO_2 (Figure 3.3.22). In 1999, the sulphur content was reduced from 500 ppm to 50 ppm (reaching gasoline levels), and for both gasoline and diesel the sulphur content was reduced to 10 ppm in 2005. Since Danish diesel and gasoline fuels have the same sulphur percentages, at present, the 2012 shares for SO_2 emissions and fuel consumption for passenger cars, heavy-duty vehicles, light-duty vehicles and 2-wheelers are the same in each case: 60, 25, 15 and 0 %, respectively (Figure 3.3.26).

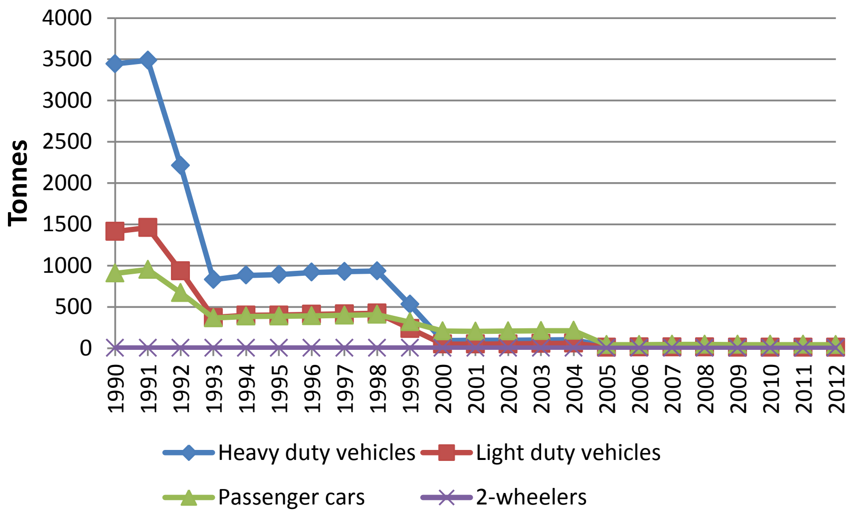

Figure 3.3.22 SO_2 emissions (tonnes) pr vehicle type for road transport 1990-2012.

Historically, the emission totals of NMVOC and CO have been very dominated by the contributions coming from private cars, as shown in Figures 3.3.24-3.3.25. However, the NMVOC and CO (and NO_x) emissions from this vehicle type have shown a steady decreasing tendency since the introduction of private catalyst cars in 1990 (EURO I) and the introduction of even more emission-efficient EURO II, III, IV and V private cars (introduced in 1997, 2001, 2006 and 2011, respectively).

In the case of NO_x, the real traffic emissions for heavy duty vehicles do not decline as intended by the EU emission legislation. This is due to the so-called engine cycle-beating effect. Outside the legislative test cycle stationary measurement points, the electronic engine control for heavy duty Euro II and III engines switches to a fuel efficient engine running mode, thus leading to increasing NO_x emissions. However, the reduction in transport activities due to the global financial crisis causes the NO_x emissions for heavy duty vehicles to decrease significantly in 2008 and 2009.

The 2012 emission shares for heavy-duty vehicles, passenger cars, light-duty vehicles and 2-wheelers for NO_x (41, 44, 15 and 0 %), NMVOC (4, 62, 7 and 13 %) and CO (6, 80, 6 and 8 %), are also shown in Figure 3.3.26.

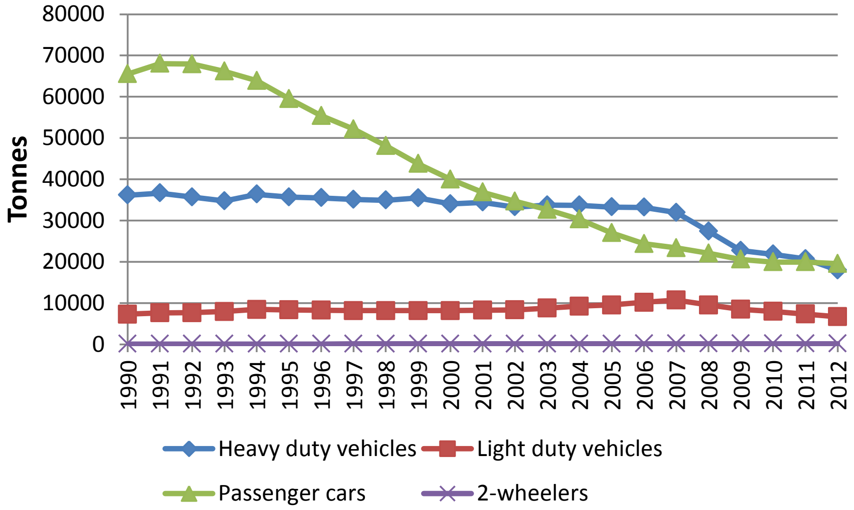

Figure 3.3.23 NO_X emissions (tonnes) pr vehicle type for road transport 1990-2012.

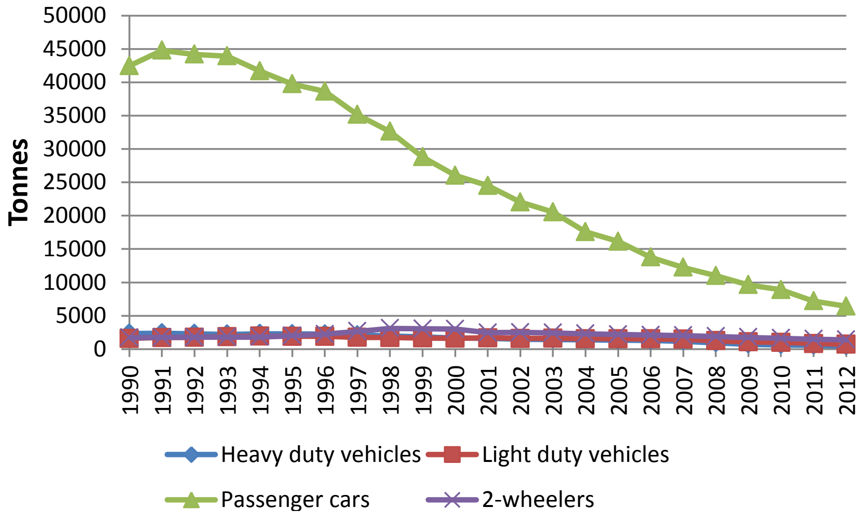

Figure 3.3.24 NMVOC emissions (tonnes) pr vehicle type for road transport 1990-2012

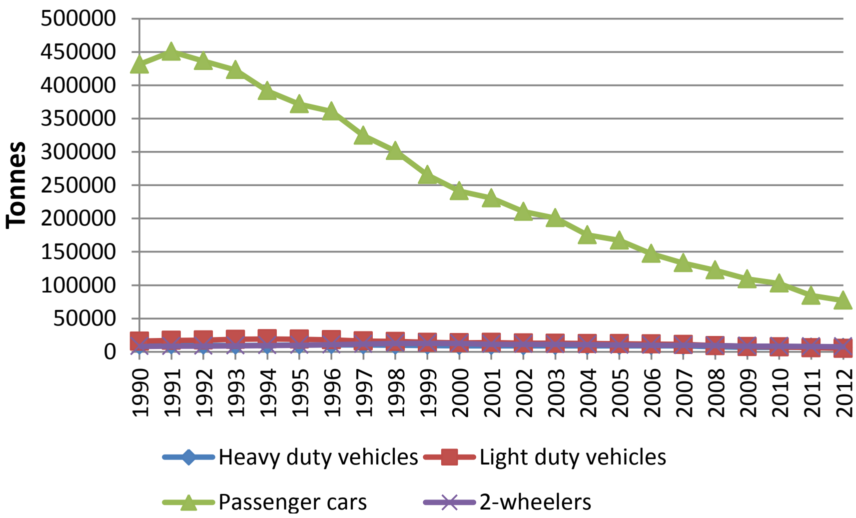

Figure 3.3.25 CO emissions (tonnes) pr vehicle type for road transport 1990-2012.

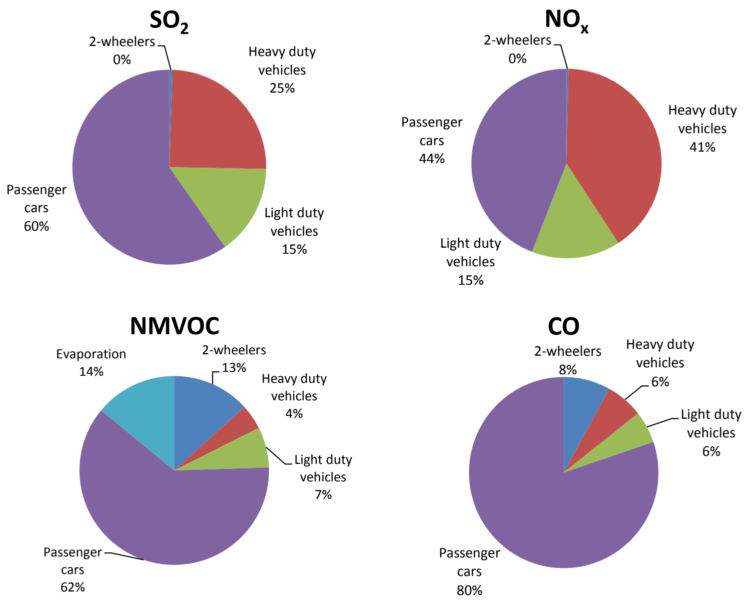

Figure 3.3.26 SO_2, NO_X, NMVOC and CO emission shares pr vehicle type for road transport in 2012

Other mobile sources

For SO_2 the trends in the Navigation (1A3d) emissions shown in Figure 3.3.27 mainly follow the development of the heavy fuel oil consumption (Figure 3.25). Though, from 1993 to 1995 relatively higher contents of sulphur in the fuel (estimated from sales) cause a significant increase in the emissions of SO_2. The SO_2 emissions for Fisheries (1A4c) correspond with the development in the consumption of marine gas oil. The main explanation for the development of the SO_2 emission curves for Railways (1A3c) and non-road machinery in Agriculture/forestry (1A4c) and Industry (1A2f), are the stepwise sulphur content reductions for diesel used by machinery in these sectors.

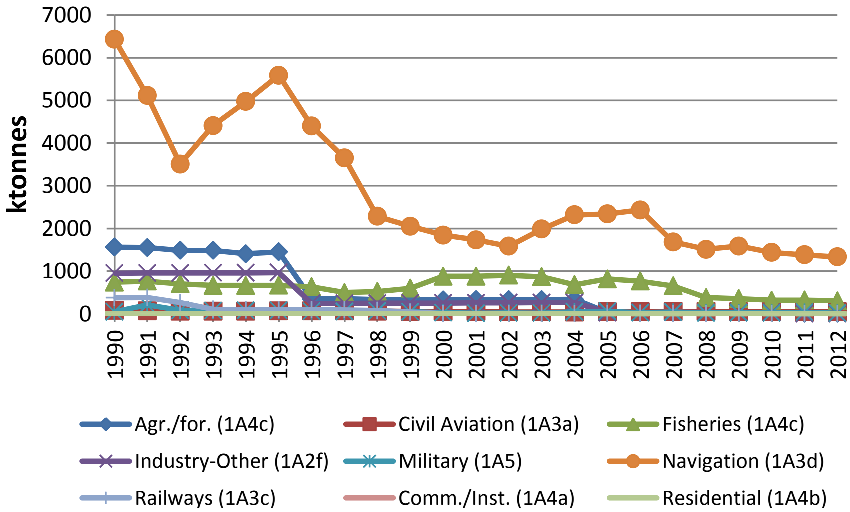

Figure 3.3.27 SO_2 emissions (tonnes) in CRF sectors for other mobile sources 1990-2012.

In general, the emissions of NO_X, NMVOC and CO from diesel-fuelled working equipment and machinery in agriculture, forestry and industry have decreased slightly since the end of the 1990s due to gradually strengthened emission standards given by the EU emission legislation directives. For industry, the emission impact from the global financial crisis becomes very visible for 2009.

NO_X emissions mainly come from diesel machinery, and the most important sources are Agriculture/forestry/fisheries (1A4c), Navigation (1A3d), Industry (1A2f) and Railways (1A3c), as shown in Figure 3.3.20. The 2012 emission shares are 48, 23, 20 and 7 %, respectively (Figure 3.3.23). Minor emissions come from the sectors, Civil Aviation (1A3a), Military (1A5) and Residential (1A4b).

The NO_X emission trend for Navigation, Fisheries and Agriculture is determined by fuel consumption fluctuations for these sectors, and the development of emission factors. For ship engines the emission factors tend to increase for new engines until mid-1990s. After that, the emission factors gradually reduce until 2000, bringing them to a level comparable with the emission limits for new engines in this year. For agricultural machines, there have been somewhat higher NO_x emission factors for 1991-stage I machinery, and an improved emission performance for stage I and II machinery since the late 1990s.

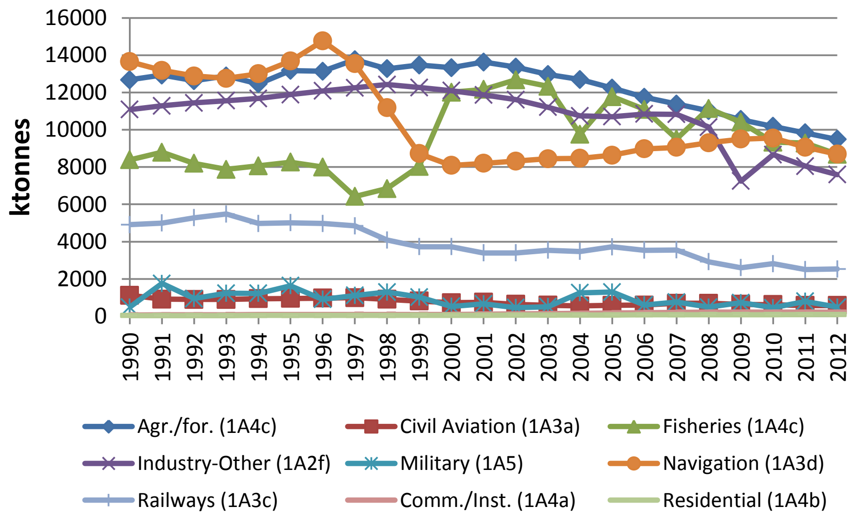

Figure 3.3.28 NO_X emissions (tonnes) in CRF sectors for other mobile sources 1990-2012.

The emission development for industry NO_x is the product of a fuel consumption increase from 1985 to 2008, most pronounced from 2005-2008, and a development in emission factors as explained for agricultural machinery. For railways, the gradual shift towards electrification explains the declining trend in diesel fuel consumption and NO_x emissions for this transport sector until 2001.

The 1990-2012 time series of NMVOC and CO emissions are shown in Figures 3.3.29 and 3.3.30 for other mobile sources. The 2012 sector emission shares are shown in Figure 3.3.31. For NMVOC, the most important sectors are Commercial/Institutional (1A4a), Agriculture/forestry/-fisheries (1A4c), Residential (1A4b), Industry (1A2f) and Navigation (1A3d) with 2012 emission shares of 37, 22, 20, 11 and 7 %, respectively. The same five sectors also contribute with most of the CO emissions. For Commercial/Institutional (1A4a), Residential (1A4b), Agriculture/forestry/fisheries (1A4c), Industry (1A2f) and Navigation (1A3d) the emission shares are 56, 20, 15, 5 and 4 %, respectively. Minor NMVOC and CO emissions come from Railways (1A3c), Civil Aviation (1A3a) and Military (1A5).

For NMVOC and CO, the significant emission increases for the commercial/-institutional and residential sectors after 2000 are due to the increased number of gasoline working machines. Improved NMVOC emission factors for diesel machinery in agriculture and gasoline equipment in forestry (chain saws) are the most important explanations for the NMVOC emission decline in the Agriculture/forestry/fisheries sector. This explanation also applies for the industrial sector, which is dominated by diesel-fuelled machinery. From 1997 onwards, the NMVOC emissions from Navigation decrease due to the gradually phase-out of the 2-stroke engine technology for recreational craft. The main reason for the significant 1985-2006 CO emission decrease for Agriculture/forestry-/fisheries is the phasing out of gasoline tractors.

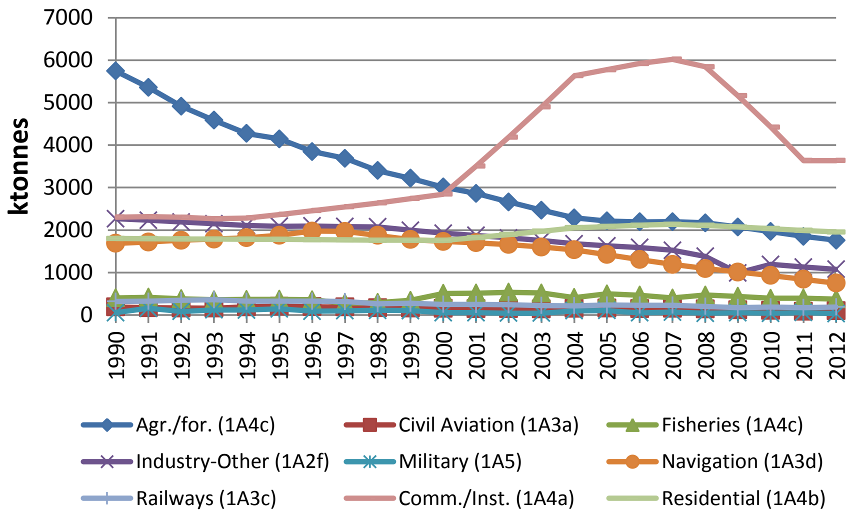

Figure 3.3.29 NMVOC emissions (tonnes) in CRF sectors for other mobile sources 1990-2012.

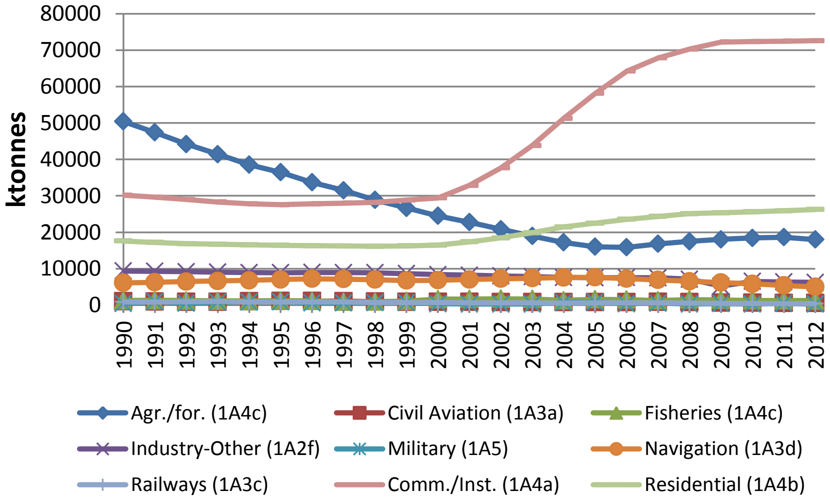

Figure 3.3.30 CO emissions (tonnes) in CRF sectors for other mobile sources 1990-2012.

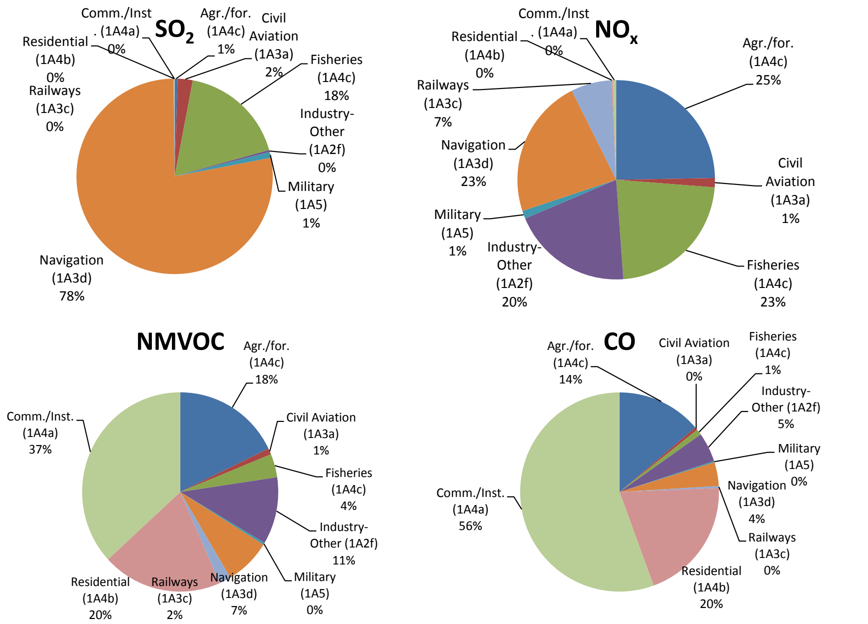

Figure 3.3.31 SO_2, NO_X, NMVOC and CO emission shares pr vehicle type for other mobile sources in 2012.

Bunkers

The most important emissions from bunker fuel consumption (fuel consumption for international transport) are SO_2, NO_X and CO_2 (and TSP, not shown). However, compared with the Danish national emission total (all sources), the greenhouse gas emissions from bunkers are small. The bunker emission totals are shown in Figure 3.3.7 for 2012, split into sea transport and civil aviation. All emission figures in the 1990-2012 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 2012.

Table 3.3.5 Emissions in 2012 for international transport.

CRF sector	SO_2	NO_X	NMVOC	CH_4	CO	CO_2	N_2O
	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	K-tonnes	Tonnes
Navigation int. (1A3d)	5 136	36 524	1 199	37	3 955	1 505	95
Civil Aviation int. (1A3a)	801	10 628	379	12	1 776	2 510	86
International total	5 937	47 153	1 578	49	5 731	4 015	181

The differences in 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 3.3.32 are similar to the fuel consumption development.

However, for navigation minor differences occur for the emissions of SO_2, NO_X and CO_2 due to varying amounts of marine gas oil and residual oil, and for SO_2 and NO_X the development in the emission factors also have an impact on the emission trends. For civil aviation, apart from the annual consumption of jet fuel, the development of the NO_X emissions is also due to yearly variations in LTO/aircraft type (earlier than 2001) and city-pair statistics (2001 onwards).

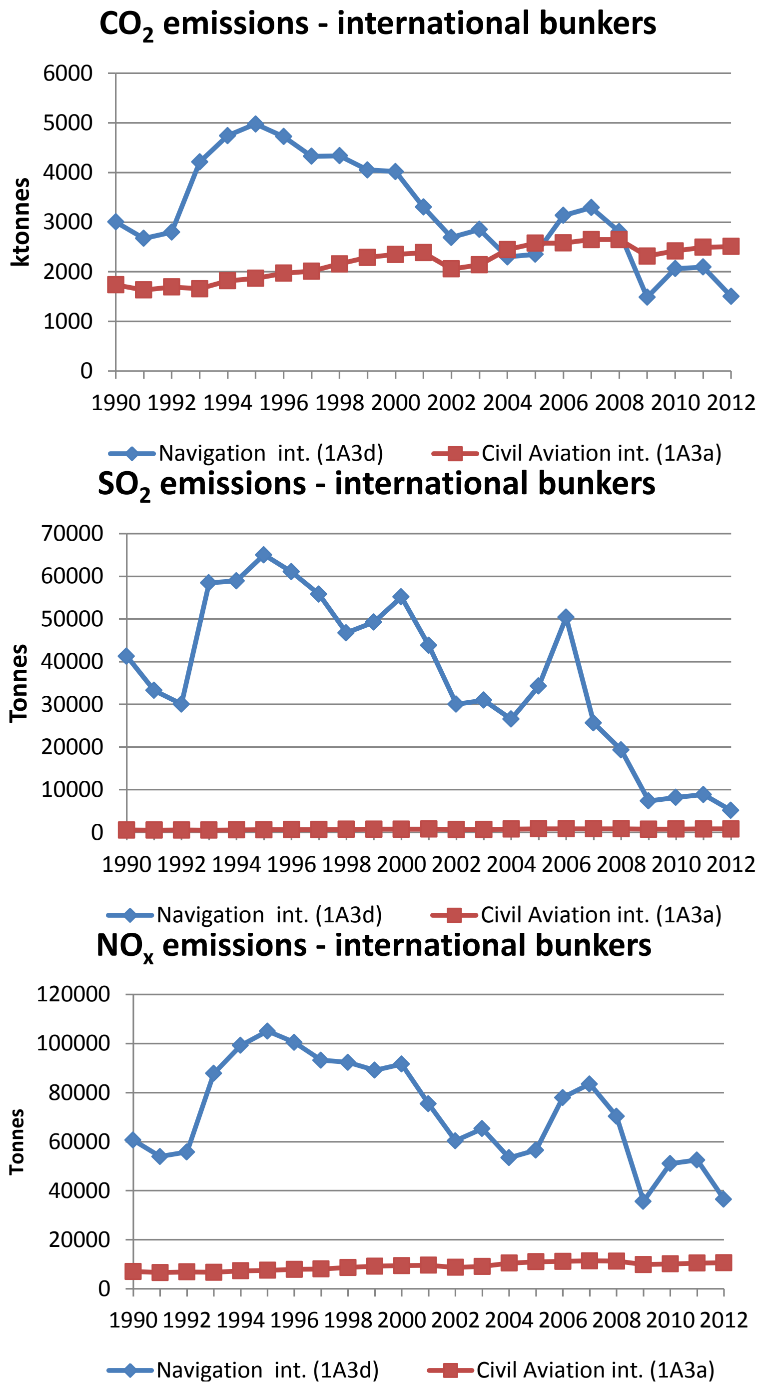

Figure 3.3.32 CO_2, SO_2 and NO_X emissions for international transport 1990-2012.

3.3.2 Methodological issues

The description of methodologies and references for the transport part of the Danish inventory is given in two sections: one for road transport and one for the other mobile sources.

Methodology and references for Road Transport

For road transport, the detailed methodology is used to make annual estimates of the Danish emissions, as described in the EMEP/EEA Air Pollutant Emission Inventory Guidebook (EMEP/EEA, 2013). The actual calculations are made with a model developed by DCE, using the European COPERT IV model methodology explained by (EMEP/EEA, 2013). 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 IV fleet classification, all present and future vehicles in the Danish fleet are grouped 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 3.3.6 gives an overview of the different model classes and sub-classes, and the layer level with implementation years are shown in Annex 3.B.1.

Table 3.3.6 Model vehicle classes and sub-classes and trip speeds.

			Trip speed [km pr h]		
Vehicle clas-	Fuel type	Engine size/weight	Urban	Rural	Highway
PC	Gasoline	< 1.4 l.	40	70	100
PC	Gasoline	1.4 – 2 l.	40	70	100
PC	Gasoline	> 2 l.	40	70	100
PC	Diesel	< 2 l.	40	70	100
PC	Diesel	> 2 l.	40	70	100
PC	LPG		40	70	100
PC	2-stroke		40	70	100
LDV	Gasoline		40	65	80
LDV	Diesel		40	65	80
LDV	LPG		40	65	80
Trucks	Gasoline		35	60	80
Trucks	Diesel	Rigid 3,5 - 7,5t	35	60	80
Trucks	Diesel	Rigid 7,5 - 12t	35	60	80
Trucks	Diesel	Rigid 12 - 14 t	35	60	80
Trucks	Diesel	Rigid 14 - 20t	35	60	80
Trucks	Diesel	Rigid 20 - 26t	35	60	80
Trucks	Diesel	Rigid 26 - 28t	35	60	80
Trucks	Diesel	Rigid 28 - 32t	35	60	80
Trucks	Diesel	Rigid >32t	35	60	80
Trucks	Diesel	TT/AT 14 - 20t	35	60	80
Trucks	Diesel	TT/AT 20 - 28t	35	60	80
Trucks	Diesel	TT/AT 28 - 34t	35	60	80
Trucks	Diesel	TT/AT 34 - 40t	35	60	80
Trucks	Diesel	TT/AT 40 - 50t	35	60	80
Trucks	Diesel	TT/AT 50 - 60t	35	60	80
Trucks	Diesel	TT/AT >60t	35	60	80
Urban buses	Gasoline		30	50	70
Urban buses	Diesel	< 15 tonnes	30	50	70
Urban buses	Diesel	15-18 tonnes	30	50	70
Urban buses	Diesel	> 18 tonnes	30	50	70
Coaches	Gasoline		35	60	80

Continued					
Coaches	Diesel	< 15 tonnes	35	60	80
Coaches	Diesel	15-18 tonnes	35	60	80
Coaches	Diesel	> 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 IV (Jensen, 2013). 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 class (trucks and buses registered from 1997+), NEDC type approval fuel efficiency value (passenger cars registered from 1997+) and vehicle first registration year.

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 programme. Total mileage per year and vehicle category are derived for the years 1985-2012, 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 detemines 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, 2013) 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 (Ekman, 2005). Additional data for the moped fleet and motorcycle fleet disaggregation is given by The National Motorcycle Association (Markamp, 2013).

In addition data from a survey made by the Danish Road Directorate (Hansen, 2010) has given information of the total mileage driven by foreign trucks on Danish roads in 2009. This mileage contribution has been added to the total mileage for Danish trucks on Danish roads, for trucks > 16 tonnes of gross vehicle weight. The data has been further processed by DTU

Transport; by using appropriate assumptions the mileage have been back-casted to 1985 and forecasted to 2012.

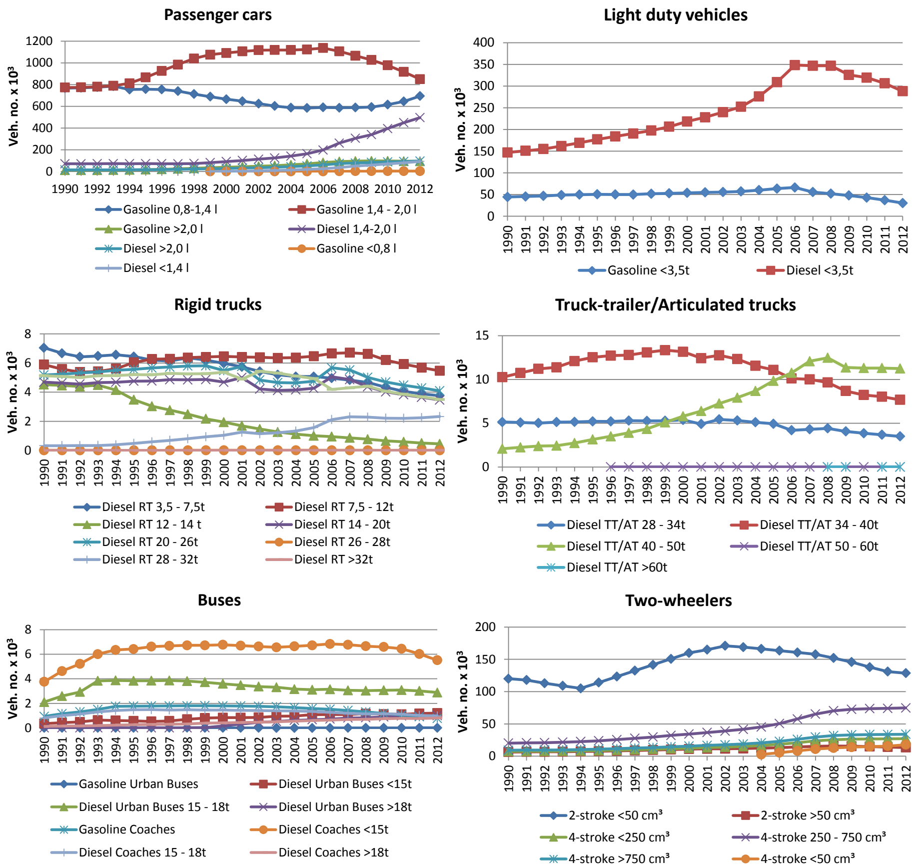

Figure 3.3.33 Number of vehicles in sub-classes in 1990-2012.

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 gasoline cars with engine sizes between 1.4 and 2 litres (from 1990-2002) and 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 smaller than 1.4 litres. These cars, however, have also increased in numbers during the later years. 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.

For the truck-trailer and articulated truck combinations there is a tendency towards the use of increasingly larger trucks throughout the time period. The decline in fleet numbers for many of the truck categories in 2007/2008 and until 2009 is caused by the impact of the global financial crisis and the reflagging of Danish commercial trucks to companies based in the neighbouring countries.

The number of urban buses has been almost constant between 1985 and 2011. The sudden change in the level of coach numbers from 1994 to 1995 is due to uncertain fleet data.

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 in general throughout the entire 1985-2012 period. The increase is, however, most visible from the mid-1990s and onwards.

The vehicle numbers are summed up in EU emission layers for each year (Figure 3.3.34) by using the correspondence between layers and first year of registration:

$$N_{j,y} = \sum_{i=FYear(j)}^{LYear(j)} N_{i,y} \qquad (1)$$

Where N = number of vehicles, j = layer, y = year, i = first year of registration.

Weighted annual mileages pr layer are calculated as the sum of all mileage driven pr 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).

For heavy duty trucks, there is a slight deviation from the strict correspondence between EU emission layers and first registration year.

In this case, specific Euro class information for most of the vehicles from 2001 onwards is incorporated into the fleet and mileage data model developed by Jensen (2012). For inventory years before 2001, and for vehicles with no Euro information the normal correspondence between layers and first year of registration is used.

Vehicle numbers and weighted annual mileages per layer are shown in Annex 3.B.1 and 3.B.2 for 1990-2012. The trends in vehicle numbers per layer are also shown in Figure 3.3.34. The latter figure shows how vehicles complying with the gradually stricter EU emission levels (EURO I, II, III, IV, V etc.) have been introduced into the Danish motor fleet.

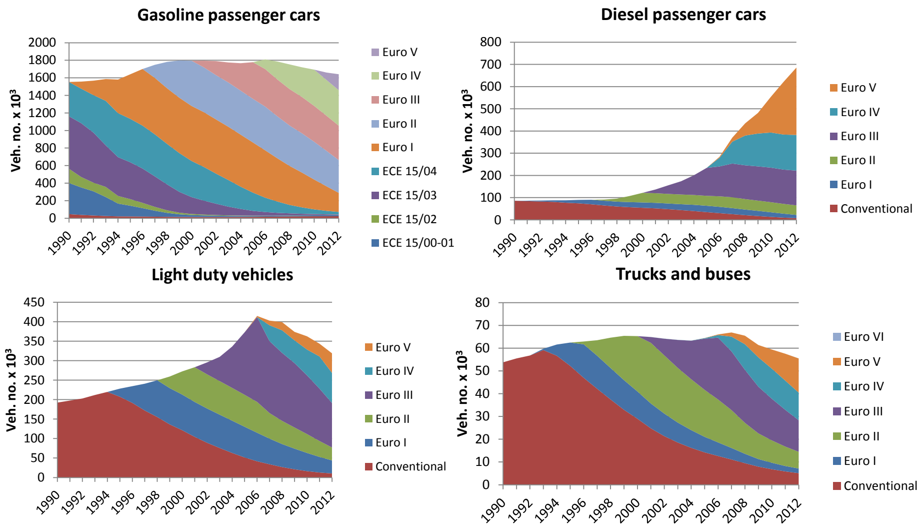

Figure 3.3.34 Layer distribution of vehicle numbers pr vehicle type in 1990-2012.

Emission legislation

The EU 443/2009 regulation sets 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 grams 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 95 g pr km is specified for the year 2020. The modalities for reaching this target and the aspects of its implementation including the excess emissions premium will have to be defined in a review to be completed no later than the beginning of 2013.
- **Eco-innovations**: because the test procedure used for vehicle type approval is outdated, certain innovative technologies cannot demonstrate their CO_2 reducing effects under the type approval test. As an interim procedure until the test procedure is reviewed by 2014, manufacturers can be granted a maximum of 7 g 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 sets 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. This needs to be confirmed in a review of the vans Regulation, based on an updated assessment of its costs and benefits that is to be completed no later than the beginning of 2013. The modalities for reaching this target and aspects of its implementation, including the excess emissions premium, will also be defined as part of the review.
- **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:** because the test procedure used for vehicle type approval is outdated, certain innovative technologies cannot demonstrate their CO_2-reducing effects under the type approval test. As an interim procedure until the test procedure is reviewed by 2014, 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.

For Euro 1-4 passenger cars and light duty trucks, the chassis dynamometer test cycle used in the EU for measuring fuel is the NEDC (New European Driving Cycle), see Nørgaard and Hansen (2004). The test cycle is also used also for emissions testing. 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 cycle4 (average speed: 19 km pr 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 seven km at an average speed of 63 km pr h. More information regarding the fuel measurement procedure can be found in the EU-directive 80/1268/-EØF.

For NO_X, VOC (NMVOC + CH_4), CO and PM, the emissions from road transport vehicles have to comply with the different EU directives listed in Table 3.3.7. The emission directives distinguish between three vehicle classes according to vehicle reference mass[5]: Passenger cars and light duty trucks (<1305 kg), light duty trucks (1305-1760 kg) and light duty trucks (>1760 kg).The specific emission limits are shown in Annex 3.B.3.

[4] 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.

[5] Reference mass: net vehicle weight + mass of fuel and other liquids + 100 kg.

Table 3.3.7 Overview of the existing EU emission directives for road transport vehicles.

Vehicle category	Emission layer	EU directive	First reg. date
Passenger cars (gasoline)	PRE ECE	-	-
	ECE 15/00-01	70/220 - 74/290	1972[a]
	ECE 15/02	77/102	1981[b]
	ECE 15/03	78/665	1982[c]
	ECE 15/04	83/351	1987[d]
	Euro I	91/441	1.10.1990[e]
	Euro II	94/12	1.1.1997
	Euro III	98/69	1.1.2001
	Euro IV	98/69	1.1.2006
	Euro V	715/2007	1.1.2011
	Euro VI	715/2007	1.9.2015
Passenger cars (diesel and LPG)	Conventional	-	-
	ECE 15/04	83/351	1987[d]
	Euro I	91/441	1.10.1990[e]
	Euro II	94/12	1.1.1997
	Euro III	98/69	1.1.2001
	Euro IV	98/69	1.1.2006
	Euro V	715/2007	1.1.2011
	Euro VI	715/2007	1.9.2015
Light duty trucks (gasoline and diesel)	Conventional	-	-
	ECE 15/00-01	70/220 - 74/290	1972[a]
	ECE 15/02	77/102	1981[b]
	ECE 15/03	78/665	1982[c]
	ECE 15/04	83/351	1987[d]
	Euro I	93/59	1.10.1994
	Euro II	96/69	1.10.1998
	Euro III	98/69	1.1.2002
	Euro IV	98/69	1.1.2007
	Euro V	715/2007	1.1.2012
	Euro VI	715/2007	1.9.2016
Heavy duty vehicles	Euro 0	88/77	1.10.1990
	Euro I	91/542	1.10.1993
	Euro II	91/542	1.10.1996
	Euro III	1999/96	1.10.2001
	Euro IV	1999/96	1.10.2006
	Euro V	1999/96	1.10.2009
	Euro VI	595/2009	1.10.2013
Mopeds	Conventional	-	-
	Euro I	97/24	2000
	Euro II	2002/51	2004
	Euro III	2002/51	2014[f]
	Euro IV	168/2013	2017
	Euro V	168/2013	2021
Motor cycles	Conventional	Conventional	0
	Euro I	97/24	2000
	Euro II	2002/51	2004
	Euro III	2002/51	2007
	Euro IV	168/2013	2017
	Euro V	168/2013	2021

a,b,c,d: Expert judgement suggest 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 in 1991 (EU starting year: 1993).

In practice, the emissions from vehicles in traffic are different from the legislation limit values and, therefore, the latter figures are considered to be too inaccurate for total emission calculations. A major constraint is that the emission approval test conditions reflect only to a small degree the large variety of emission influencing factors in the real traffic situation, such as cumulated mileage driven, engine and exhaust after treatment maintenance levels and driving behaviour.

Therefore, in order to represent the Danish fleet and to support average national emission estimates, emission factors must be chosen which derive from numerous emissions measurements, using a broad range of real world driving patterns and a sufficient number of test vehicles. It is similar important to have separate fuel consumption and emission data for cold-start emission calculations and gasoline evaporation (hydrocarbons).

For heavy-duty vehicles (trucks and buses), the emission limits are given in g per kWh and the measurements are carried out for engines in a test bench, using the EU ESC (European Stationary Cycle) and ETC (European Transient Cycle) test cycles, depending on the Euro norm and exhaust gas after-treatment system installed. A description of the test cycles is given by Nørgaard and Hansen (2004). Measurement results in g per kWh from emission approval tests cannot be directly used for inventory work. Instead, emission factors used for national estimates must be transformed into g per km, and derived from a sufficient number of measurements which represent the different vehicle size classes, Euro engine levels and real world variations in driving behaviour.

Fuel consumption and emission factors

Trip-speed dependent basis factors for fuel consumption and emissions are taken from the COPERT model using trip speeds as shown in Table 3.3.6. The factors are listed in Annex 3.B.4. For EU emission levels not represented by actual data, the emission factors are scaled according to the reduction factors given in Annex 3.B.5.

The fuel consumption and emission factors used in the Danish inventory come from the COPERT IV model. 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.

For passenger cars, real measurement results are behind the emission factors for Euro 1-4 vehicles, and those earlier. For light duty trucks the measurements represent Euro 1 and prior vehicle technologies. For mopeds and motorcycles, updated fuel consumption and emission figures are behind the conventional and Euro 1-3 technologies. For heavy-duty trucks and buses the experimental basis is computer simulated emission factors for Euro 0-V engines.

Adjustment for fuel efficient vehicles

In the Danish fleet and mileage database, the type approval fuel efficiency value based on the NEDC driving cycle (TA_{NEDC}) is registered for each single car. Further, a modified fuel efficiency value (TA_{inuse}) is calculated using TA_{NEDC}, vehicle weight and engine size as input parameters. The TA_{inuse} value better reflects the fuel consumption associated with the NEDC driving cycle under real ("inuse") traffic conditions (Emisia, 2012).

From 2006 up to last historical year represented by fleet data, the average CO_2 emission factor (by fleet number) is calculated for each year's new sold cars, based on the registered TA_{NEDC} values. Using the average CO_2 emission factor for the last historical year as starting point, the average emission factor for each year's new sold cars are linearly reduced, until the emission factor reaches 95 g CO_2 per km in 2020.

From 2006 up to last historical year, the average CO_2 emission factor (by fleet number) is also calculated for each year's new sold cars, and for each fuel type/engine size combination, based on TA_{NEDC} and TA_{inuse}.

The linear reduction of the average emission factor for each year's new sold cars is then used to reduce the CO_2 emission factors for new sold cars based on TA_{inuse}, between last historical year and 2020, for each of the fuel type/engine size fleet segments.

Subsequently for each layer and inventory year, CO_2 emission factors are calculated based on TA_{inuse} and weighted by total mileage. On the same time corresponding layer specific CO_2 factors from COPERT IV are set up valid for Euro 4+ vehicles in the COPERT model. The COPERT IV CO_2 factors are derived from fuel consumption factors assessed by the developers of COPERT IV (Emisia, 2012) to represent the COPERT test vehicles under the NEDC driving cycle in real world traffic ($TA_{COPERT\ IV,inuse}$).

In a final step the ratio between the layer specific CO_2 emission factors for the Danish fleet and the COPERT Euro IV vehicles under TA_{inuse} are used to scale the trip speed dependent fuel consumption factors provided by COPERT IV for Euro 4 layers onwards.

Adjustment for EGR, SCR and filter retrofits

In COPERT IV updated emission factors have recently been made available for Euro V heavy duty vehicles using EGR and SCR exhaust emission after-treatment 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.

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. These retrofit data are included in the Danish inventory by assuming that particulate emissions are lowered by 80 % compared with the emissions from the same Euro technology with no filter installed (Winther, 2011).

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.

Deterioration factors

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 stabilise 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 (2013), 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":

$$UDF = U_A \cdot MTC + U_B \text{, MTC < } U_{MAX} \tag{3}$$

$$UDF = U_A \cdot U_{MAX} + U_B \text{, MTC >= } U_{MAX} \tag{4}$$

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. For trip speeds between 19 and 63 km per hour 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:

$$DF_{j,y} = \frac{\sum_{i=FYear(j)}^{LYear(j)} DF_{i,y} \cdot N_{i,y} \cdot M_{i,y}}{\sum_{i=FYear(j)}^{LYear(j)} DF_{i,y} \cdot N_{i,y}} \tag{5}$$

where DF is the deterioration factor.

For N_2O and NH_3, COPERT IV takes into account deterioration as a linear function of mileage for gasoline fuelled EURO 1-4 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 (2013), 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.

Emissions and fuel consumption for hot engines

Emissions and fuel consumption results for operationally hot engines are calculated for each year and for layer and road type. The 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 3.3.7. 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:

$$E_{j,k,y} = DF_{j,k,y} \cdot EF_{j,k,y} \cdot S_k \cdot N_{j,y} \cdot M_{j,y} \quad (7)$$

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 simulated separately. 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 2013 are given in Cappelen et al. (2012). 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 (2013). For conventional gasoline and all diesel vehicles the extra emissions become:

$$CE_{j,y} = \beta \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr - 1) \quad (8)$$

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 future 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 future 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 IV. 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 IV. 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 (2013), 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.

Evaporative emissions from gasoline vehicles

For each year, evaporative emissions of hydrocarbons are simulated in the forecast model as hot and warm running losses, hot and warm soak loss and diurnal emissions. The calculation approach is the same as in COPERT III. All emission types depend on RVP (Reid Vapour Pressure) and ambient temperature. The emission factors are shown in EMEP/EEA (2013).

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. In the model, hot and warm running losses occur for hot and cold engines, respectively. 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), the emission factors are only one tenth of the uncontrolled factors used for conventional gasoline vehicles.

$$R_{j,y} = N_{j,y} \cdot M_{j,y} \cdot ((1-\beta) \cdot HR + \beta \cdot WR) \qquad (10)$$

where R is running loss emissions and HR and WR are the hot and warm running loss emission factors, respectively.

In the model, hot and warm soak emissions for carburettor vehicles also occur for hot and cold engines, respectively. These emissions are calculated as number of trips (broken down into cold and hot trip numbers using the β-factor) times respective emission factors:

$$S_{j,y}{}^{C} = N_{j,y} \cdot \frac{M_{j,y}}{l_{trip}} \cdot ((1-\beta) \cdot HS + \beta \cdot WS) \qquad (11)$$

where S^C is the soak emission, l_{trip} = the average trip length, and HS and WS are the hot and warm soak emission factors, respectively. Since all catalyst vehicles are assumed to be carbon canister controlled, no soak emissions are estimated for this vehicle type. Average maximum and minimum temperatures pr month are used in combination with diurnal emission factors to estimate the diurnal emissions from uncontrolled vehicles $E^d(U)$:

$$E_{j,y}{}^{d}(U) = 365 \cdot N_{j,y} \cdot e^{d}(U) \quad (12)$$

Each year's total is the sum of each layer's running loss, soak loss and diurnal emissions.

Fuel consumption balance

The calculated fuel consumption in COPERT IV 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 Agency data (see DEA, 2013). The DEA data are further processed for gasoline 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.

The standard approach to achieve a fuel balance in annual emission inventories is to multiply the annual mileage with a fuel balance factor derived as the ratio between simulated and statistical fuel figures for gasoline and diesel, respectively. This method is also used in the present model.

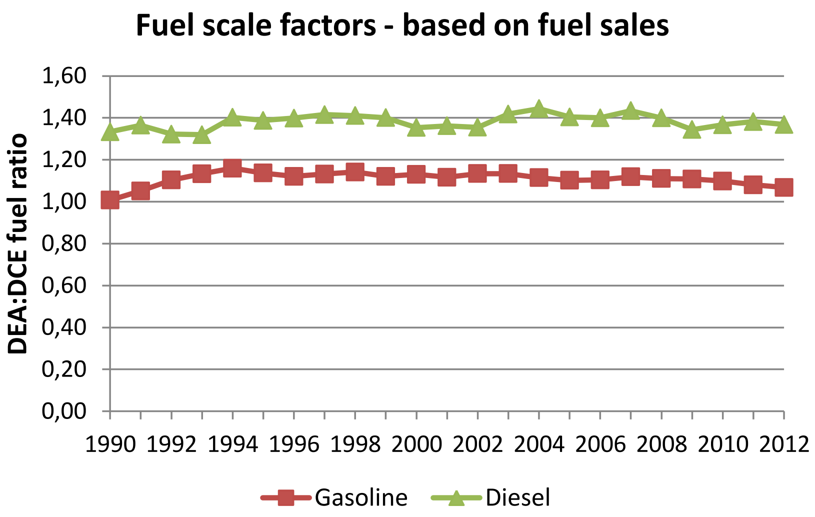

Figure 3.3.35 DEA:DCE Fuel ratios (mileage adjustment factors) based on DEA fuel sales data and DCE fuel consumption estimates.

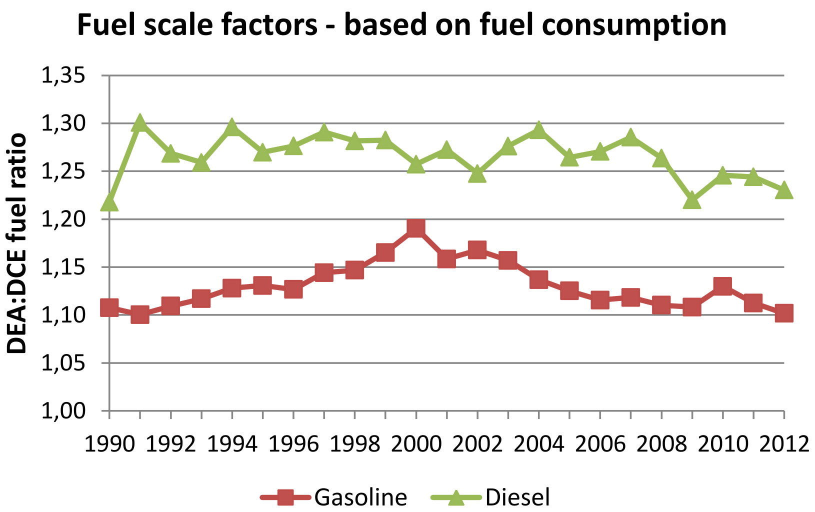

Figure 3.3.36 DEA:DCE Fuel ratios (mileage adjustment factors) based on DEA fuel consumption data and DCE fuel consumption estimates.

In Figure 3.3.35 and Figure 3.3.36 the COPERT IV:DEA gasoline and diesel fuel consumption ratios are shown for fuel sales and fuel consumption from 1990-2012. The data behind the figures are also listed in Annex 3.B.8. The fuel consumption figures are related to the traffic on Danish roads.

Per fuel type, all mileage numbers are equally scaled in order to obtain fuel equilibrium, and hence the mileage factors used are the reciprocal values of the COPERT IV:DEA fuel consumption: fuel sales ratio.

The reasons for the differences between DEA sales figures and bottom-up fuel estimates are mostly due to a combination of the uncertainties related to COPERT IV 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 per vehicle type are shown in Annex 3.B.7 for 1990-2012. The total fuel consumption and emissions are shown in Annex 3.B.8, per vehicle category and as grand totals, for 1990-2012 (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 2012.

In the following Figures 3.3.37 - 3.3.40, 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 1990-2012).

For CO_2 the neat gasoline/diesel emission factors shown in Table 3.3.8 are country specific values, and come from the DEA. 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 is added to all fuel commercially available. Following the IPCC guideline definitions, bio ethanol is regarded as CO_2 neutral for the transport sector as such. 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 3.3.8), and hence, no thermal efficiency changes are expected for the fuels. Consequently, the energy based fuel consumption factors (MJ/km) derived from COPERT IV are used also in this case.

As a function of the current ethanol/biodiesel energy percentage, $BF\%_E$, (Table 4.3) the average fuel related CO_2 emission factors, $emf_{CO2,E}(BF\%)$ become:

$$EF_{CO_2,E}(BF\%) = EF_{CO_2,E}(BF0) \cdot (100 - BF\%_E) \quad (13)$$

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 kilometre 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 IV:

$$EF_{CO_2,km}(BF\%) = EF_{CO_2,E}(BF\%) \cdot FC_E(BF0) \quad (14)$$

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, bio ethanol/biodiesel, and aggregated CO_2 factors are shown in Table 3.3.8.

Table 3.3.8 Fuel-specific CO_2 emission factors and biofuel shares for road transport in DK.

	Emission factors (g/MJ)							
Fuel type	1990-2005	2006	2007	2008	2009	2010	2011	2012
Neat gasoline	73	73	73	73	73	73	73	73
Neat diesel	74	74	74	74	74	74	74	74
LPG	63.1	63.1	63.1	63.1	63.1	63.1	63.1	63.1
Bio ethanol	0	0	0	0	0	0	0	0
Biodiesel	0	0	0	0	0	0	0	0
Gasoline, average	73	72.9	72.8	72.8	72.8	71.7	70.5	
Diesel, average	74	74	74	74	73.9	74	71.5	
	Biofuel share (BF%) of Danish road transport fuels							
	1990-2005	2006	2007	2008	2009	2010	2011	2012
	0	0.09	0.14	0.13	0.21	0.69	3.40	5.30

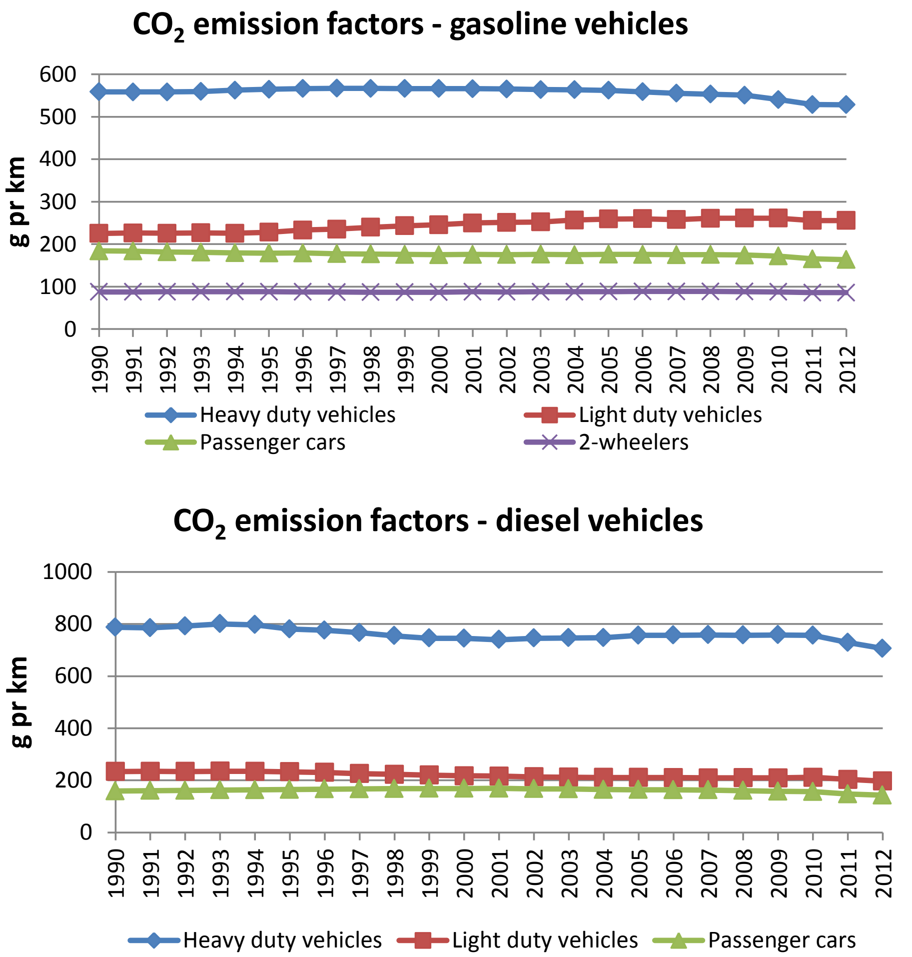

Figure 3.3.37 Km related CO_2 emission factors per vehicle type for Danish road transport (1990-2012).

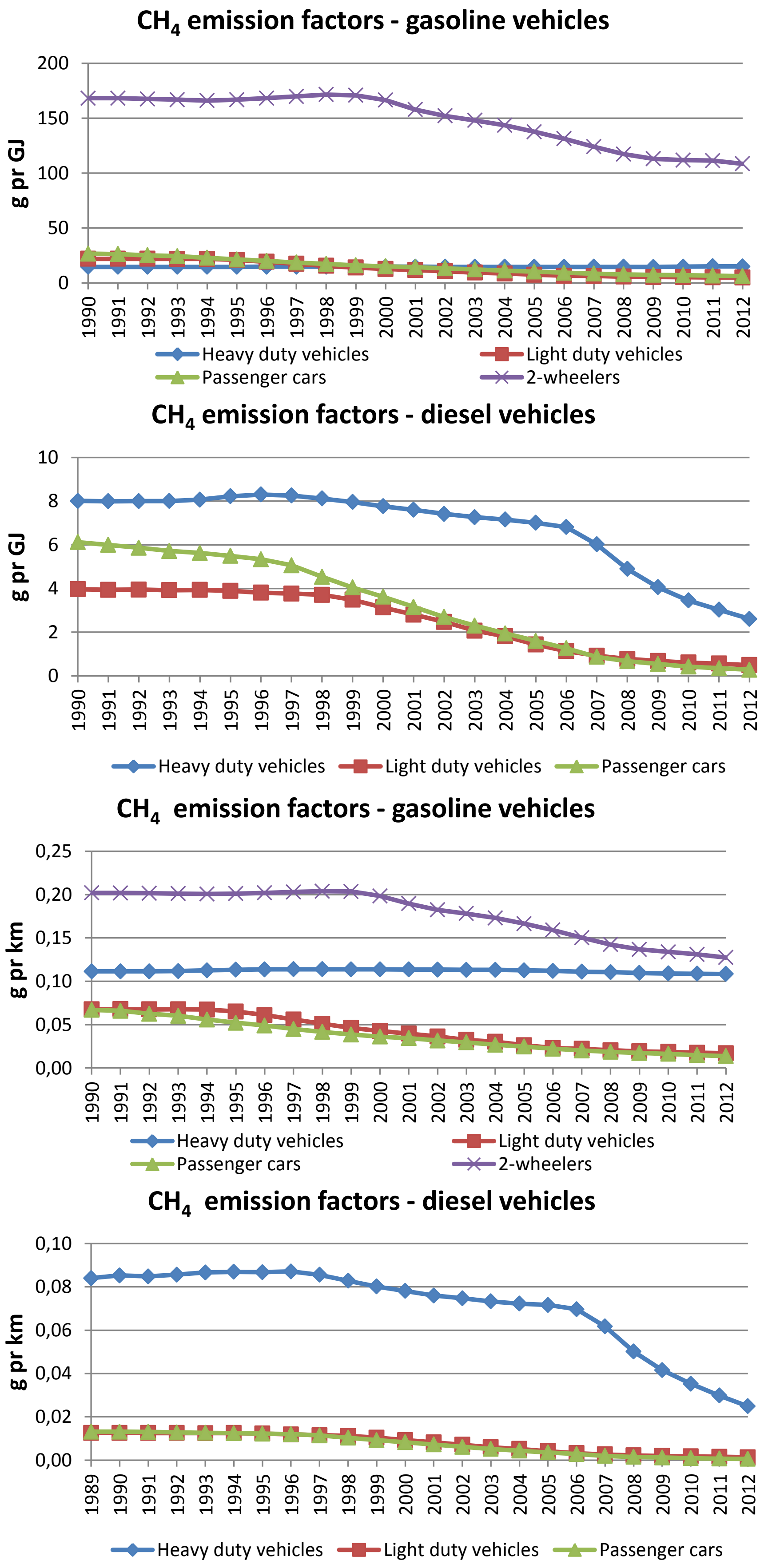

Figure 3.3.38 Fuel and km related CH_4 emission factors per vehicle type for Danish road transport (1990-2012).

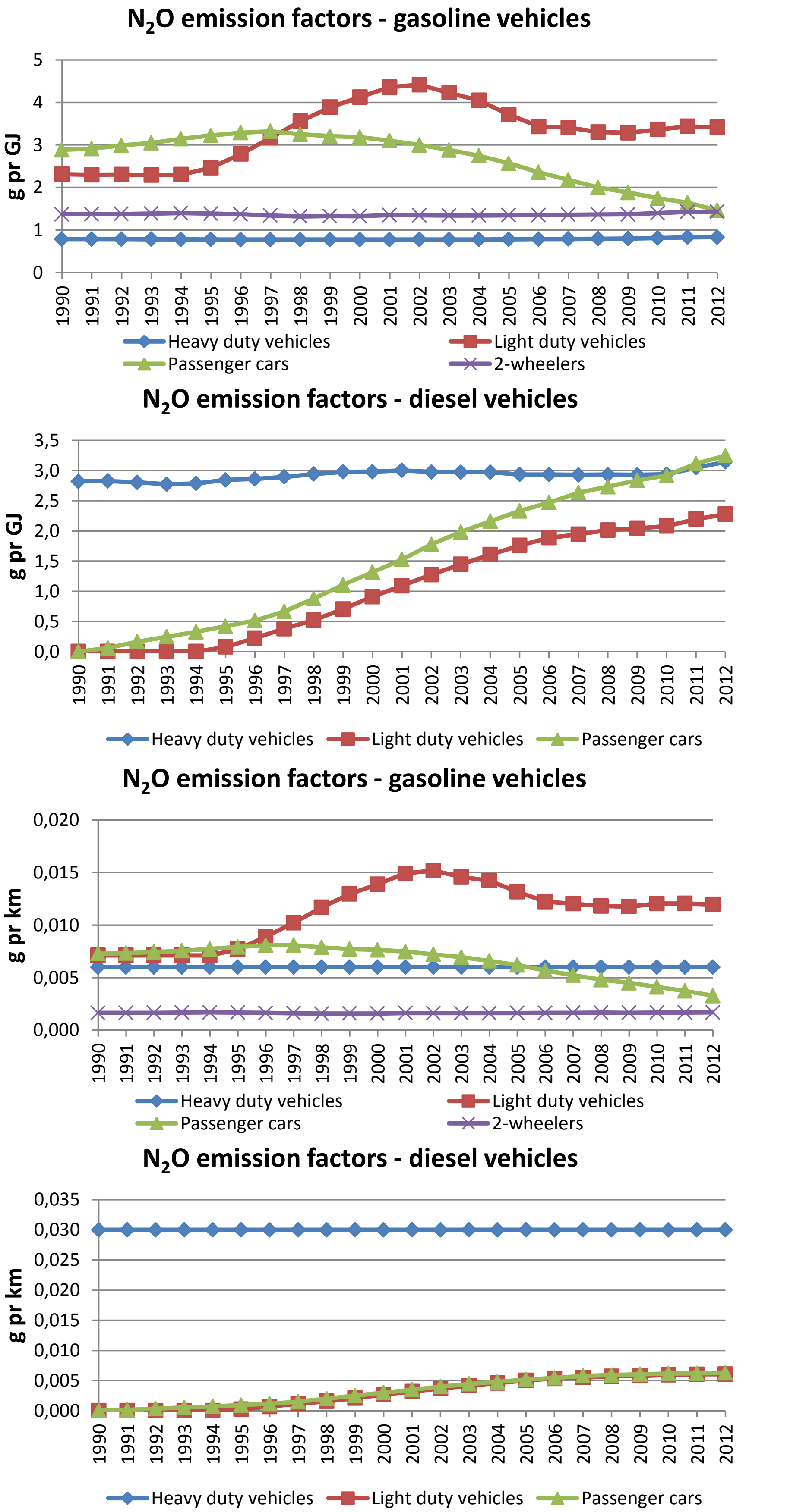

Figure 3.3.39 Fuel and km related N_2O emission factors per vehicle type for Danish road transport (1990-2012).

Methodologies and references for other mobile sources

Other mobile sources are divided into several sub-sectors: sea transport, fishery, air traffic, railways, military, and working machinery and equipment in the sectors agriculture, forestry, industry and residential. The emission calculations are made using the detailed method as described in the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2013) for air traffic, off-road working machinery and equipment, and ferries, while for the remaining sectors the simple method is used.

3.3.3 Activity data

Air traffic

The activity data for air traffic consists of air traffic statistics provided by the Danish Transport Authority and Copenhagen Airport. Fuel statistics for jet fuel consumption and aviation gasoline are obtained from the Danish energy statistics (DEA, 2013).

For 2001 onwards, per flight records are provided by the Danish Transport Authority as data codes for aircraft type, and origin and destination airports (city-pairs).

Subsequently the aircraft types are separated by DCE into larger aircraft using jet fuel (jet engines, turbo props, helicopters) and small aircraft types with piston engines using aviation gasoline. This is done by using different aircraft dictionaries, internet look-ups and by communication with the Danish Transport Authority. Each of the larger aircraft type is then matched with a representative type for which fuel consumption and emission data are available from the EMEP/EEA databank. Relevant for this selection is aircraft maximum take off mass, engine types, and number of engines. A more thorough explanation is given in Winther (2001a, b).

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[6], in a time series from 2001-2012. The airport split is necessary to make due to the differences in LTO emission factors (c.f. 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 an origin-destination airport matrix and having flight distances attached. This level of detail satisfies the demand from UNFCCC to provide precise documentation for the part of the inventory for the Kingdom of Denmark being outside the Danish mainland.

In the later years many flights in Denmark are being made by the new aircraft types CRJ9, E70, E170 and E175. These aircraft types are not represented by data in the EMEP/EEA databank. Instead new fuel consumption and emission factors have been calculated using fuel consumption and emission indexes from the ICAO Engine Exhaust Emission Database (www.caa.co.uk) for the CFM34-8C5 engine type which is installed in CRJ9, E70, E170 and E175. For LTO the fuel consumption and emission indexes are directly avail-

[6] Excluding flights for Greenland and the Faroe Islands. These flights are separately listed in Annex 3.B.10.

able from the ICAO database. For cruise, distance related indexes are calculated by weighting the baseline CFM34-8C5 indexes with the development in distance related emission indexes for the B737 400 representative aircraft type taken from the EMEP/EEA database.

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.

For inventory years prior to 2001, detailed LTO/aircraft type statistics are obtained from Copenhagen Airport (for this airport only), while information of total take-off numbers for other Danish airports is provided by the Danish Transport 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.

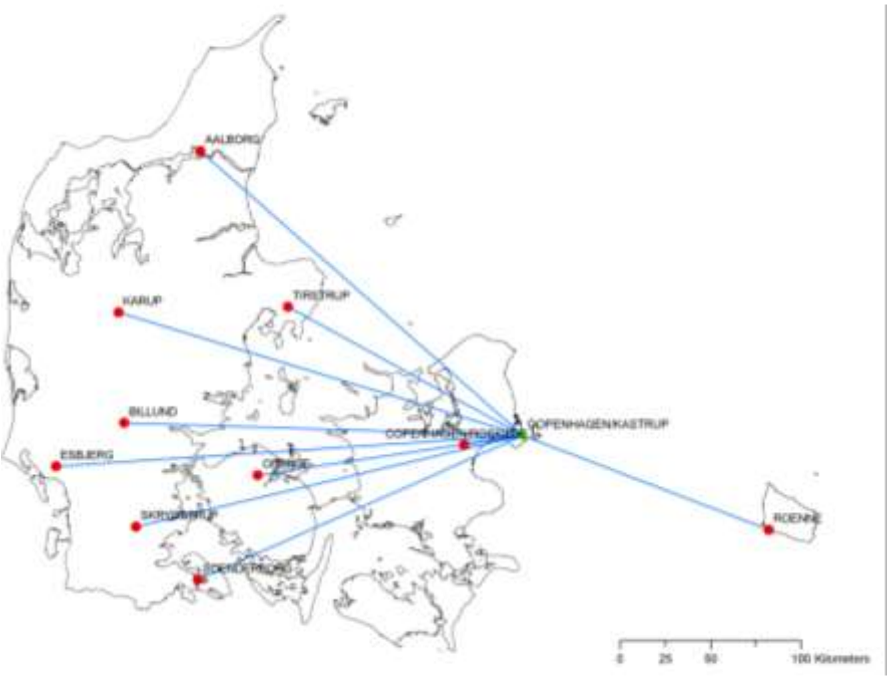

Figure 3.3.40 Most frequent domestic flying routes for large aircraft in Denmark.

Copenhagen Airport is the starting or end point for most of the domestic aviation made by large aircraft in Denmark (Figure 3.3.40; 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 Transport 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 is merely marginal.

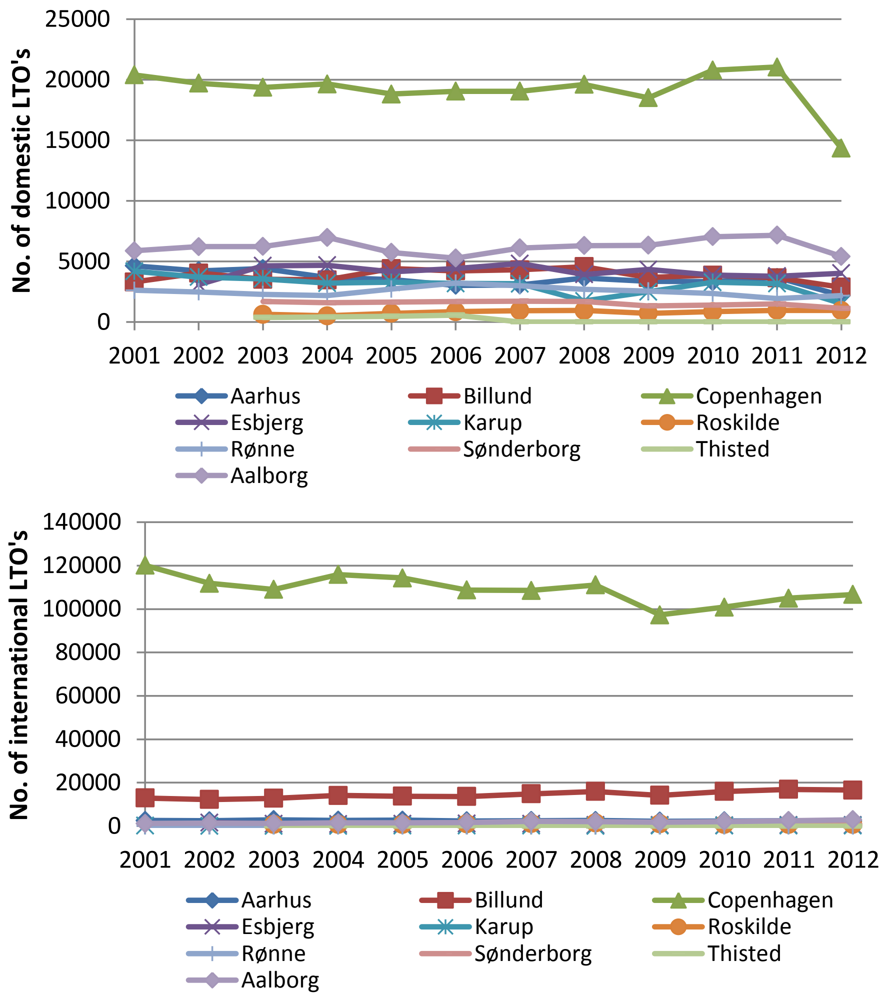

Figure 3.3.41 No. of LTO's for the most important airports in Denmark 2001-2012.

Figure 3.3.41 shows the number of domestic and international LTO's for Danish airports[7], in a time series from 2001-2012.

Non-road working machinery and equipment

Non-road working machinery and equipment are used in agriculture, forestry and industry, for household/gardening purposes and in inland waterways (recreational craft). Information on the number of different types of machines, their respective load factors, engine sizes and annual working hours has been provided by Winther et al. (2006) for the years until 2004. For later inventory years, supplementary stock data are annually provided by the Association of Danish Agricultural Machinery Dealers and the Association of Producers and Distributors of Fork Lifts in Denmark. The stock development from 1990-2012 for the most important types of machinery are shown in Figures 3.3.42 - 3.3.49. The stock data are also listed in Annex 3.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 from key experts in the field of industrial non road activities a significant decrease in the activities is assumed for 2009 due to the global financial crisis. This reduction is in the order of 25 % for 2009 for industrial non road in general (pers. comm. Per Stjernqvist, Volvo Con-

[7] Flights for Greenland and the Faroe Islands are included under domestic in the figure.

struction Equipment 2010). For fork lifts, 5 % and 20 % reductions are assumed for 2008 and 2009, respectively (pers. comm. Peter H. Møller, Rocla A/S).

For agriculture, the total number of agricultural tractors and harvesters per year are shown in the Figures 3.3.42 - 3.3.43, respectively. The figures clearly show a decrease in the number of small machines, these being replaced by machines in the large engine-size ranges.

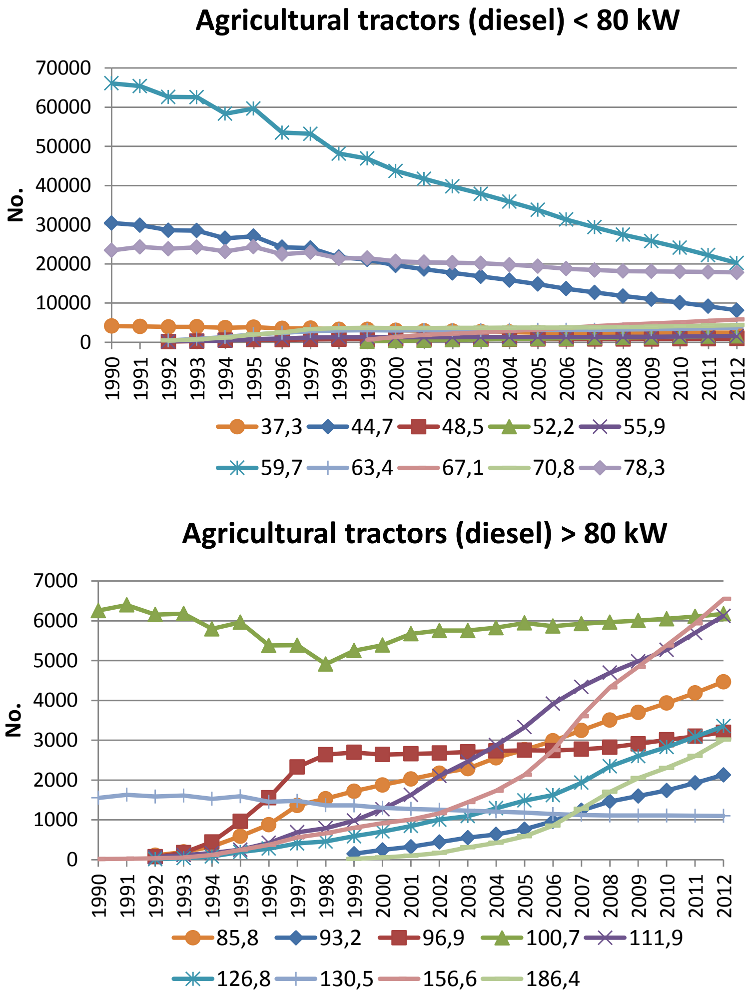

Figure 3.3.42 Total numbers in kW classes for tractors from 1990 to 2012.

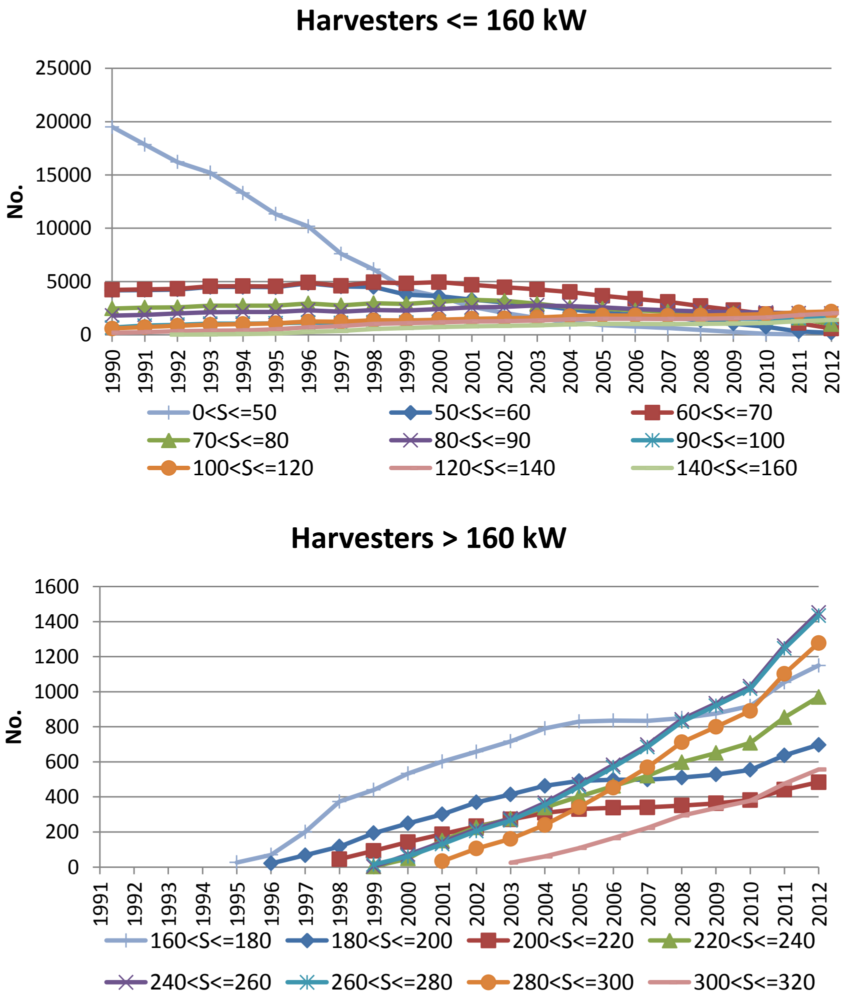

Figure 3.3.43 Total numbers in kW classes for harvesters from 1990 to 2012.

The tractor and harvester developments towards fewer vehicles and larger engines, shown in Figure 3.3.44, are very clear. From 1990 to 2012, tractor and harvester numbers decrease by around 22 % and 42 %, respectively, whereas the average increase in engine size for tractors is 35 % and 169 % for harvesters, in the same time period.

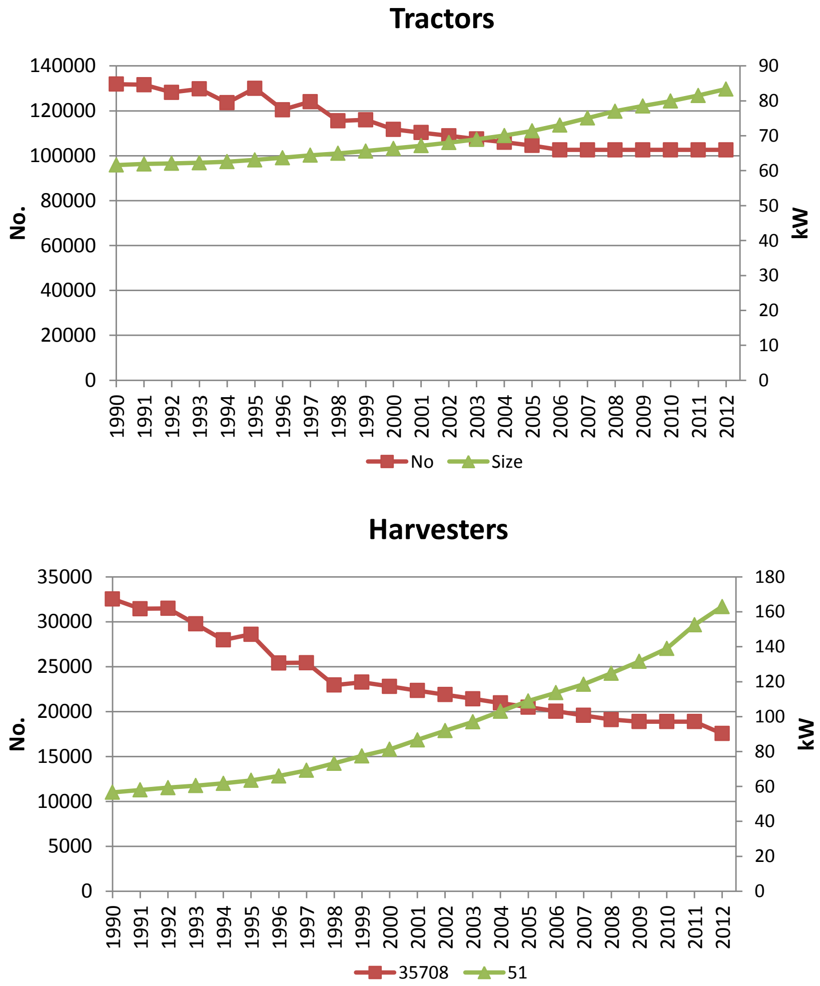

Figure 3.3.44 Total numbers and average engine size for tractors and harvesters (1990 to 2012).

The most important machinery types for industrial use are different types of construction machinery and fork lifts. The Figures 3.3.45 and 3.3.46 show the 1990-2012 stock development for specific types of construction machinery and diesel fork lifts. For most of the machinery types there is an increase in machinery numbers from 1990 onwards, due to increased construction activities. It is assumed that track type excavators/wheel type loaders (0-5 tonnes), and telescopic loaders first enter into use in 1991 and 1995, respectively.

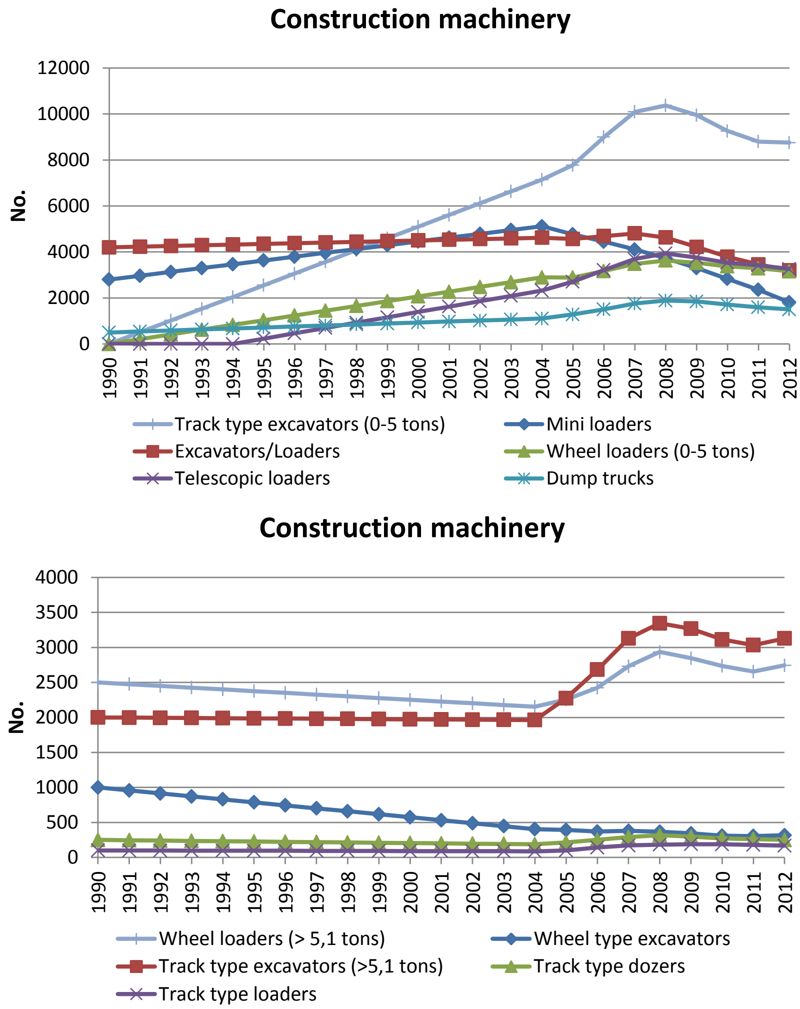

Figure 3.3.45 1990-2012 stock development for specific types of construction machinery.

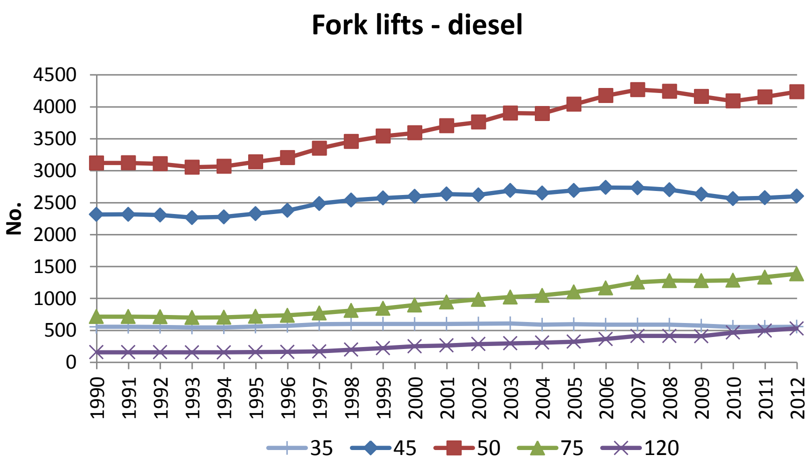

Figure 3.3.46 Total numbers of diesel fork lifts in kW classes from 1990 to 2012.

The emission level shares for tractors, harvesters, construction machinery and diesel fork lifts are shown in Figure 3.3.47, and present an overview of the penetration of the different pre-Euro engine classes, and engine stages complying with the gradually stricter EU stage I and II emission limits. The average lifetimes of 30, 25, 20 and 10 years for tractors, harvesters, fork lifts and construction machinery, respectively, influence the individual engine technology turn-over speeds.

The EU emission directive Stage I and II implementation years relate to engine size, and for all four machinery groups the emission level shares for the specific size segments will differ slightly from the picture shown in Figure 3.3.47. Due to scarce data for construction machinery, the emission level penetration rates are assumed to be linear and the general technology turnover pattern is as shown in Figure 3.3.47.

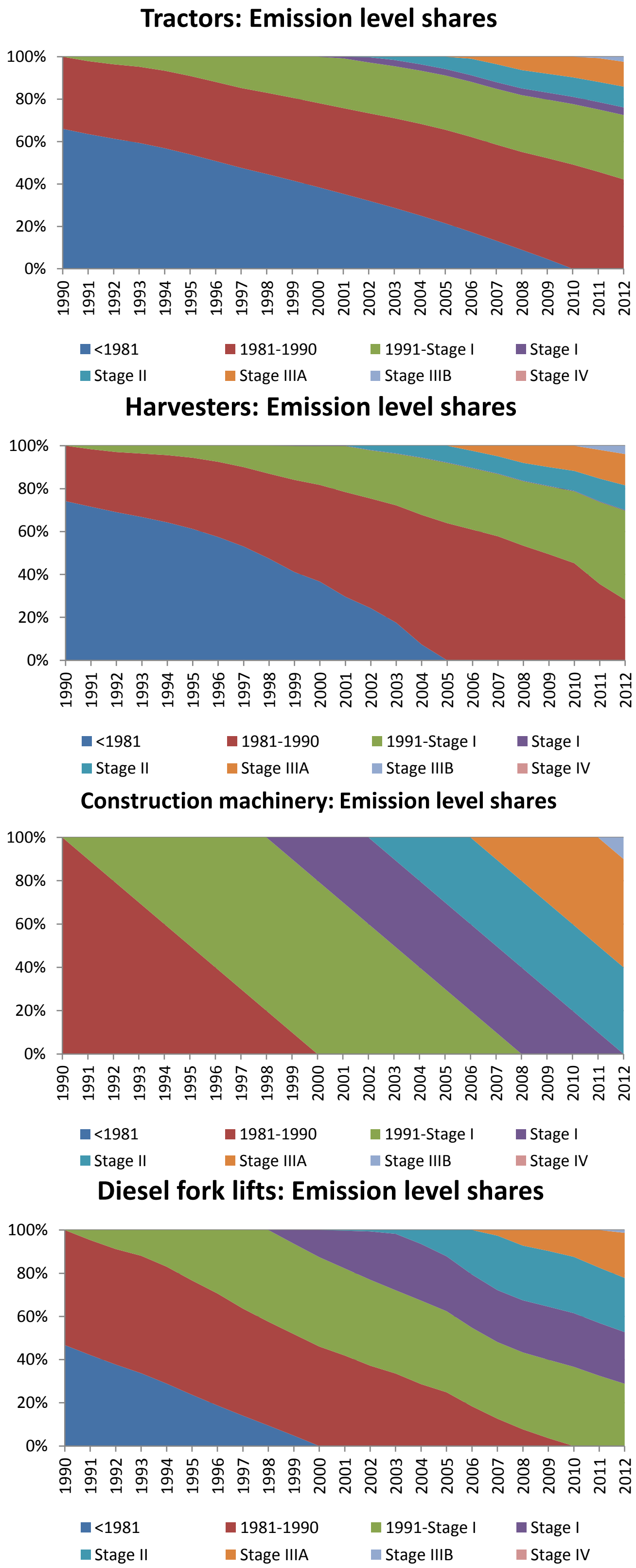

Figure 3.3.47 Emission level shares for tractors, harvesters, construction machinery and diesel fork lifts (1990 to 2012).

The 1990-2012 stock development for the most important household and gardening machinery types is shown in Figure 3.3.48.

For lawn movers and cultivators, the machinery stock remains approximately the same for all years. The stock figures for chain saws, shrub clearers, trimmers and hedge cutters increase from 1990 until 2004, and for riders this increase continues also after 2004. The yearly stock increases, in most cases, become larger after 2000. The lifetimes for gasoline machinery are short and, therefore, there new emission levels (not shown) penetrate rapidly.

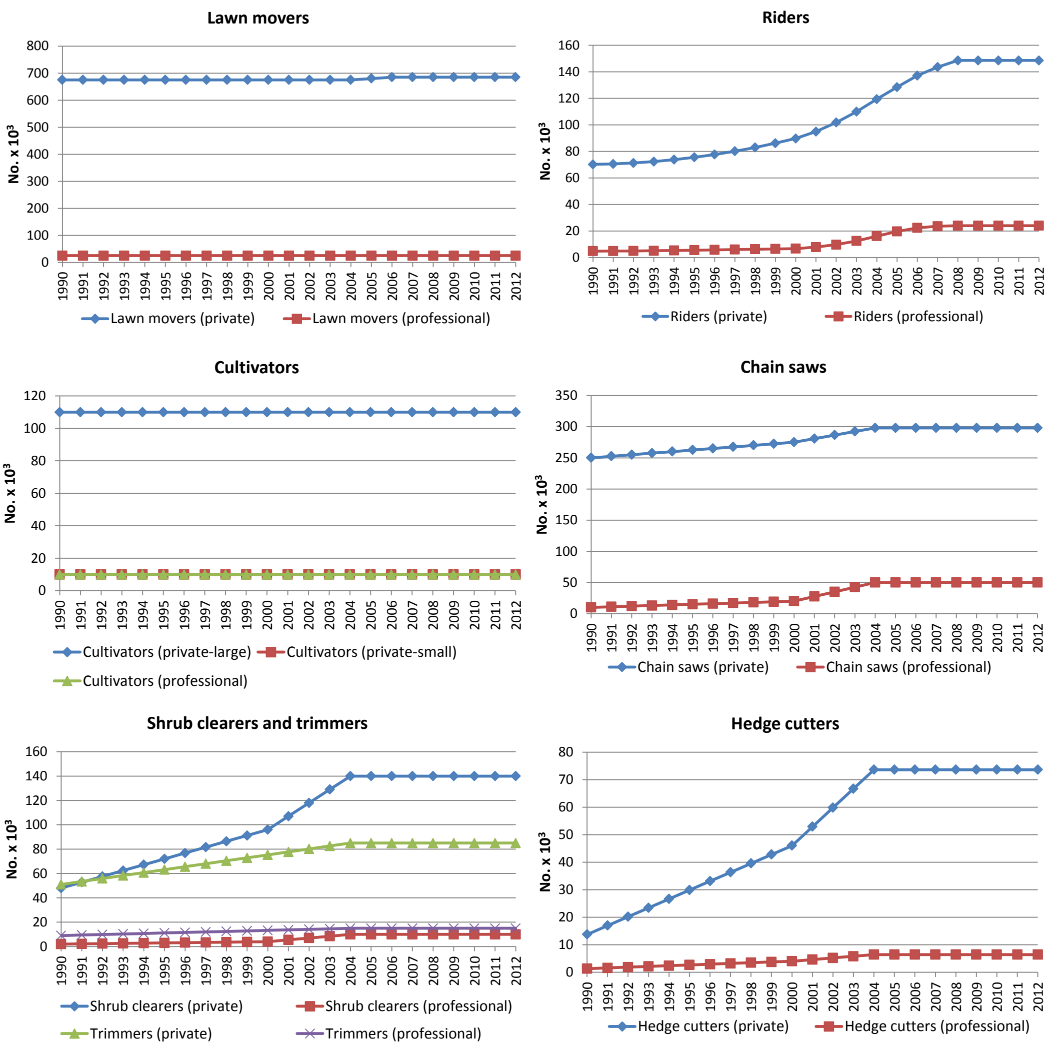

Figure 3.3.48 Stock development 1990-2012 for the most important household and gardening machinery types.

Figure 3.3.49 shows the development in numbers of different recreational craft from 1990-2012. The 2004 stock data for recreational craft are repeated for 2005+, since no new fleet information has been obtained.

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).

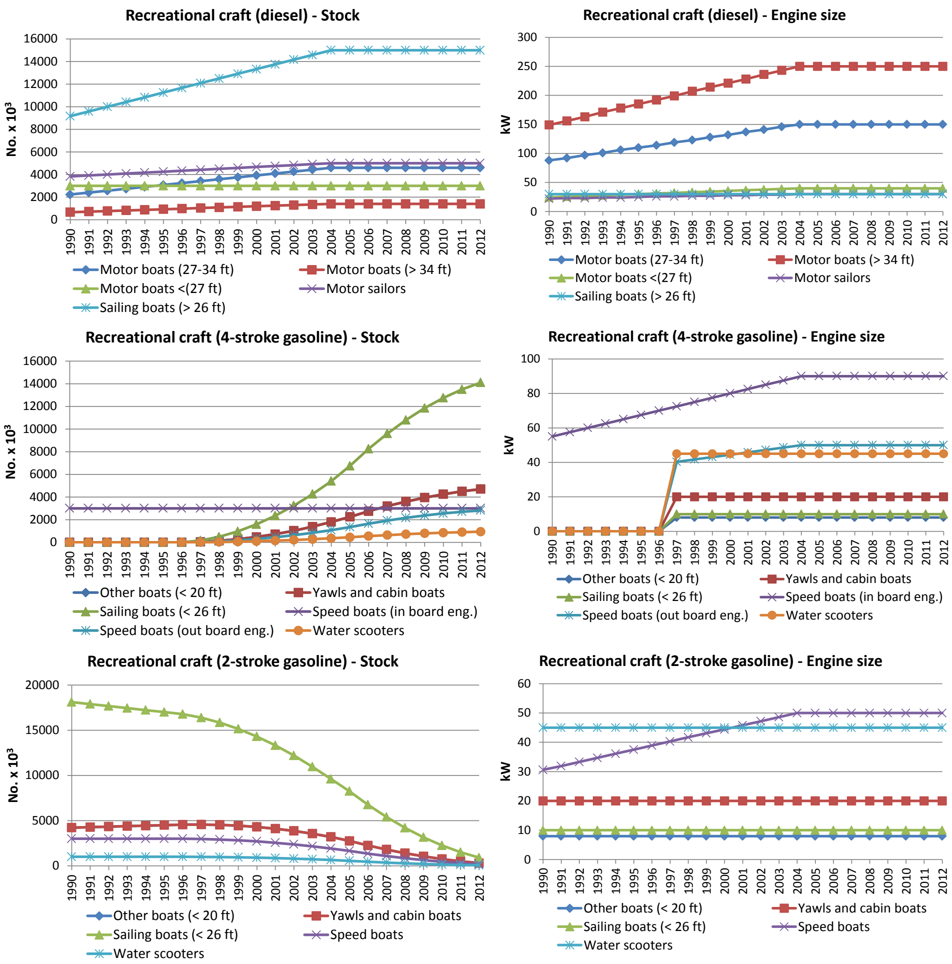

Figure 3.3.49 1990-2012 Stock and engine size development for recreational craft.

National sea transport

A detailed methodology is used to estimate the fuel consumption figures for national sea transport, based on fleet activity estimates for regional ferries, local ferries and other national sea transport (Winther, 2008).

Table 3.3.9 lists the most important domestic ferry routes in Denmark in the period 1990-2012. For these ferry routes and the years 1990-2005, the following detailed traffic and technical data have been gathered by Winther (2008): Ferry name, year of service, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size and sailing time (single trip).

For 2006-2012, the above mentioned traffic and technical data for specific ferries have been provided by Kristensen (2013) in the case of Mols-Linien (Sjællands Odde-Ebeltoft, Sjællands Odde-Århus, Kalundborg-Århus), by Jørgensen (2013) for Færgen A/S (Køge-Rønne, Tårs-Spodsbjerg). For Esbjerg/Hanst-holm/Hirtshals-Torshavn traffic and technical data have been provided by Dávastovu (2011).

Table 3.3.9 Domestic 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
Hundested-Grenaa	1990-1996
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+
Tårs-Spodsbjerg	1990+

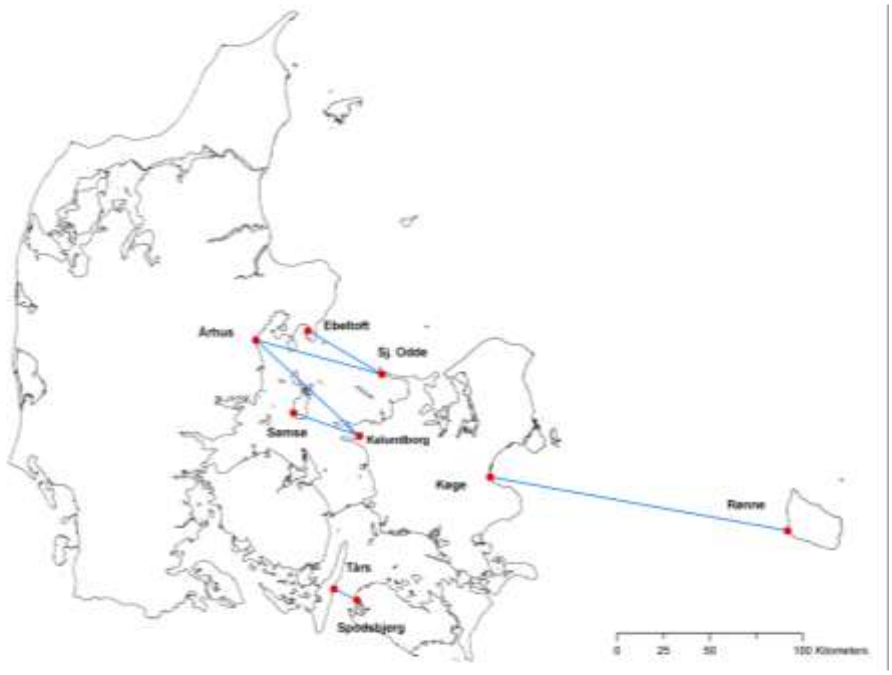

Figure 3.3.50 Domestic regional ferry routes in Denmark (2012).

The number of round trips per ferry route from 1990 to 2011 is provided by Statistics Denmark (2013), see Figure 3.3.51 (Esbjerg/Hanstholm/Hirtshals-Torshavn not shown). The traffic data are also listed in Annex 3.B.12, together with different ferry specific technical and operational data.

For each ferry, Annex 3.B.12 lists the relevant information as regards ferry route, name, year of service, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size and sailing time (single trip).

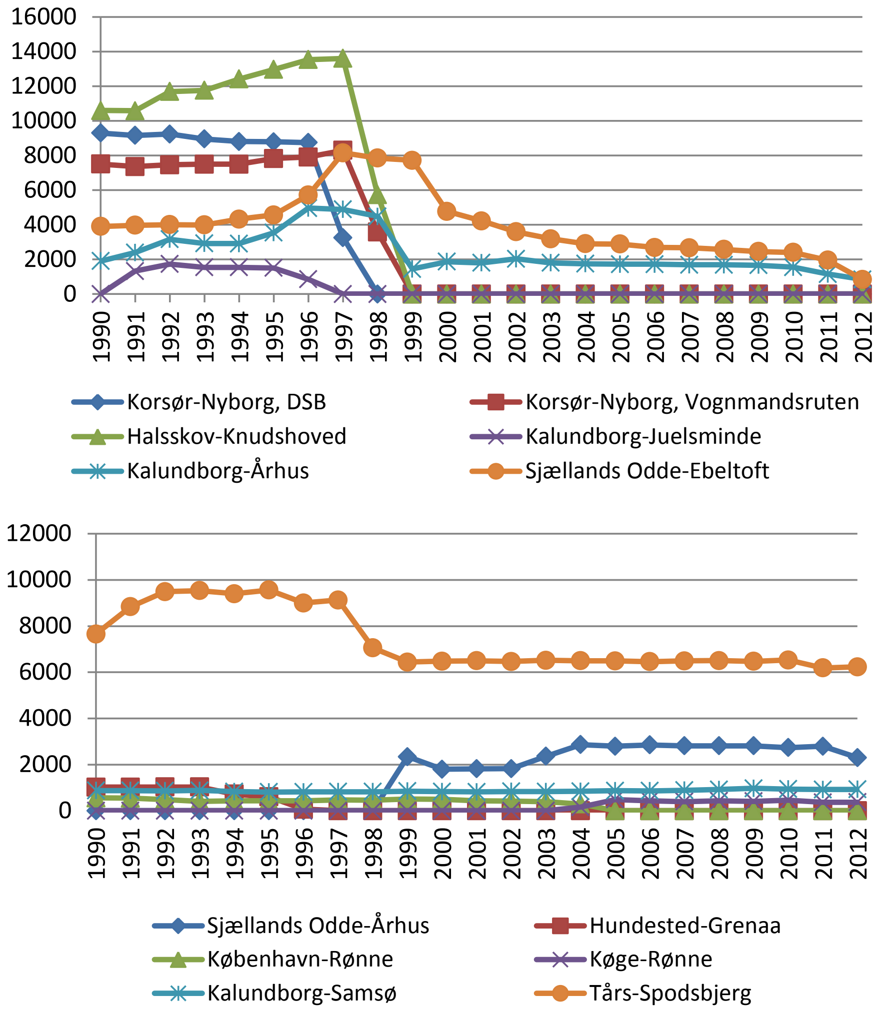

Figure 3.3.51 No. of round trips for the most important ferry routes in Denmark 1990-2012.

It is seen from Table 3.3.9 (and Figure 3.3.51) 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.

For the local ferries, a bottom-up estimate of fuel consumption for 1996 has been taken from the Danish work in Wismann (2001). The latter project calculated fuel consumption and emissions for all sea transport in Danish waters in 1995/1996 and 1999/2000. In order to cover the entire 1990-2012 inventory period, the fuel figure for 1996 has been adjusted according to the developments in local ferry route traffic shown in Annex 3.B.12.

Fuel sold for freight transport by Royal Arctic Line between Aalborg (Denmark) and Greenland and by Eim Skip - East route between Aarhus (Denmark) and Torshavn (Faroe Islands) are included under other national sea transport in the Danish inventories. In both cases all fuel is being bought in Denmark (Rasmussen, 2013 and Thorarensen, 2013).

For the remaining part of the traffic between two Danish ports, other national sea transport, bottom-up estimates for fuel consumption have been calculated for the years 1995 and 1999 by Wismann (2007). These fuel consumption estimates are used as activity data for the inventory years until 1995 and 1999 onwards. Interpolated figures are used for the inventory years 1996-1998.

The calculations use the database set up for Denmark in the Wismann (2001) study, with actual traffic data from the Lloyd's LMIS database (not including ferries). The database was split into three vessel types: bulk carriers, container ships, and general cargo ships; and five size classes: 0-1000, 1000-3000, 3000-10000, 10000-20000 and >20000 DTW. The calculations assume that bulk carriers and container ships use heavy fuel oil, and that general cargo ships use gas oil. For further information regarding activity data for local ferries and other national sea transport, please refer to Winther (2008).

The fleet activity data for regional ferries, and the fleet activity based fuel consumption estimates for local ferries and other national sea transport replace the fuel based activity data which originated directly from the DEA statistics.

Other sectors

The activity data for military, railways, international sea transport and fishery consists of fuel consumption information from DEA (2013). For international sea transport, the basis is fuel sold in Danish ports for vessels with a foreign destination, 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 bottom-up fuel estimates for the ferry routes Esbjerg/Hanstholm-Torshavn, and fuel reports from Royal Arctic Line and Eim Skip is being subtracted from the fuel sales figures for international sea transport prior to inventory fuel input.

For fisheries, the calculation methodology described by Winther (2008) remains fuel based. However, the input fuel data differ from the fuel sales figures previously used. The changes are the result of further data processing of the DEA reported gas oil sales for national sea transport and fisheries, prior to inventory input. For years when the fleet activity estimates of fuel consumption for national sea transport (not including trips to Greenland/Faroe Islands) are smaller than DEA reported fuel sold for national sea transport, fuel is added to fisheries in the inventory. In the opposite case, fuel is being subtracted from the original DEA fisheries fuel sales figure in order to make up the final fuel consumption input for fisheries in the inventories.

The updated fuel consumption time series for national sea transport lead, in turn, to changes in the energy statistics for fisheries (gas oil) and industry (heavy fuel oil), so the national energy balance can remain unchanged.

For all sectors, fuel consumption figures are given in Annex 3.B.15 for the years 1990 and 2012 in CollectER format.

Emission legislation

For the engines used by other mobile sources, no legislative limits exist for specific fuel consumption. And no legislative limits exist for the emissions of CO_2 which are directly fuel dependent. The engines, however, do have to comply with the emission legislation limits agreed by the EU and, except for ships, the VOC emission limits influence the emissions of CH_4, these forming part of total VOC.

For non-road working machinery and equipment, and 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 relate to non-road 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 railway machinery. For tractors the relevant directives are 2000/25 and 2005/13. For gasoline, the directive 2002/88 distinguishes between hand-held (SH) and not hand-held (NS) types of machinery.

For engine type approval, the emissions (and fuel consumption) are measured using various test cycles (ISO 8178). Each test cycle consists of a number of measurement points for specific engine loads during constant operation. The specific test cycle used depends on the machinery type in question and the test cycles are described in more details in the directives.

Table 3.3.10 Overview of EU emission directives relevant for diesel fuelled non-road machinery.

Stage/ Engine size [kW]	CO	VOC	NO_X	VOC+NO_X	PM	Diesel machinery			Tractors	
							Implement. date		EU	Implement.
	[g pr kWh]					EU Directive	Transient	Constant	directive	date
Stage I										
37<=P<75	6.5	1.3	9.2	-	0.85	97/68	1/4 1999	-	2000/25	1/7 2001
Stage II										
130<=P<560	3.5	1	6	-	0.2	97/68	1/1 2002	1/1 2007	2000/25	1/7 2002
75<=P<130	5	1	6	-	0.3		1/1 2003	1/1 2007		1/7 2003
37<=P<75	5	1.3	7	-	0.4		1/1 2004	1/1 2007		1/1 2004
18<=P<37	5.5	1.5	8	-	0.8		1/1 2001	1/1 2007		1/1 2002
Stage IIIA										
130<=P<560	3.5	-	-	4	0.2	2004/26	1/1 2006	1/1 2011	2005/13	1/1 2006
75<=P<130	5	-	-	4	0.3		1/1 2007	1/1 2011		1/1 2007
37<=P<75	5	-	-	4.7	0.4		1/1 2008	1/1 2012		1/1 2008
19<=P<37	5.5	-	-	7.5	0.6		1/1 2007	1/1 2011		1/1 2007
Stage IIIB										
130<=P<560	3.5	0.19	2	-	0.025	2004/26	1/1 2011	-	2005/13	1/1 2011
75<=P<130	5	0.19	3.3	-	0.025		1/1 2012	-		1/1 2012
56<=P<75	5	0.19	3.3	-	0.025		1/1 2012	-		1/1 2012
37<=P<56	5	-	-	4.7	0.025		1/1 2013	-		1/1 2013
Stage IV										
130<=P<560	3.5	0.19	0.4	-	0.025	2004/26	1/1 2014		2005/13	1/1 2014
56<=P<130	5	0.19	0.4	-	0.025		1/10 2014			1/10 2014

Table 3.3.11 Overview of the EU Emission Directive 2002/88 for gasoline fuelled non-road machinery.

	Catego-ry	Engine size [ccm]	CO [g pr kWh]	HC [g pr kWh]	NO_X [g pr kWh]	$HC+NO_X$ [g pr kWh]	Implemen-tation date
	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

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 3.3.12a. 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 3.3.12b the Stage II emission limits are shown for recreational craft. CO and HC+NOx limits are provided for gasoline engines depending on the rated engine power and the engine type (stern-drive vs. outboard) while CO, HC+NOx, and particulate emission limits are defined for Compression Ignition (CI) engines depending on the rated engine power and the swept volume.

Table 3.3.12a 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 3.3.12b 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 3.2.13 Overview of the EU Emission Directive 2004/26 for railway locomotives and motorcars.

	Engine size [kW]		CO [g pr kWh]	HC [g pr kWh]	NO_x [g pr kWh]	HC+NOX [g pr kWh]	PM [g pr kWh]	Implement. date
Locomotives	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
	Stage IIIB	RB	3.5	-	-	4	0.025	1/1 2012
Motor cars	Stage IIIA							
	130<P	RC A	3.5	-	-	4	0.2	1/1 2006
	Stage IIIB							
	130<P	RC B	3.5	0.19	2	-	0.025	1/1 2012

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 — Aircraft Engine Emissions to the Convention on International Civil Aviation (ICAO Annex 16, 1993). 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 feet (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 four categories:

a) For engines of a type or model for which the date of manufacture of the first individual production model is on or before 31 December 1995, and for which the production date of the individual engine is on or before 31 December 1999.
b) For engines of a type or model for which the date of manufacture of the first individual production model is after 31 December 1995, or for individual engines with a production date after 31 December 1999.
c) For engines of a type or model for which the date of manufacture of the first individual production model is after 31 December 2003.
d) For engines of a type or model for which the date of manufacture of the first individual production model is after 31 December 2007.

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 formulas in Table 3.3.14.

Table 3.3.14 Current certification limits for NO_x for turbo jet and turbo fan engines.

	Engines first produced before 31.12.1995 & for engines manufactured up to 31.12.1999	Engines first produced after 31.12.1995 & for engines manufactured after 31.12.1999	Engines for which the date of manufacture of the first individual production model was after 31 December 2003	Engines for which the date of manufacture of the first individual production model was after 31 December 2007
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			$Dp/F_{oo} = 19 + 1.6\pi_{oo}$	$Dp/F_{oo} = 16.72 + 1.4080\pi_{oo}$
Thrust between 26.7 kN and not more than 89 kN			$Dp/F_{oo} = 37.572 + 1.6\pi_{oo} - 0.208F_{oo}$	$Dp/F_{oo} = 38.54862 + (1.6823\pi_{oo}) – (0.2453F_{oo}) – (0.00308\pi_{oo}F_{oo})$
Engines of pressure ratio more than 30 and less than 62.5				
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 82.6 or more			$Dp/F_{oo} = 32+1.6\pi_{oo}$	$Dp/F_{oo} = 32+1.6\pi_{oo}$

Source: International Standards and Recommended Practices, Environmental Protection, ICAO Annex 16 Volume II Part III Paragraph 2.3.2, 2nd edition July 1993, plus amendments: Amendment 3 (20 March 1997),Amendment 4 (4 November 1999),Amendment 5 (24 November 2005).

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 http://www.caa.co.uk, hosted by the UK Civil Aviation Authority.

For seagoing vessels, NO_x emissions are regulated as explained in Marpol 73/78 Annex VI, formulated by IMO (International Maritime Organisation). The legislation is relevant 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 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 ≤ n < 2000 RPM.

- 9,8 g pr kWh, n ≥ 2000 RPM.

Further, the Marine Environment Protection Committee (MEPC) of IMO has approved proposed amendments to MARPOL Annex VI to be agreed by IMO in October 2008 in order to strengthen the emission standards for NO_x and the sulphur contents of heavy fuel oil used by ship engines.

For NO_x emission regulations, a three tiered approach is considered, which 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.
- Tier II: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2011.
- Tier III[8]: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2016.

As for the existing NO_x emission limits, the new Tier I-III NO_x legislation values rely on the rated engine speeds. The emission limit equations are shown in Table 3.3.15.

Table 3.3.15 Tier I-III NOx emission limits for ship engines (amendments to MARPOL Annex VI).

	NO_x limit	RPM (n)
Tier I	17 g pr kWh	n < 130
	45 x 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 x 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 x n-0.2 g pr kWh	130 ≤ n < 2000
	2 g pr kWh	n ≥ 2000

The Tier I emission limits are identical with the existing emission limits from MARPOL Annex VI.

Also to be agreed by IMO in October 2008, 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 3.3.16 shows the current legislation in force, and the amendment of MARPOL Annex VI to be agreed by IMO in October 2008.

[8] For ships operating in a designated Emission Control Area. Outside a designated Emission Control Area, Tier II limits apply.

Table 3.3.16 Current legislation in relation to marine fuel quality.

Legislation		Heavy fuel oil		Gas oil	
		S- %	Impl. date (day/month/year)	S- %	Impl. date
EU-directive 93/12		None		0.2[1]	1.10.1994
EU-directive 1999/32		None		0.2	1.1.2000
EU-directive 2005/33[2]	SECA - Baltic sea	1.5	11.08.2006	0.1	1.1.2008
	SECA - North sea	1.5	11.08.2007	0.1	1.1.2008
	Outside SECA's	None		0.1	1.1.2008
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[3]		

[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

[3] Subject to a feasibility review to be completed no later than 2018. If the conclusion of such a review becomes negative the effective date would default 1 January 2025.

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 are country-specific and come from the DEA. The N_2O emission factors are taken from the EMEP/EEA guidebook (EMEP/EEA, 2013).

For military ground material, aggregated CH_4 emission factors for gasoline and diesel are derived from the road traffic emission simulations. The CH_4 emission factors for railways are derived from specific Danish VOC measurements from the Danish State Railways (Delvig, 2013) and a NMVOC/CH_4 split, based on expert judgement.

For agriculture, forestry, industry, household gardening and inland waterways, the VOC emission factors are derived from various European measurement programmes and the current EU emission legislation; see IFEU (2004) and Winther et al. (2006). The NMVOC/CH_4 split is taken from USEPA (2004). The baseline emission factors are shown in Annex 3.B.10.

For national sea transport and fisheries, the VOC emission factors come from Trafikministeriet (2000). Specifically for the ferries used by Mols Linjen new VOC emission factors are provided by Kristensen (2008), originating from measurement results by Hansen et al. (2004), Wismann (1999) and PHP (1996). Kristensen (2013) has provided complimentary emission factor data for new ferries.

For ship engines VOC/CH_4 splits are taken from EMEP/EEA (2013), and all emission factors are shown in Annex 3.B.13.

The CH_4 emission factors for domestic aviation come from the EMEP/EEA (2013). 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 all sectors, emission factors for the years 1990 and 2012 are given in CollectER format in Annex 3.B.15.

Table 3.3.17 shows the aggregated emission factors for CO_2, CH_4 and N_2O in 2012 used to calculate the emissions from other mobile sources in Denmark.

Table 3.3.17 Fuel-specific emission factors for CO_2, CH_4 and N_2O for other mobile sources in Denmark.

SNAP ID	CRF ID	Category		Fuel type	Emission factors[9] CH_4 g pr GJ	CO_2 g pr GJ	N_2O g pr GJ
1A5	080100	Military		AvGas	21.90	73.00	2.00
1A5	080100	Military		Diesel	1.14	74.00	2.81
1A5	080100	Military		Gasoline	7.39	73.00	1.46
1A5	080100	Military		Jet fuel	2.65	72.00	2.30
1A3c	080200	Railways		Diesel	2.17	74.00	2.04
1A3d	080300	Inland waterways		Diesel	2.55	74.00	2.97
1A3d	080300	Inland waterways		Gasoline	64.41	73.00	1.55
1A3d	080402	National sea traffic		Diesel	1.66	74.00	4.68
1A3d	080402	National sea traffic		LPG	20.26	63.10	0.00
1A3d	080402	National sea traffic		Residual oil	1.95	78.00	4.89
1A4c	080403	Fishing		Diesel	1.79	74.00	4.68
1A4c	080403	Fishing		LPG	20.26	63.10	0.00
Memo item	080404	International sea traffic		Diesel	1.78	74.00	4.68
Memo item	080404	International sea traffic		Residual oil	1.96	78.00	4.89
1A3a	080501	Air traffic, Dom. < 3000 ft.	Other airports	AvGas	21.90	73.00	2.00
1A3a	080501	Air traffic, Dom. < 3000 ft.	Other airports	Jet fuel	1.82	72.00	9.24
Memo item	080502	Air traffic, Int. < 3000 ft.	Other airports	AvGas	21.90	73.00	2.00
Memo item	080502	Air traffic, Int. < 3000 ft.	Other airports	Jet fuel	4.24	72.00	7.24
1A3a	080503	Air traffic, Dom. > 3000 ft.	Other airports	Jet fuel	0.00	72.00	2.30
Memo item	080504	Air traffic, Int. > 3000 ft.	Other airports	Jet fuel	0.00	72.00	2.30
1A4c	080600	Agriculture		Diesel	0.80	74.00	3.19
1A4c	080600	Agriculture		Gasoline	159.58	73.00	1.71
1A4c	080700	Forestry		Diesel	0.42	74.00	3.21
1A4c	080700	Forestry		Gasoline	30.97	73.00	0.46
1A2f	080800	Industry		Diesel	0.88	74.00	3.10
1A2f	080800	Industry		Gasoline	108.83	73.00	1.49
1A2f	080800	Industry		LPG	7.69	63.10	3.50
1A4b	080900	Household and gardening		Gasoline	75.45	73.00	1.26
1A4a	081100	Commercial and institutional		Gasoline	64.42	73.00	1.13
1A3a	080501	Air traffic, Dom. < 3000 ft.	Copenhagen airport	AvGas	21.90	73.00	2.00
1A3a	080501	Air traffic, Dom. < 3000 ft.	Copenhagen airport	Jet fuel	2.07	72.00	5.66
Memo item	080502	Air traffic, Int. < 3000 ft.	Copenhagen airport	AvGas	21.90	73.00	2.00
Memo item	080502	Air traffic, Int. < 3000 ft.	Copenhagen airport	Jet fuel	3.76	72.00	3.87
1A3a	080503	Air traffic, Dom. > 3000 ft.	Copenhagen airport	Jet fuel	0.00	72.00	2.30
Memo item	080504	Air traffic, Int. > 3000 ft.	Copenhagen airport	Jet fuel	0.00	72.00	2.30

[9] References. CO_2: Country-specific. N_2O: EMEP/EEA. CH_4: Railways: DSB/DCE; Agriculture/Forestry/Industry/Household-Gardening: IFEU/USEPA; National sea traffic/Fishing/International sea traffic: Trafikministeriet/EMEP/EEA; domestic and international aviation: EMEP/EEA.

Factors for deterioration, transient loads and gasoline evaporation for non road 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), 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).

3.3.4 Calculation method

Air traffic

For aviation, the domestic and international estimates are made separately for landing and take-off (LTOs < 3000 ft), and cruising (> 3000 ft).

By using the LTO mode specific fuel flow and emission indices from EMEP/EEA (2013), the fuel consumption and emission factors for the full LTO cycle can be 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:

$$FC^{a}_{LTO} = \sum_{m=1}^{4} t_m \cdot ff_{a,m} \qquad (15)$$

Where FC = fuel consumption (kg), m = LTO mode (approach/landing, taxiing, 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:

$$E^{a}_{LTO} = \sum_{m=1}^{4} FC_{a,m} \cdot EI_{a,m} \qquad (16)$$

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), whereas for taxiing the appropriate time interval is 13 minutes in Copenhagen Airport and 5 minutes in other airports present in the Danish inventory.

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.

The calculations for cruise use the distance specific fuel consumption and emissions given by EMEP/EEA (2013) per representative aircraft type. Data interpolations or extrapolations are made – in each case determined by the great circle distance between the origin and the destination airports.

If the great circle 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:

$$E(y) = E_{x_i} + \frac{(y - x_i)}{x_{i+1} - x_i} \cdot (E_{x_{i+1}} - E_{x_i}) \quad y<x_{max}, i = 0,1,2....max-1 \qquad (17)$$

In (15) x_i and x_{max} denominate the separate distances and the maximum distance, respectively, with known fuel consumption and emissions. If the flight distance y exceeds x_{max} the maximum figures for fuel consumption and emissions must be extrapolated and the equation then becomes:

$$E(y) = E_{x_{max}} + \frac{(y - x_{max})}{x_{max} - x_{max-1}} \cdot (E_{x_{max}} - E_{x_{max-1}}) \quad y>x_{max} \qquad (18)$$

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 2012[10]. 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 in the model is around 0.8, 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.

Prior to 2001, the calculation procedure was first to estimate each year's fuel consumption and emissions for LTO. Secondly, total cruising fuel consumption was found year by year as the statistical fuel consumption total minus the calculated fuel consumption for LTO. Lastly, the cruising fuel consumption was split into a domestic and international part by using the results from a Danish city-pair emission inventory in 1998 (Winther, 2001a). For more details of this latter fuel allocation procedure, see Winther (2001b).

Non-road working 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:

$$E_{Basis}(X)_{i,j,k} = N_{i,j,k} \cdot HRS_{i,j,k} \cdot P \cdot LF_i \cdot EF_{y,z} \qquad (19)$$

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

[10] Excluding flights for Greenland and the Faroe Islands.

emission level, z. The deterioration factors for diesel and gasoline 2-stroke engines are found from:

$$DF_{i,j,k}(X) = \frac{K_{i,j,k}}{LT_i} \cdot DF_{y,z} \tag{20}$$

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:

$$DF_{i,j,k}(X) = \sqrt{\frac{K_{i,j,k}}{LT_i}} \cdot DF_{y,z} \tag{21}$$

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 a given machinery type, engine size and engine age in year X, relies only on emission level and load factor, and is denominated as:

$$TF_{i,j,k}(X) = TF_z \tag{22}$$

Where i = machinery type, j = engine size, k = engine age and z = emission level.

The transient factors inserted in (20) 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.

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 17-20:

$$E(X)_{i,j,k} = E_{Basis}(X)_{i,j,k} \cdot TF(X)_{i,j,k} \cdot (1 + DF(X)_{i,j,k}) \tag{23}$$

The evaporative hydrocarbon emissions from fuelling are calculated as:

$$E_{Evap,\,fueling,i} = FC_i \cdot EF_{Evap,\,fueling} \tag{24}$$

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:

$$E_{Evap,\tan k,i} = N_i \cdot EF_{Evap,\tan k,i} \tag{25}$$

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.

Ferries, other national sea transport and fisheries

The fuel consumption and emissions in year X, for regional ferries are calculated as:

$$E(X) = \sum_i N_i \cdot T_i \cdot S_{i,j} \cdot P_i \cdot LF_j \cdot EF_{k,l,y} \quad (26)$$

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, EF = fuel consumption/emission factor in g pr kWh, i = ferry service, j = ferry, k = fuel type, l = engine type, y = engine year.

For the remaining navigation categories, the emissions are calculated using a simplified approach:

$$E(X) = \sum_i EC_{i,k} EF_{k,l,y} \quad (27)$$

Where E = fuel consumption/emissions, EC = energy consumption, EF = fuel consumption/emission factor in g per kg fuel, i = category (local ferries, other national sea, fishery, international sea), k = fuel type, l = engine type, y = average engine year.

The emission factor inserted in (27) 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:

$$EF_{k,l,y} = \frac{\sum_{year=X}^{year=X-LT} EF_{k,l}}{LT_{k,l}} \quad (28)$$

Other sectors

For military and railways, the emissions are estimated with the simple method using fuel-related emission factors and fuel consumption from the DEA:

$$E = FC \cdot EF \quad (29)$$

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 2012 and as time series 1990-2012 in Annex 3.B.15 (CRF format).

Fuel balance between DEA statistics and inventory estimates

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. This is the case for non road machinery, where relevant DEA statistical sectors also include fuel consumed by stationary sources.

In other situations, fuel consumption figures estimated by DCE from specific bottom-up calculations are regarded as more reliable than DEA reported sales. This is the case for national sea transport.

In the following the transferral of fuel consumption data from DEA statistics into inventory relevant categories is explained for national sea transport and fisheries, non road 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 sea transport and fisheries

For national sea transport in Denmark, the fuel consumption estimates obtained by DCE (see 3.3.3 Activity data – national sea transport) are regarded as much more accurate than the DEA fuel sales data, since the large fluctuations in reported fuel sales cannot be explained by the actual development in the traffic between different national ports. As a consequence, the new bottom-up estimates replace the previous fuel based figures for national sea transport.

There are different potential reasons for the differences between estimated fuel consumption and reported sales for national sea transport in Denmark. According to the DEA, the latter fuel differences are most likely explained by inaccurate costumer specifications made by the oil suppliers. This inaccuracy can be caused by a sector misallocation in the sales statistics between national sea transport and fisheries for gas oil, and between national sea transport 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”).

Following this, for fisheries and industry the updated fuel consumption time series for national sea transport lead, in turn, to changes in the fuel activity data for fisheries (gas oil), industry (heavy fuel oil) and international sea transport, so the national energy balance can remain unchanged.

For fisheries, fuel investigations made prior to the initiation of the work made by Winther (2008) have actually pointed out a certain area of inaccuracy 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). Hence, for fisheries small amounts of fuel oil are transferred to national sea transport, and in addition small amounts of gasoline and diesel are transferred to recreational craft.

Non road machinery and recreational craft

For diesel and LPG, the non-road fuel consumption estimated by DCE 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 from road transport is needed to reach the fuel consumption goal.

The amount of diesel and LPG in DEA industry not being used by non-road 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 are subsequently subtracted from the DEA fishery sector. For gasoline, the DEA reported fuel consumption for fisheries is far too small to fill the fuel gap, and hence the missing fuel amount is taken from the DEA road transport sector.

Bunkers

The distinction between domestic and international emissions from aviation and navigation should be in accordance with the Revised 1996 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 freight transport 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

Uncertainty estimates for greenhouse gases on Tier 1 and Tier 2 levels, are made for road transport and other mobile sources using the guidelines formulated in the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000). 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. Please refer to Chapter 1.7 for further information regarding the calculation procedure for Tier 2 uncertainty calculations.

Table 3.3.18 Tier 1 Uncertainties for activity data, emission factors and total emissions in 2012 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 2012		5.3	26.6	152.0
Trend uncertainty		6.0	5.4	66.8

Table 3.3.19 Tier 2 Uncertainty factors for activity data and emission factors in 2012.

Category	Activity data %	CO_2 %	CH_4 %	N_2O %
Road transport	2	5	40	500
Military	2	5	100	1000
Railways	2	5	100	1000
Pleasure craft	41	5	100	1000
Regional ferries	20	5	100	1000
Local ferries	20	5	100	1000
Fisheries	2	5	100	1000
Greenland & Faroe Islands	20	5	100	1000
Other national sea transport	20	5	100	1000
Civil aviation	10	5	100	1000
Agriculture	24	5	100	1000
Forestry	30	5	100	1000
Industry	41	5	100	1000
Household and gardening	35	5	100	1000
Commercial and institutional	35	5	100	1000

Table 3.3.20 Tier 2 Uncertainty estimates for CO_2, CH_4, N_2O and CO_2-eq. in 2012.

		1990			2012			1990-2012		
		Median	Uncertainty (%)		Median	Uncertainty (%)		Median	Uncertainty (%)	
		Emission	Lower (-)	Upper (+)	Emission	Lower (-)	Upper (+)	Emission	Lower (-)	Upper (+)
CO_2	ktonnes	13624	5	5	15354	5	5	13	9	9
CH_4	tonnes	2695	28	39	997	26	37	-63	33	47
N_2O	Tonnes	694	46	202	753	43	183	10	299	521
CO_2 eq.	Ktonnes	13924	5	6	15635	5	6	12	10	11

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 2010 inventory (Winther, 2012).

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.
- Civil Aviation Agency of Denmark: Flight statistics.
- Non-road 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, 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 and lower heating values (all fuel types).
- COPERT IV: Road transport (all exhaust components, except CO_2, SO_2).
- Danish State Railways: Diesel locomotives (NO_X, VOC, CO and TSP).
- EMEP/EEA guidebook: Civil aviation and supplementary.
- Non road machinery: References given in NERI reports.
- National sea transport and fisheries: TEMA2000 (NO_X, VOC, CO and TSP) and MAN Diesel (sfc, NO_X).

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[1]	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 Transport Authority	Jess Nørgaard	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	Bo Henry Eriksen	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 IV emission factors[3]	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	Per Delvig	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

[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 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.

Here, 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 and fisheries, respectively.

In the case of Danish national sea transport, fuel consumption estimates are obtained by DCE (Winther, 2008), since they are regarded as much more accurate than the DEA fuel sales data. For the latter source, the large fluctuations in reported fuel sales cannot be explained by the actual development in the traffic between different national ports.

In order to maintain the national energy balance, the updated fuel consumption time series for national sea transport lead, in turn, to changes in the fuel activity data for fisheries (gas oil) and industry (heavy fuel oil).

The DCE fuel modifications, thus, give DEA-SNAP differences for road transport, national sea transport 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 Car 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 Programme.

Danish Transport Authority (Civil Aviation Agency of Denmark)

The Danish Transport 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.

Non-road machinery (stock and operational data)

A great deal of new 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. The source for the agricultural machinery stock of tractors and harvesters is Statistics Denmark. Sales figures for tractors, harvesters and construction machinery, together with operational data and supplementary information, are obtained from The Association of Danish Agricultural Machinery Dealers. IFAG (The Association of Producers and Distributors of Fork Lifts in Denmark) provides fork-lift sale figures, whereas total stock numbers for gasoline equipment are obtained from machinery manufacturers with large Danish market shares, with figures validated through discussions with KVL. 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).

No statistical register exists for non-road machinery types and this affects the accuracy of stock and operational data. For tractors and harvesters, Statistics Denmark provide total stock data based on information from questionnaires and the registers of crop subsidy applications kept by the Ministry of Food, Agriculture and Fishery. In combination with new sales figures pr engine size from The Association of Danish Agricultural Machinery Dealers, the best available stock data are obtained. In addition, using the sources for construction machinery and fork lift sale figures are regarded as the only realistic approach for consolidated stock information for these machinery types. Use of this source-type also applies in the case of machinery types (gasoline equipment, recreational craft) where data is even scarcer.

To support the 2012 inventory, new 2012 stock data for tractors, harvesters, fork lifts and construction machinery was obtained from the same sources as in Winther et al. (2006). 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, 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 sea transport (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 new sales per year, The National Motorcycle Association is considered to be 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 IV

COPERT IV provides factors for fuel consumption and for all exhaust emission components which are included in the national inventory. For several reasons, COPERT IV 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 programmes and, apart from updated fuel consumption and emission factors, the use of COPERT IV by many European countries ensures a large degree of cross-national consistency in reported emission results.

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 to be 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 evaluated specifically for detailed national inventory use by a group of experts representing civil aviation administration, air traffic management, emission modellers and inventory compilers.

In addition, the EMEP/EEA guidebook is the source of non-exhaust TSP, PM_{10} and $PM_{2.5}$ 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 et al. (2006). The fuel consumption and emission data is regarded as the most comprehensive data collection on a European level, having been thoroughly evaluated by German emission measurement and non-road experts within the framework of a German non-road inventory project.

National sea transport and fisheries

Emission factors for NO_X, VOC, CO and TSP are taken from the TEMA2000 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 NO_X, additional information of emission factors in a time series going back to 1949, and PM_{10} and $PM_{2.5}$ fractions of total TSP was provided by the engine manufacturer MAN Diesel.

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) 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 Authority 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 to be 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 increase even further 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 Transport 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 Transport Authority flight 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 IV-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 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 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, 2012) 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 international guidelines (Winther, 2005: Kyoto notat, in Danish). This paper will be translated into English and the conclusions will be implemented in the future national inventory reports.

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.

Se 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 the DCE transport models 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 DCE transport models (road, civil aviation, non-road machinery/recreational craft, navigation/fisheries). The sub-routines 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 pr 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 cruise 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 DCE models. For the transport modes military and railways, the DEA fuel consumption figures go directly into Data Storage Level 2. This is also the case for the railway emission factors obtained from Danish State Railways and, generally, for the emission factors, which are kept constant over the years.

The DCE model simulations of fuel consumption and emission factors for road transport, civil aviation and non-road machinery refer to Data Processing Level 1.

When DCE transport 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 DCE 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, 2008, 2012) and Winther et al. (2006). Further formal descriptions of DCE 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 programme 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 by 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 (Data2012 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 DCE 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 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.

A spreadsheet "Check CRF 2011.xls" has been set up to check that the fuel consumption and emission totals from CollectER imported in Data2012 NIR-UNECE.mdb are identical to the fuel consumption and emission totals from the CRF.

3.3.7 Recalculations and improvements

The following recalculations and improvements of the emission inventories have been made since the emission reporting in 2012.

Road transport
Based on the updated version of COPERT IV launched in 2013, new vehicle sub categories have been introduced in the emission inventories for mopeds and passenger cars. For mopeds a division is now made between 2-stroke and 4-stroke engine technologies and for passenger cars small engine sizes below 0.8 l. for gasoline and below 1.4 l. for diesel have been included. Also NO_x emission factors for euro 5 diesel passenger cars have been updated in the model based on the new COPERT IV version.

Small errors in input gasoline fuel consumption for the years 2009-2011 and for input diesel fuel consumption in the years 2010-2011 have been corrected.

The percentage emission change interval and year of largest percentage differences (low %; high %, year) for the different emission components are: CO_2 (-0.5 %; -0.05 %, 2008), CH_4 (-0.2 %; 2.4 %, 2011) and N_2O (-0.4 %; 0.3 %, 2008).

Navigation
Minor changes in ferry input data has been made for the years 2008-2011 causing minor emission changes for domestic navigation. The following largest percentage differences (in brackets) for domestic navigation are noted for: CO_2 (-1.0 %), CH_4 (-0.8 %) and N_2O (-1.1 %).

Agriculture**/forestry/fisheries**
The number and engine size of machine pool tractors has been updated for the years 2007-2011. The number of ATV's has been changed for the years 2009-2011.

Errors in the fuel consumption for fisheries in 2000, 2010 and 2011 have been corrected.

In 2000 the following percentage differences (in brackets) for agriculture/forestry/fisheries are noted for: CO_2 (9.1 %), CH_4 (3.7 %) and N_2O (11.9 %) due to fuel consumption changes in fisheries. For other years than 2000, the following largest percentage differences (in brackets) are noted for: CO_2 (-3.7 %), CH_4 (5 %) and N_2O (-4.9 %).

Industry

The number of mini loaders has been updated for the years 2004-2011.

The following largest percentage differences (in brackets) for industrial non road machinery are noted for: CO_2 (1.0 %), CH_4 (1.6 %) and N_2O (1.6 %).

Civil aviation

An error in the CH_4 emission factor has been corrected for the years 1985-2000. The emission factors are now in line with the factors proposed by the EMEP/EEA emission inventory guidebook. The CH_4 emission percentage differences are between -31 % and -42 %.

Military

Emission factors derived from the new road transport simulations have caused some emission changes from 1985-2010.The following largest percentage differences (in brackets) for military are noted for: CO_2 (0 %), CH_4 (0.6 %) and N_2O (0.2 %).

3.3.8 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.

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3.4 Additional information, CRF sector 1A Fuel combustion

Reference approach, feedstocks and non-energy use of fuels

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 IPCC Reference Manual (IPCC, 1997). 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.

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, 2013). 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, 1997). The country-specific emission factors are not used in the reference approach, the approach being for the purposes of verification. The emission factor for fossil waste is, however, based on the emission factor applied in the national approach.

The Climate Convention reporting tables include a comparison of the national approach and the reference approach estimates. To make results comparable, the incineration of fossil waste and the corresponding CO_2 emission have been added in the reference approach. Furthermore, consumption for non-energy purposes is subtracted in the reference approach, because non-energy use of fuels is included in other sectors (Industrial processes and Solvent use) in the Danish national approach. The consumption for non-energy purposes have been subtracted in the reference approach by setting the fraction of carbon stored equal to 1.00 for fuels used for non-energy purposes.

Three fuels are used for non-energy purposes: lubricants, bitumen and white spirit. The total consumption for non-energy purposes is relatively low – 11.5 PJ in 2012.

The CO_2 emission from oxidation of lube oil during use was 32 Gg in 2012 and this emission is reported in the industrial processes sector. The reported emission corresponds to 20 % of the CO_2 emission from lube oil consumption assuming full oxidation. This is in agreement with the 2006 IPCC Guidelines (IPCC, 2006) methodology for lube oil emissions. Methodology and emission data for lube oil are shown in NIR Chapter 4.8.

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 indrect CO_2 emission from white spirit was 17 Gg in 2012 corresponding to 62 % of the CO_2 emission from white spirit assuming full oxidation. The NMVOC emission data for white spirit are shown in NIR Chapter 5, Table 5.4.

The CO_2 emission from bitumen is included as part of the emission from the source sectors *2A5 Asphalt roofing* and *2A6 Road paving with asphalt*.

According to IPCC Good Practice Guidance (IPCC, 2000) the difference should be within 2 %. A comparison of the national approach and the reference approach is illustrated in Figure 3.4.1.

In 2012, the fuel consumption rates in the two approaches differ by 0.97 % and the CO_2 emission differs by 0.97 %. In the period 1990-2012 both the fuel consumption and the CO_2 emission differ by less than 2.0 %. The differences are below 1% for all years except 1998, 2001, 2009 and 2011. The results from the national approach and the reference approach are compared in Figure 3.4.1.

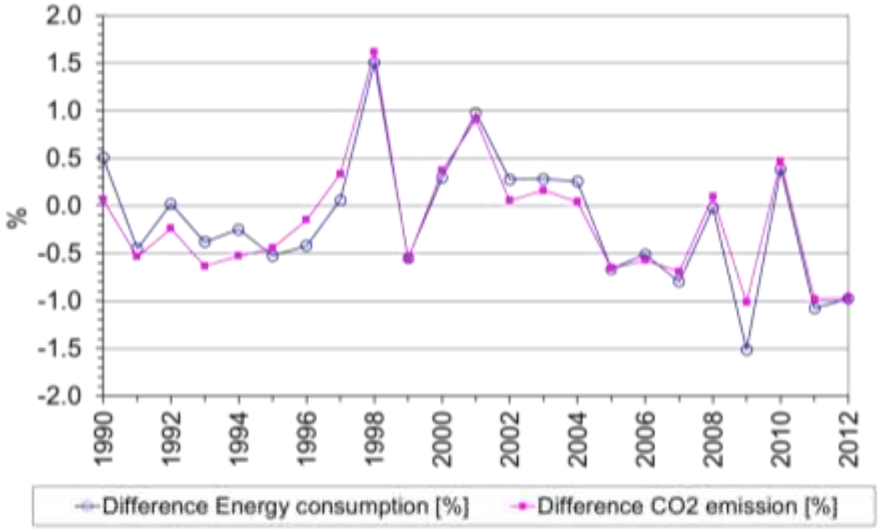

Figure 3.4.1 Comparison of the reference approach and the national approach.

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 and 2009 are due to high statistical differences in the Danish energy statistics in these years.

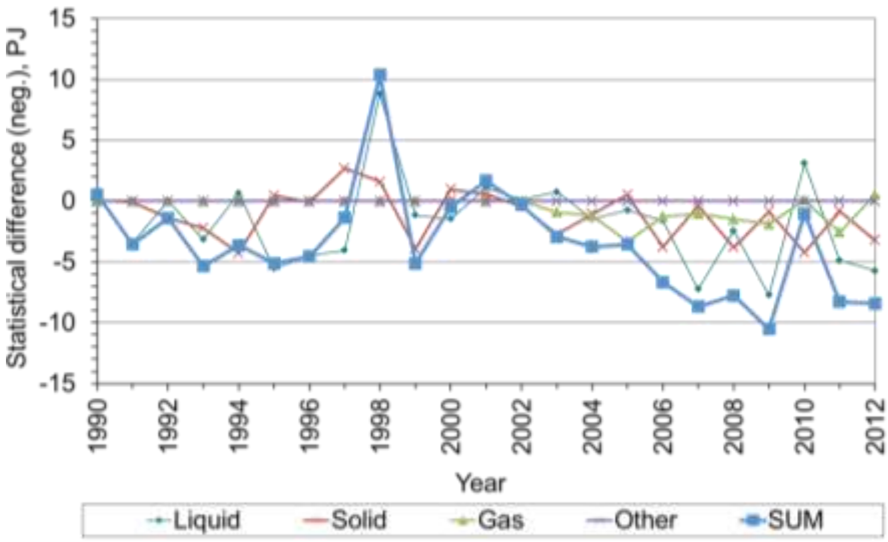

Figure 3.4.2 Statistical difference in the Danish energy statistics (DEA, 2013).

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3.5 Fugitive emissions (CRF sector 1B)

Fugitive emissions from fuels include emissions from production, storage, refining and transport of oil and natural gas. Emissions from solid fuels are not occurring in Denmark. 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 with the fugitive emissions share of national total emission.

Table 3.5.1 National and fugitive emissions of CO_2, CH_4 N_2O and GHG in 2012, and the fugitive emissions share of national total emissions.

Compound	National emission		Fugitive emission		Fugitive/national emission	
CO_2	39 412	Gg	221	Gg	0.6	%
CH_4	261	Gg	5.0	Gg	1.9	%
N_2O	19	Gg	0.002	Gg	0.01	%
GHG	51 637	Gg CO_2 eqv.	327	Gg CO_2 eqv.	0.6	%

The key category analysis shows that CO_2 from offshore flaring is a Tier 1 Level key category in 1990 and 2012. Further CH_4 from Refinery processes is a Tier 2 Trend key source in 1990-2012 (Table 3.5.2).

Table 3.5.2 Key categories in the fugitive emission sector.

CRF table	Pollutant	Emission source	Key category identification	
			Tier 1	Tier 2
1.B.2	CO_2	Flaring in refinery	-	-
1.B.2	CO_2	Flaring off-shore	Level 1990 and 2012	-
1.B.2	CO_2	Land based activities	-	-
1.B.2	CO_2	Off-shore activities	-	-
1.B.2	CO_2	Transmission of natural gas	-	-
1.B.2	CO_2	Distribution of natural gas	-	-
1.B.2	CO_2	Venting in gas storage	-	-
1.B.2	CH_4	Flaring in refinery	-	-
1.B.2	CH_4	Flaring off-shore	-	-
1.B.2	CH_4	Refinery processes	-	Trend 1990-2012
1.B.2	CH_4	Land based activities	-	-
1.B.2	CH_4	Off-shore activities	-	-
1.B.2	CH_4	Transmission of natural gas	-	-
1.B.2	CH_4	Distribution of natural gas	-	-
1.B.2	CH_4	Venting in gas storage	-	-
1.B.2	N_2O	Flaring in refinery	-	-
1.B.2	N_2O	Flaring off-shore	-	-

Calculations of fugitive emissions are mainly based on Tier 3 methodologies. Only calculation of emissions from Onshore loading of ships and distribution of oil products are using Tier 2 and Tier 1 methodologies. In accordance with the IPCC Good Practice Guidance (2000) emission calculations for fugitive key sources are done using higher methodological tiers than Tier 1. The applied methodologies 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
1B2a ii	Oil – Production , Offshore activities	CO_2	Tier 3	D
		CH_4	Tier 3	OTH (EMEP/EEA 2013)
		NMVOC	Tier 3	OTH (EMEP/EEA 2013)
1B2a ii	Oil – Production , Onshore activities	CO_2	Tier 2, Tier 3	D
		CH_4	Tier 2, Tier 3	PS, OTH (EMEP/EEA 2013)
		NMVOC	Tier 2, Tier 3	PS, OTH (EMEP/EEA 2013)
1B2a iv	Oil - Refining /Storage	CH_4	Tier 3	PS
		NMVOC	Tier 3	PS
		SO_2	Tier 3	PS
1B2a v	Oil - Distribution of oil products	NMVOC	Tier 1	CS
1B2b	Natural gas	CO_2	Tier 3	CS
		CH_4	Tier 3	CS
		NMVOC	Tier 3	CS
1B2c	Venting /flaring	CO_2	Tier 3	PS *
		CH_4	Tier 3	PS, OTH (EMEP/EEA 2009)
		N_2O	Tier 3	D, OTH (OLF, 1993)
		NO_x	Tier 3	PS **, CS, OTH (EMEP/EEA 2009)
		CO	Tier 3	OTH (EMEP/EEA 2009)
		NMVOC	Tier 3	PS, CS, OTH (EMEP/EEA 2009)
		SO_2	Tier 3	CS

PS: plant specific. CS: country specific, D: default (IPCC, 2000), OTH: other.
* Plant specific emission factors are available from the EU ETS from 2006 and forward. For earlier years country specific emission factors are applied.
** Plant specific emission factors are available for one refinery.

3.5.1 Source category description

According to the IPCC sector definitions the category *fugitive emissions* is a sub-category under the main-category Energy (Sector 1). The category *fugitive emissions* (Sector 1B) is segmented into sub-categories covering emissions from solid fuels (coal mining and handling (1B1a), solid fuel transformation (1B1b) and other (1B1c)) and from oil and natural gas (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 is not occurring in Denmark. Therefore only emissions of particulate matter from storage and handling of coal are considered.
- 1B2a: Fugitive emissions from oil include emissions from extraction, storage, and transmission of crude oil, distribution of oil products and fugitive emissions from refining. Emission data for offshore extraction of oil and gas are not available separately, and consequently emissions from gas extraction are included in 1B2a
- 1B2b: Fugitive emissions from natural gas include emissions from transmission and distribution of natural gas. Emissions from gas extraction are included in1B2a.
- 1B2c: Venting and flaring include activities onshore and offshore. Flaring occur both offshore and onshore in gas treatment and storage plants and in refineries. Venting occurs in gas storage plants. Venting of gas is assumed to be negligible in extraction and in refineries as controlled venting enters the gas flare system.

Activity data, emission factors and emissions are stored in the Danish emission database on SNAP sector categories (Selected Nomenclature for Air Pollution). In Table 3.5.4 the corresponding SNAP codes and IPCC sectors relevant to fugitive emissions are shown. Further, the table holds the SNAP names for the SNAP codes and the overall activity (e.g. oil and natural gas).

Table 3.5.4 List of the IPCC sectors and corresponding SNAP codes for the categories included in the Danish emission inventory model.

IPCC sectors	SNAP code	SNAP name	Activity
1 B 1 a	050103 *	Storage of solid fuel	Coal mining and handling
1 B 2 a ii	050201	Land-based activities	Oil
1 B 2 a ii	050202 **	Offshore activities	Oil
1 B 2 a iv	040101	Petroleum products processing	Oil
1 B 2 a iv	040103	Other	Oil
1 B 2 a v	050503	Service stations (including refuelling of cars)	Oil
1 B 2 b iii	050601	Pipelines	Natural gas
1 B 2 b iv	050603	Distribution networks	Natural gas
1 B 2 c 2 i	090203	Flaring in oil refinery	Flaring
1 B 2 c 2 ii	050699	Venting in gas storage	Venting
1 B 2 c 2 ii	090206	Flaring in oil and gas extraction	Flaring

*Only relevant for emissions of particulate matter from storage and handling of coal.

**In the Danish inventory emissions from extraction of gas are united under "Extraction, 1st treatment and loading of liquid fossil fuels/offshore activities" (IPCC 1B2a / SNAP 050202).

Table 3.5.5 summarizes the Danish fugitive emissions in 2012. The methodologies, activity data and emission factors used for calculation are described in the following chapters.

Table 3.5.5 Summary of the Danish fugitive emissions 2012. P refers to point source and A to area source.

IPCC code	SNAP code	Source	Pollutant	Emission	Unit
1B2a i	050201	A	NMVOC	*1 948*	Mg
1B2a i	050201	A	CH_4	*837*	Mg
1B2a i	050201	A	CO_2	*<0.1*	Gg
1B2a i	050202	A	NMVOC	*1 891*	Mg
1B2a i	050202	A	CH_4	*1 744*	Mg
1B2a i	050202	A	CO_2	*4*	Gg
1B2a iv	040101	P	SO_2	*0 **	Mg
1B2a iv	040101	P	NMVOC	*3 932*	Mg
1B2a iv	040101	P	CH_4	*2 227*	Mg
1B2a iv	040103	P	SO_2	*889*	Mg
1B2a v	050503	A	NMVOC	*977*	Mg
1B2b iii	050601	A	NMVOC	*4*	Mg
1B2b iii	050601	A	CH_4	14	Mg
1B2b iii	050601	A	CO_2	< 0.1	Gg
1B2b iv	050603	A	NMVOC	*57*	Mg
1B2b iv	050603	A	CH_4	*147*	Mg
1B2b iv	050603	A	CO_2	*< 0.1*	Gg
1B2c	050699	P	NMVOC	*20*	Mg
1B2c	050699	P	CH_4	*57*	Mg
1B2c	050699	P	CO_2	*< 0.1*	Gg
1B2c	090203	P	SO_2	*167*	Mg
1B2c	090203	P	NO_x	*23*	Mg
1B2c	090203	P	NMVOC	*32*	Mg
1B2c	090203	P	CH_4	*7*	Mg
1B2c	090203	P	CO	*74*	Mg
1B2c	090203	P	CO_2	*22*	Gg
1B2c	090203	P	N_2O	*0.2*	Mg
1B2c	090206	A	SO_2	*1*	Mg
1B2c	090206	A	NO_x	*87*	Mg
1B2c	090206	A	NMVOC	*8*	Mg
1B2c	090206	A	CH_4	*15*	Mg
1B2c	090206	A	CO	*75*	Mg
1B2c	090206	A	CO_2	*192*	Gg
1B2c	090206	A	N_2O	*1*	Mg
1B2c	090206	P	SO_2	*<0.1*	Mg
1B2c	090206	P	NOx	*9*	Mg
1B2c	090206	P	NMVOC	*0.3*	Mg
1B2c	090206	P	CH_4	*0.5*	Mg
1B2c	090206	P	CO	*1*	Mg
1B2c	090206	P	CO_2	*2*	Gg
1B2c	090206	P	N_2O	*<0.1*	Mg

* From 2001 SO_2 emissions from oil refining are included in stationary combustion.

3.5.2 Methodological issues

The following chapters give descriptions on the methods of calculation used in the Danish emission inventory. Further, the activity data and emission factors that form the basis for the calculations are described according to data source and values.

Test 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, offshore 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. The EU ETS data used are fully in line with the requirements in the IPCC good practice guidance 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 Chapter 1.4.10. 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 good practice guidance have been selected to ensure time series consistency. This is described in the specific sections.

***Refineries*:**

Activity data are measured with flow meters and amounts are reported with high accuracy and the oxidation factor is set to 1. CO_2 emission factors are calculated according to the relevant Tier given in the EU Commission Decision of 18 July 2007 (EU Commission, 2007). For combustion of fuel gas, 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 of flare gas.

***Offshore installations*:**

Activity data are measured with flow meters and amounts are reported with high accuracy (± 1.5 % for combustion and ± 7.5 – ± 17.5 % for flare). The oxidation factor is set to 1. CO_2 emission factors are calculated according to the relevant Tier given in the EU Commission Decision of 18 July 2007 (EU Commission, 2007). For combustion of fuel gas the Tier 3 methodology, which is activity specific, is applied, while the country specific Tier 2a methodology is applied for diesel. CO_2 emissions factors for flaring are calculated using the Tier 3 methodology based on the measured carbon contents of flare gas.

Fugitive emissions from oil (1B2a)

The emissions from oil derive from offshore activities (extraction of oil and gas, and offshore loading of ships), onshore activities (storage and handling at the raw oil terminal, and onshore loading of ships), service stations and refineries. In the case of service stations emissions from reloading of tankers and refuelling of vehicles are included. The emissions from refineries derive from petroleum products processing (oil refining). Emissions from flaring in refineries are included in the chapters concerning flaring.

Activities

Fugitive emissions from oil include emissions from extraction, the raw oil terminal, and onshore and offshore loading of ships.

The total emission can be expressed as:

$$E_{total} = E_{extraction} + E_{shiploading} + E_{oil\,terminal} \quad \text{(Eq. 3.5.1)}$$

Fugitive emissions from extraction

According to the EMEP/EEA Guidebook (EMEP/EEA, 2009) the total fugitive emissions of volatile organic compounds (VOC) from extraction of oil and gas can be estimated by means of equation 3.5.2.

$$E_{extraction,VOC} = 40.2 \cdot N_P + 1.1 \cdot 10^{-2} P_{gas} + 8.5 \cdot 10^{-6} \cdot P_{oil} \quad \text{(Eq. 3.5.2)}$$

where $E_{extraction,VOC}$ is the emission of VOC in Mg pr year, N_P is the number of platforms, P_{gas} is the production of gas, 10^6 Nm^3 and P_{oil} is the production of oil, 10^6 tonnes.

It is assumed that the VOC contains 75 % methane (CH_4) and 25 % NMVOC (EMEP/EEA, 2013), and in consequence the total emission of CH_4 and NMVOC for extraction of oil and gas can be calculated as:

$$E_{extraction,CH_4} = 0.75 \cdot E_{extraction,VOC} \quad \text{(Eq. 3.5.3)}$$

$$E_{extraction,NMVOC} = 0.25 \cdot E_{extraction,VOC} \quad \text{(Eq. 3.5.4)}$$

Loading of ships

Fugitive emissions of CH_4 and NMVOC from loading of ships include the transfer of oil from storage tanks or directly from the well into ships. The activity also includes losses during transport. When oil is loaded hydrocarbon vapour will be displaced by oil and new vapour will be formed, both leading to emissions. The emissions from ships are calculated by equation 3.5.5.

$$E_{ships} = EF_{ships,onshore} \cdot L_{oil,onshore} + EF_{ships,offshore} \cdot L_{oil,ofshore} \quad \text{(Eq. 3.5.5)}$$

where EF_{ships} is the emission factor for loading of ships offshore and onshore and L_{oil} is the amount of oil loaded.

Raw oil terminal

The CH_4 and NMVOC emissions from storage and handling of oil are given in the environmental reports from DONG Oil Pipe A/S for 2012 (DONG Oil Pipe A/S, 2013). An implied emission factor is calculated for use in the reporting template on the basis of the amount of oil transported in pipelines according to equation 3.5.6.

$$IEF_{tanks} = \frac{E_{tanks}}{T_{oil}} \quad \text{(Eq. 3.5.6)}$$

where IEF_{tanks} is the implied emission factor for storage of raw oil in tanks, E_{tanks} is the emission and T_{oil} is the amount of oil transported in pipelines.

H5 Service stations

NMVOC emissions from service stations are estimated as outlined in equation 3.5.7.

$$E_{service\,stations} = \left(EF_{reloading} \cdot T_{fuel}\right) + \left(EF_{refuelling} \cdot T_{fuel}\right) \quad \text{(Eq.3.5.7)}$$

where $EF_{reloading}$ is the emission factor for reloading of tankers to underground storage tanks at the service stations, $EF_{refuelling}$ is the emission factor for refuelling of vehicles and T_{fuel} is the amount of gasoline used for road transport.

Oil refining

When oil is processed in the refineries, part of the volatile organic compounds (VOC) is emitted to the atmosphere. The VOC emissions from the petroleum refinery process include non-combustion emissions from handling and storage of feedstock (raw oil), from the petroleum product processing and from handling and storage of products. Emissions from flaring in refineries are included under "Flaring". Emissions related to process furnaces in refineries are included in stationary combustion with the relevant emission factors. When only the total VOC emission is given by the refinery the emission of CH_4 and NMVOC is estimated due to the assumption that 10 % of VOC is CH_4 and the remaining 90 % is NMVOC (Hjerrild, 1997).

Both the non-combustion processes including product processing and sulphur recovery plants emit SO_2. The SO_2 emissions are calculated by the refineries and implemented in the emission inventory without further calculation.

Fugitive emissions from gas (1B2b)

Transmission and distribution of gas

The fugitive emission from transmission, storage and distribution is based on information from the gas companies. The transmission and distribution companies give data on the transported amount and length and material of the pipeline systems. The fugitive losses from pipelines are provided by the transmission company. The natural gas and town gas distribution companies don't include fugitive losses in their annual reports, but only the total gas loss including measure uncertainty, erroneous debited customers and displacements between production periods and settlement period. The share of the total gas loss owing to fugitive losses is estimated based on further information from one of four Danish distribution companies and used for the remaining companies. From the fugitive losses of natural gas from transmission and distribution pipelines the emissions of CH_4 and NMVOC are calculated based on the gas quality measured by Energinet.dk. The same approach is used for town gas, which is natural gas admixed ~ 50 % ambient air.

Flaring

Emissions from flaring are estimated from the amount of gas flared offshore, in gas treatment/storage plants and in refineries and from the corresponding emission factors. From 2006 data on offshore flaring (flared amounts, calorific values and CO_2 emission factors) are given in the reports under the EU ETS and thereby flaring can be split to the individual production units. For previous years only the total flared amount are available.

3.5.3 Activity data

Extraction of oil and gas and loading of ships

Activity data used in the calculations of the emissions from oil and gas production and loading of ships are shown in Table 3.5.6. Data are based on information from the Danish Energy Agency (2013a) and from the environmental reports from DONG Oil Pipe A/S (DONG Oil Pipe A/S, 2013).

Table 3.5.6 Activity data for 2012.

Activity	Symbols	Amounts	Data source
Number of platforms	N_p	54	Danish Energy Agency, 2013a
Produced gas, 10^6 Nm^3	P_{gas}	5 617	Danish Energy Agency, 2013a
Produced oil, 10^3 m^3	$P_{oil,vol}$	11 728	Danish Energy Agency, 2013a
Produced oil, 10^3 tonnes	P_{oil}	10 086	Danish Energy Agency, 2013a
Oil loaded, 10^3 m^3	$L_{oil\ offshore}$	1 549	Danish Energy Agency, 2013a
Oil loaded, 10^3 tonnes	$L_{oil\ offshore}$	1 332	Danish Energy Agency, 2013a
Oil loaded, 10^3 m^3	$L_{oil\ on\text{-}shore}$	10 500	DONG Oil Pipe A/S, 2013
Oil loaded, 10^3 tonnes	$L_{oil\ on\text{-}shore}$	9 030	DONG Oil Pipe A/S, 2013

Density of crude oil = 0.86 tonnes per m^3

As seen in Figure 3.5.1 the production of oil and gas in the North Sea has generally increased in the years 1990-2004. Since 2004 the production has decreased. The number of platforms is yet still increasing (Figure 3.5.2). 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.

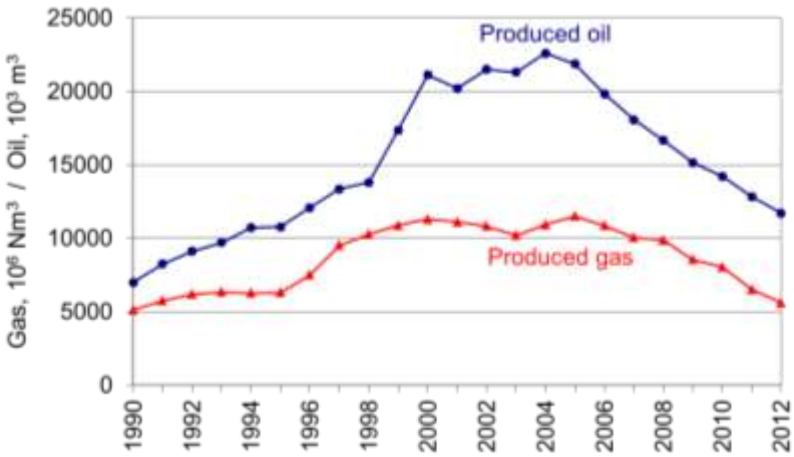

Figure 3.5.1 Production of oil and gas in the Danish part of the North Sea.

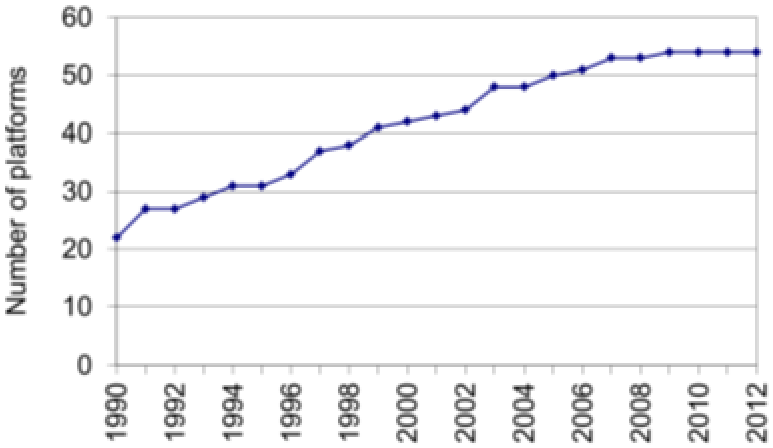

Figure 3.5.2 The number of platforms in the Danish part of the North Sea.

The amounts of oil loaded offshore on ships roughly follow the trend of the oil and gas production (Figure 3.5.3). In case of onshore loading of ships the trend is more smoothed.

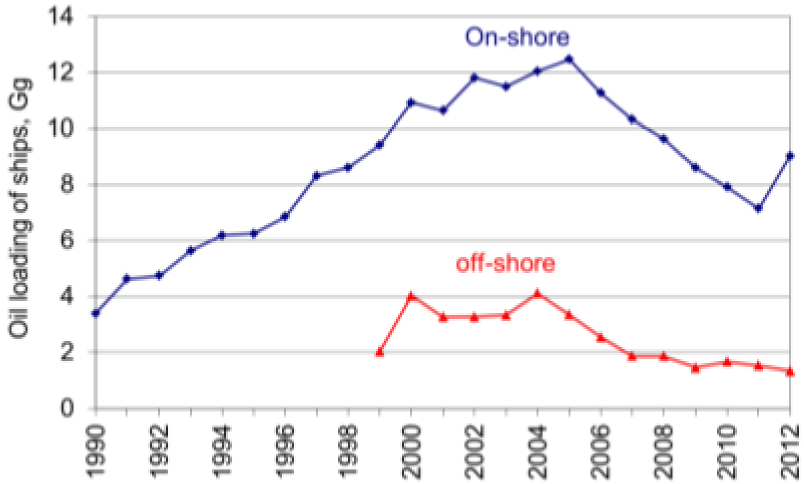

Figure 3.5.3 Onshore and offshore loading of ships.

Oil refining

Data on the amount of crude oil processed in the two Danish refineries are given by the refineries in their annual environmental report (A/S Dansk Shell, 2013 and Statoil A/S, 2013). Until 1996 a third refinery was in operation, leading to a decrease in the processed crude oil amount from 1996 to 1997. Data are shown in Figure 3.6.4. The amount of crude oil being processed was 7 894 Gg in 2012.

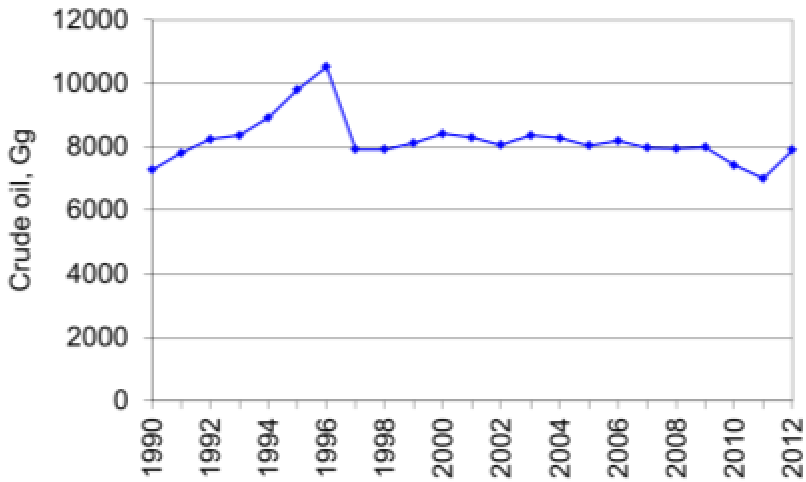

Figure 3.5.4 Oil refineries. Processed crude oil in Danish refineries.

Service stations

The Danish Energy statistics contains data on the sale of gasoline that are the basis for estimating emissions of NMVOC from service stations. The gasoline sales show an increase from 1990-1998 and a decreasing trend since 1999 as shown in Figure 3.5.5. In 2012 the gasoline sale was 1 389 Gg.

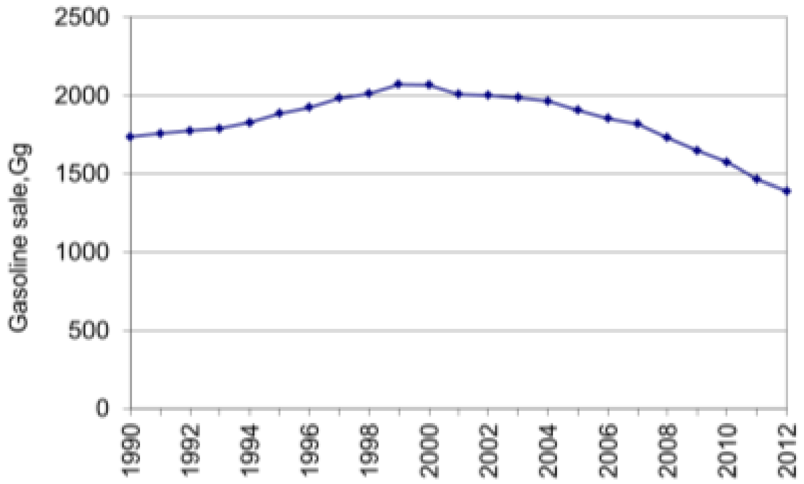

Figure 3.5.5 Gasoline sales in Denmark.

Transmission, storage and distribution of gas

The activity data used in the calculation of the emissions from natural gas are shown in Table 3.5.7. 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 2003, Karll 2005, Oertenblad 2006, Oertenblad 2007). From 2008 onwards transmission rates refer to Energinet.dk. 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.

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 2003, Karll 2005, Oertenblad 2006, Oertenblad 2007). Since 2007 the distribution rates are given by the companies. Distribution rates for town gas is based on the available data from the Danish town gas distribution companies of which more are closed down today. Distribution losses for 1990-2000 are based on annual environmental report of DONG Energy. For 2000-2006 the average losses-% for the gas distribution companies are used. From 2007 data on distribution losses available from the companies are used.

Table 3.5.7 Activity data on transmission and distribution of gas for selected years of the time series. Town gas is included in distribution.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
Transmission, Mm3 *	2 739	4 689	7 079	7 600	7 565	6 500	7 462	6 181	5 365
Distribution of natural gas, Mm3 **	1 714	3 054	3 181	3 265	3 113	2 870	3 416	2 933	2 728
Distribution of town gas, Mm3 ***	35	35	34	32	22	20	22	21	24

* Transmission rates for 1990-1998 refer to the annual environmental report of DONG Energy. In 1999-2006 transmission rates refer to the Danish Gas Technology Centre (Karll 2003, Karll 2005, Oertenblad 2006, Oertenblad 2007). From 2008 onwards transmission rates refer to Energinet.dk.

**) In 1990-98 distribution rates 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 2003, Karll 2005, Oertenblad 2006, Oertenblad 2007). Since 2007 the distribution rates are given by the companies.

***) The distribution of town gas is based on the available data from the Danish town gas distribution companies of which more are closed down today.

In 2012 the gas transmission was 5 365 Mm_n^3 and the distribution rate is 2 752 Mm_n^3, hereof 24 Mm_n^3 town gas (Figure 3.5.6). 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.

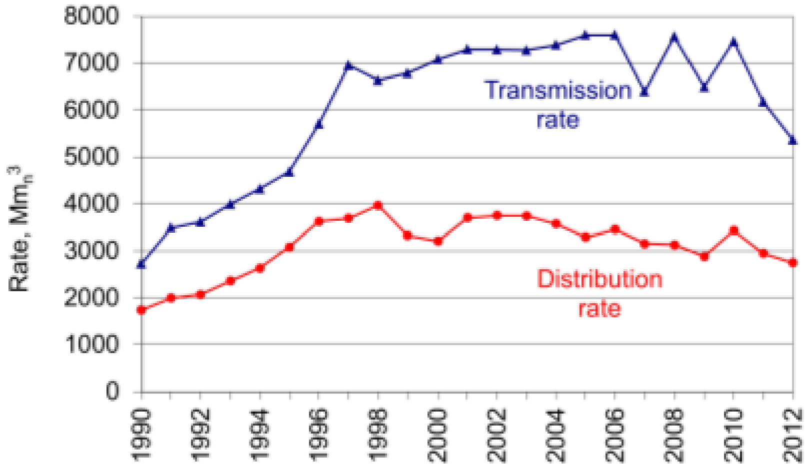

Figure 3.5.6 Rates for transmission and distribution of gas. Distribution cower both natural gas and town gas.

Data on the transmission pipelines excluding offshore pipelines and on the distribution network are given by Energinet.dk, DGC and the distribution companies concerning length and material. The length of the transmission pipelines is approximately 900 km. Because the distribution system in Denmark is relatively new most of the distribution network is made of plastic (PE). In 2012 the length of the distribution network was around 20 000 km. The major part is made of plastic (approximately 90 %) and the remaining part is made of steel. 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 greater. 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. It must be noted that two town gas distribution companies have been closed in recent years (one in 2004 and another in 2006). There are only two town gas distribution companies left, and therefore the data availability is scarce.

Venting and flaring

Venting

In Denmark there are two natural gas storage facilities. Both are obligated to make an environmental report on annual basis. Data on gas input and withdrawal are included and were 445 Mm^3 and 634 Mm^3 in 2012, respectively. Venting and flaring at the gas storage plants are included in the inventory. 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 facilities are shown in Figure 3.4.8. As venting rates are not available for the years 1990-1994, the average for 1995-1998 is used.

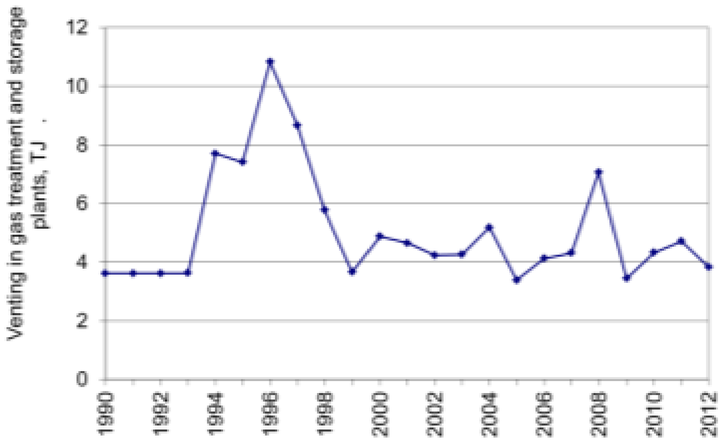

Figure 3.5.7 Amount vented in gas treatment and storage plants.

Flaring

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 amounts are given in the EU ETS reporting. Activity data for flaring in refineries are shown in Figure 3.5.8. Data are not available for the years 1990-1993. The flaring amount for 1994 has been adopted for the previous years. Use of a mean value for the following five or ten years as applied for e.g. flaring in storage and treatment plants are not appropriate in this case, as one of three refineries was closed down in 1996.

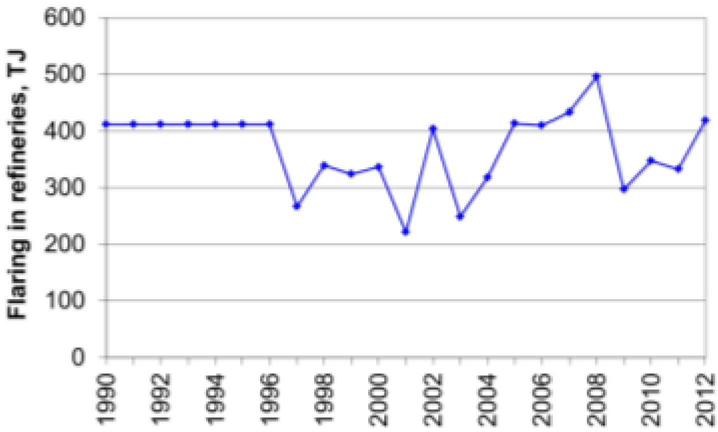

Figure 3.5.8 Amount flared in refineries (annual environmental reports from A/S Dansk Shell and Statoil A/).

Offshore flaring amounts are given in Denmark's oil and gas production (Danish Energy Agency, 2013a) while flaring in treatment/storage plants are given in environmental reports by Dong Energy and Energinet.dk (Dong Energy, 2013a,b; Energinet.dk, 2013a). Flaring rates are shown in Figure 3.5.9 and 3.5.10.

Flaring rates in gas treatment and gas storage plants are not available until 1994. The mean value for the following five years (1994 to 1998) has been adopted as basis for the emission calculation for the years 1990-1993. The large amount of flared gas in 2007 owe to a larger maintenance work at the gas treatment plant.

Figure 3.5.9 Amount flared in gas treatment and storage plants.

Offshore flaring amounts have been decreasing over the last 10 years period in accordance with the decrease in production as seen in Figure 3.5.1. Further, there is focus on reduction of the amount being flared for environmental reasons.

Figure 3.5.10 Amounts of gas flared in offshore exploration.

3.5.4 Emission factors

Extraction of oil and gas and loading of ships

Emissions of CH_4 and NMVOC from extraction of oil and gas are calculated from standard formula as listed in equation 3.5.3 and 3.5.4. Emissions of CO_2 from extraction of oil and gas and from transport of oil in pipelines are based on the emission factor from IPCC Good Practice Guidance (IPCC, 2000). IEF for extraction and pipeline oil are shown in Table 3.5.8.

Table 3.5.8 Implied emission factors for CO_2, CH_4 and NMVOC for extraction and storage/transport of oil.

	CO_2, g/Mg crude oil	CH_4, g/Nm3 crude oil transported via pipeline	NMVOC, g/Nm3 crude oil transported via pipeline
Extraction *	367	24.0	8.0
Pipeline oil **	0.53	70.3	54.5

* Based on EMEP/EEA, 2009 and Danish Energy Agency, 2012a.

** Default EF for CO_2 from IPCC, 2000, and IEF for CH_4 and NMVOC from DONG Oil Pipe A/S, 2013.

In the EMEP/EEA Guidebook standard emission factors for different countries are given (EMEP/EEA, 2013). In the Danish emission inventory the Norwegian emission factors are used for estimation of fugitive emissions from loading of ships onshore and offshore for the years 1990-2009. During 2009 new emission reducing technologies (degassing unit) were installed at the crude oil terminal. Measurements were carried out at the terminal before and after installation show a decrease of 21 % of the CH_4 emission and 25 % of the NMVOC emission from loading of ships. The reduced emission factors used for 2010 onwards are listed in Table 3.5.9.

Table 3.5.9 Emission factors for loading of ships onshore and offshore.

	CH_4, fraction of loaded		NMVOC, fraction of loaded	
	1990-2009	2010 onwards	1990-2009	2010 onwards
Ships offshore *	0.00005	0.00005	0.001	0.001
Ships on-shore **	0.00001	0.0000079	0.0002	0.00015

* EMEP/EEA, 2013.

** EMEP/EEA, 2013; Miljøcenter Odense, 2010.

Oil refining

The refineries deliver information on consumption of fuel gas and fuel oil. The calorific values are given by the refineries in the reporting to the EU ETS from 2006. Before 2006 the calorific values given by the refineries were used when available. When not available standard calorific values given in the basic data tables from the Danish Energy Agency combined with the conversion factor between fuel gas and fuel oil given by the refinery were used for calculation.

Emissions of SO_2, NO_x and VOC are given 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 and the remaining 90 % is NMVOC (Hjerrild, 1997).

Service stations

The NMVOC emission from service stations is calculated by use of different emission factors for the time series as shown in Table 3.5.10. In 1994 the emission factors for NMVOC from service stations were investigated by Fenhann and Kilde (1994) for the years 1990, 1991 and 1992, individually. The emission factors reported for reloading and refuelling for 1990 were used for the years 1985-1990, while the emission factors for 1991 was used for that year only. For the years 1992-1995 only emission factor for refuelling reported by Fenhann and Kilde (1994) was used in the Danish emission inventory. For reloading of tankers the British emission factor - as given in the UK Emission Factor Database - was adopted for the years 1992-2000. From 2008 the emission factors from the EMEP/EEA guidebook 2009 are used for reloading and refuelling. For the years 2001-2007 and 1996-2007 the emission factors for reloading and refuelling, respectively, are estimated by using interpolation.

Table 3.5.10   Emission factors used for estimating NMVOC from service stations.

Year	Reloading of tankers, kg NMVOC pr tonnes gasoline	Refuelling of vehicles, kg NMVOC pr tonnes gasoline	Sum of reloading and refuelling, kg NMVOC pr tonnes gasoline	Source (reloading/refuelling)
1985-1990	1.28	1.52	2.80	Fenhann & Kilde,1994 / Fenhann & Kilde,1994
1991	0.64	1.52	2.16	Fenhann & Kilde,1994 / Fenhann & Kilde,1994
1992-1995	0.08	1.52	1.60	UK emf. database / Fenhann & Kilde,1994
1996	0.08	1.45	1.53	UK emf. database / interpolation 1995-2008
1997	0.08	1.39	1.47	UK emf. database / interpolation 1995-2008
1998	0.08	1.32	1.40	UK emf. database / interpolation 1995-2008
1999	0.08	1.25	1.33	UK emf. database / interpolation 1995-2008
2000	0.08	1.19	1.27	UK emf. database / interpolation 1995-2008
2001	0.077	1.12	1.20	Interpolation 2000-2008 / 1995-2008
2002	0.073	1.05	1.13	Interpolation 2000-2008 / 1995-2008
2003	0.070	0.99	1.05	Interpolation 2000-2008 / 1995-2008
2004	0.067	0.92	0.98	Interpolation 2000-2008 / 1995-2008
2005	0.063	0.85	0.91	Interpolation 2000-2008 / 1995-2008
2006	0.060	0.78	0.84	Interpolation 2000-2008 / 1995-2008
2007	0.056	0.72	0.77	Interpolation 2000-2008 / 1995-2008
2008 onwards	0.053	0.65	0.70	EMEP/EEA 2013 / EMEP/EEA 2013

Transmission, storage and distribution of gas

The fugitive emissions from transmission, storage and distribution 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 (Table 3.5.11). For distribution of town gas the emission factor is reduced due to the admixture of 50 % atmospheric air to the natural gas.

Table 3.5.11 Annual gas composition, lower heating value and density for Danish natural gas (Energinet.dk).

		Unit	1990	2000	2005	2008	2009	2010	2011	2012
Methane	CH_4	molar-%	90.92	86.97	88.97	89.80	90.08	89.95	89.10	88.84
Ethane	C_2H_6	molar-%	5.08	6.88	6.14	5.77	5.70	5.71	5.98	6.11
Propane	C_3H_8	molar-%	1.89	3.17	2.50	2.26	2.17	2.19	2.36	2.44
i-Butane	i-C_4H_{10}	molar-%	0.36	0.43	0.40	0.37	0.37	0.37	0.37	0.37
n-Butane	n-C_4H_{10}	molar-%	0.50	0.61	0.55	0.53	0.52	0.54	0.55	0.54
i-Petane	i-C_5H_{12}	molar-%	0.14	0.11	0.11	0.13	0.13	0.13	0.13	0.13
n-Petane	n-C_5H_{12}	molar-%	0.10	0.08	0.08	0.08	0.08	0.08	0.09	0.08
n-Hexane and heavier hydrocarbons	C^{6+}	molar-%	0.09	0.06	0.05	0.06	0.06	0.06	0.06	0.06
Nitrogen	N_2	molar-%	0.31	0.34	0.29	0.30	0.29	0.31	0.37	0.36
Carbon dioxide	CO_2	molar-%	0.60	1.35	0.90	0.71	0.59	0.66	0.98	1.06
Lower heating value	H_n	MJ/m^3_n	39.176	40.154	39.671	39.485	39.459	39.461	39.507	39.548
Density	ρρ	kg/m^3_n	0.808	0.846	0.825	0.817	0.814	0.816	0.824	0.827

Venting and flaring

Venting

CH_4 and NMVOC emissions from venting are given in the environmental reports for the gas storage facilities (DONG Energy, 2013a; Energinet.dk, 2013a). CO_2 emissions from venting are calculated from country specific emission factors based on annual natural gas composition published by Energinet.dk.

Flaring in refineries

The composition of fuel gas is given for 2008 by one of the two refineries. As the composition for fuel gas is marked different than the composition of natural gas, which has been used in earlier year's calculations, the same fuel gas composition is used in calculations for the other Danish refinery.

The new emission factors for CH_4 and NMVOC based on fuel gas composition data from one refinery have been included in the inventory for all years from 1990 and onwards. The CO_2 emission factor is based on the refineries reporting to the EU ETS for the years 2006 and onwards. Before 2006 corresponding data are not available and the CO_2 emission factors are calculated from the annual natural gas composition given by Energinet.dk. NO_x emissions are provided by one refinery. Emission factors from the EMEP/EEA Guidebook (2013) are used to calculate emissions of CO and for NO_x where plant specific data are not available. The emission factor applied for N_2O is based on the 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 3.5.12.

Table 3.5.12 Emission factors for flaring in refineries.

Pollutant	Emission factor	Unit
NO_x *	32.2	g per GJ
NMVOC	76.4	g per GJ
CH_4	18.1	g per GJ
CO	177	g per GJ
CO_2 **	51.83 / 58.59	kg per GJ
N_2O	0.47	g per GJ

* Direct measured emission of NO_x is available for one refinery and the emission factor is used for the remaining refinery only.

** The CO_2 emission is based on the refineries reports for ETS and is source specific.

Flaring offshore

The emission factors for offshore flaring are shown in Table 3.5.13. Since 2006 the CO_2 emission factor is calculated according to the reporting for EU ETS. Corresponding data are not available for earlier years and therefore the CO_2 emission factor is assumed to follow the same time series as for natural gas combusted in stationary combustion plants.

The NO_x emission factor is based on the conclusion in a Danish study of NO_x emissions from offshore flaring carried out by the Danish Environmental Protection Agency (2008). The recommended NO_x emission factor (31 g per GJ or 0.0015 tonnes NO_x per tonnes gas) corresponds well with the emission factors used to estimate NO_x emission in other countries with oil production in the North Sea (Netherlands: approximately 0.0014 tonnes NO_x per tonnes gas and United Kingdom: approximately 0.0013 tonnes NO_x per tonnes gas).

Emission factors for N_2O are based on IPCC (2000) and emission factors for NMVOC and CO are based on the EMEP/EEA Guidebook (2009). The emission factor for CH_4 is based on OLF (1993).

Emissions from flaring in gas treatment and storage plants are calculated from the same emission factors which are used for offshore flaring. Only difference is the CO_2 emission factor for the years from 2006. The emission factor used for the plants are based on the same data source, the reporting for EU ETS, but the values are different than for offshore flaring. The gas that are flared in the treatment and storage plants are natural gas with the same composition as natural gas distributed in Denmark. Therefore, the emission factors in the EU ETS reports are the same as the one calculated on basis of the gas composition given by Energinet.dk.

Table 3.5.13 Emission factors for offshore flaring in 2012.

Pollutant	Emission factor	Unit
SO_2	0.014	g per Nm^3
NO_x	1.227	g per Nm^3
NMVOC	0.105	g per Nm^3
CH_4	0.211	g per Nm^3
CO	1.055	g per Nm^3
CO_2	2.707	kg per Nm^3
N_2O	0.021	g per Nm^3

3.5.5 Emissions

Extraction of oil and gas and loading of ships

From the activity data in Table 3.5.6, equation 3.5.3 and equation 3.5.4 the fugitive emissions of CH_4 and NMVOC from extraction are calculated. Corresponding emissions from loading of ships can be estimated by Table 3.5.6 and equation 3.5.5. The emissions are listed in Table 3.5.14 to Table 3.5.17 along with the emissions from oil pipelines and storage tanks given in the environmental reports from DONG Oil Pipe A/S (2013). CO_2 emissions from oil pipeline and storage tanks, as well as from extraction are calculated from standard emission factors (IPCC 2000).

Table 3.5.14 Emissions of CO_2, CH_4 and NMVOC from onshore loading of ships.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
CO_2, Gg	NA	NA	NA	NA	NA	NA	NA	NA	NA
CH_4, Mg	34	62	109	125	96	86	63	56	71
NMVOC, Mg	678	1 249	2 183	2 494	1 926	1 720	1 187	1 071	1 355

Table 3.5.15 Emissions of CO_2, CH_4 and NMVOC from Oil pipeline and storage tanks.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
CO_2, Gg	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
CH_4, Mg	783	1 209	1 700	2 100	1 648	1 300	984	822	766
NMVOC, Mg	1 726	2 664	4 000	4 500	3 625	2 098	763	638	594

Table 3.5.16 Emissions of CO_2, CH_4 and NMVOC from Fugitive emissions from extraction.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
CO_2, Gg	2	4	7	7	5	5	5	4	4
CH_4, Mg	708	990	1 365	1 608	1 684	1 703	1 698	1 685	1 677
NMVOC, Mg	236	330	455	536	561	568	566	562	559

Table 3.5.17 Emissions of CO_2, CH_4 and NMVOC from Offshore loading of ships.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
CO_2, Gg	NA	NA	NA	NA	NA	NA	NA	NA	NA
CH_4, Mg	NA	NA	201	167	93	73	83	76	67
NMVOC, Mg	NA	NA	4 021	3 337	1 856	1 451	1 658	1 525	1 332

Oil refining

In Table 3.5.18 the activity data and emissions of VOC from the Danish refineries are listed for selected years in the time series. Further, the emissions of SO_2 from oil refining and sulphur recovery in refineries are shown. The emission of SO_2 has shown a pronounced decrease since 1990 because of technical improvements at the refineries. Note that SO_2 from refining and recovery prior to 1994 was aggregated and reported as an area. Note also that SO_2 from oil refining from 2001 are included in stationary combustion.

The large fluctuations in the SO_2 emission from sulphur recovery owe to outage and shut downs of the sulphur recovery units. The SO_2 emission from sulphur recovery has shown a gradual decrease from 1995 to 2000.

Table 3.5.18 Oil Refineries. Emissions of NMVOC and SO_2 from oil refining and SO_2 from sulphur recovery.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
Crude oil, 1000 Mg	7 263	9 802	8 508	8 033	7 933	7 978	7 414	6 997	7 414
VOC, Mg	3 667	5 815	4 845	3 442	3 588	3 877	3 867	3 868	3 932
SO_2, oil refining, Mg [1,2]	3 335	585	178	IE	IE	IE	IE	IE	IE
SO_2, sulphur recovery, Mg [1]		2 437	803	390	987	481	1 019	1 179	889

[1)] Prior to 1994 SO_2 emissions from oil refining and sulphur recovery are aggregated and reported as area.

[2)] From 2001 SO_2 emissions from oil refining are included in stationary combustion.

Service stations

Emissions from service stations are calculated using the emission factors in Table 3.5.10 and the sold amounts of gasoline given by the Danish energy statistics (Danish Energy Agency, 2013b). The NMVOC emissions are listed in Table 3.5.19.

Table 3.5.19 Emissions of NMVOC from service stations for selected years of the time series.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
NMVOC, Mg	4 856	3 016	2 616	1 742	1 216	1 158	1 106	1 027	977

Transmission, storage and distribution of gas

The gas transmission company gives 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 (Oertenblad, 2007). For the years 1991-1998 the CH_4 emissions for transmission are estimated on the basis of 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.

The distribution companies provide emissions of CH_4 for the years 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.

The emissions of NMVOC are calculated on the basis of the CH_4 emission according to the gas quality measured by Energinet.dk (equation 3.5.8).

$$E_{NMVOC} = E_{CH_4} \times \left(w_{NMVOC} / w_{CH_4} \right) \qquad \text{(Eq.3.5.8)}$$

where w_{NMVOC} is the weight-% NMVOC and w_{CH_4} is the weight-% CH_4 according to the gas quality of the current year.

Emissions of CH_4 and NMVOC from transmission of natural gas (including storage) and distribution of natural gas and town gas are shown in Table 3.5.20 and Table 3.5.21, respectively. Emissions of CO_2 from transmission and distribution are very limited amounts and therefore not included in the tables.

As the pipelines in Denmark are relatively new and made of plastic, emissions other than from construction and maintenance are considered not occurring. The decrease in emission from transmission in 2007 is caused by the completion of a greater construction work and rerouting of a major pipeline. In preparation for construction work on a new compressor station, there has been laid a number of new line valve stations in 2011. Before this work could be done, larger amounts of natural gas were vented to drain the pipes. Therefore emissions from transmission of natural gas are significantly higher in 2011 than in the previous years.

Emissions from distribution of gas mainly owe to excavations and maintenance of the pipelines, but also difference between the calendar year and the meter reading year might influence the annual variations. As the town gas distribution network is significant older the gas losses and thus the emissions are larger than for the natural gas distribution network, even though the distribution rates for natural gas far exceeds the rates for town gas.

Data on distribution of town gas is limited as more distribution companies are closed. For the active companies, data are available for part of the time series only. Gap filling and extrapolation of distribution and loss amounts to early years are done in collaboration with the individual companies to the extent possible.

Table 3.5.20 CH_4 emission from transmission of natural gas and distribution of natural gas and town gas for selected years.

CH_4, Mg	1990	1995	2000	2005	2008	2009	2010	2011	2012
Transmission	190	597	86	141	16	9	26	171	14
Distribution, natural gas	56	99	49	66	51	49	37	49	71
Distribution, town gas	202	211	178	176	95	85	106	106	75

Table 3.5.21 NMVOC emission from transmission of natural gas and distribution of natural gas and town gas for selected years.

NMVOC emission, Mg	1990	1995	2000	2005	2008	2009	2010	2011	2012
Transmission	41	135	26	36	4	2	6	43	4
Distribution, natural gas	12	22	15	17	12	12	9	12	18
Distribution, town gas	683	700	680	587	56	48	53	50	39

Venting and Flaring

Venting

Venting is limited to the gas storage plants and thus the emissions are of minor importance (Table 3.5.5). The emissions of CH_4 and NMVOC from venting are given in the environmental reports for the gas storage plants (DONG Energy, 2012a,b; Energinet.dk, 2012a). Calculation of CO_2 emissions are based on venting amounts and annual composition of Danish natural gas. Venting emissions are included in Figure 3.5.12 and Figure 3.5.13.

Flaring

As shown in Figure 3.5.11 there was a marked increase in the amount of offshore flaring 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 time series for the emission of CO_2 from offshore flaring fluctuates due to the fluctuations in the fuel rate and to a minor degree due to the CO_2 emission factor. The latter is based on gas quality measurements. From 2006 the calorific values for flare gas are given at installation level in the EU ETS.

This information is incorporated in the inventory for the years 2006-2007 for part of the offshore installations, and from 2008 and onwards for all installations. This has led to an increase of the CO_2 emission factor. The average of the emission factors for 2008-2010 is adopted for 1990-2007. Fuel rate and CO_2 emission are shown in Figure 3.5.11.

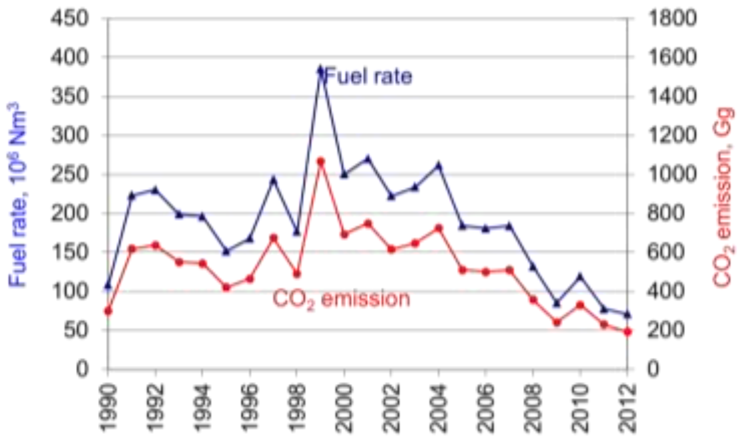

Figure 3.5.11 Fuel rate and CO_2 emission from offshore flaring of gas.

The emissions of other pollutants than CO_2 from offshore flaring 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 and NMVOC from flaring and venting are shown in Figure 3.5.12 and 3.5.13.

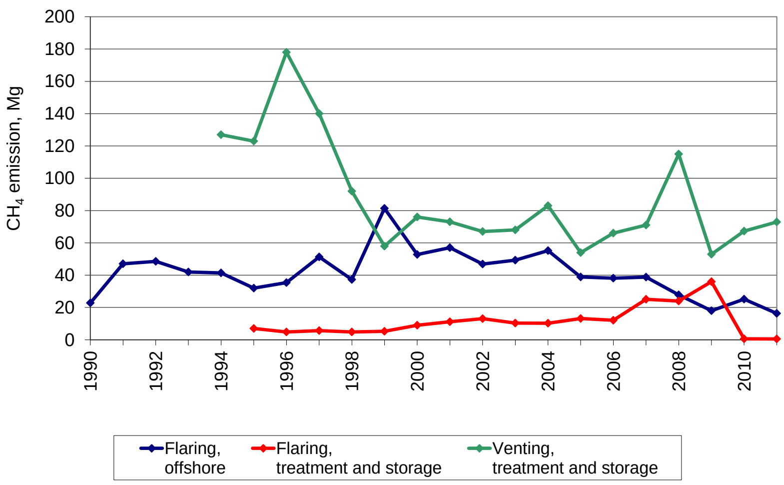

Figure 3.5.12 CH_4 emissions from venting and flaring of gas.

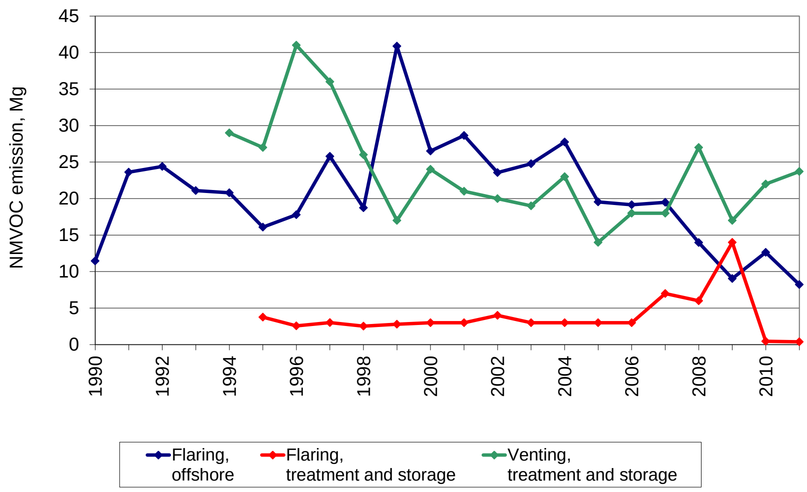

Figure 3.5.13 NMVOC emissions from venting and flaring of gas.

The decrease in the emissions from 2009 to 2010 for gas storage and treatment plants owes to a change from continuous to regulating power operation of the power producing gas turbine at the gas storage plant.

Table 3.5.22 Emissions from flaring offshore and in gas treatment/storage plants.

Year	1990	1995	2000	2005	2008	2009	2010	2011	2012
	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg
CO_2	302	423	695	513	360	244	333	232	195
SO_2	2	2	4	3	2	1	2	1	1
NO_x	134	188	310	231	168	111	155	103	96
NMVOC	15	20	30	23	20	23	13	9	8
CO	115	161	265	195	141	91	127	83	76

Flaring also occurs in refineries. Flaring in refineries is a significant fugitive emission source for SO_2. In 1990-1993, emissions from petroleum product processing were included in emissions from flaring in refineries (1B2c). From 1994 the data delivery format was changed, which made it possible to split the emissions into contributions from flaring and processing, respectively. Emissions from processing are from 1994 included in the category Oil, Refining/Storage.

The decreasing emissions of SO_2 from 1995 to 1998 are due to technical improvements of the sulphur recovery system at one of the two Danish refineries (Table 3.5.23). The increase in SO_2 from flaring in refineries in 2005 and 2007 was due to planned shutdowns due to inspection and maintenance at one of the two refineries. Further, in 2007-2009 the same refinery has had problems with the ATS system leading to an increased SO_2 emission from flaring.

Table 3.5.23 Emissions from flaring in refineries.

	1990*	1995	2000	2005	2008	2009	2010	2011	2012
	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg
CO_2, Gg	23	23	19	23	27	16	19	19	22
SO_2 *, Mg	943	203	51	296	380	453	288	242	167
NO_x, Mg	13	13	11	26	26	17	19	18	23
NMVOC, Mg	31	31	26	32	38	23	27	25	32
CO, Mg	73	73	60	73	88	53	62	59	74

*In 1990-1993 emissions from petroleum product processing were included in flaring in refineries due to the data delivery form.

3.5.6 Uncertainties and time series consistency

Two set of uncertainty estimates are made for the Danish emission inventory for greenhouse gases based on Tier 1 and Tier 2 methodology, respectively. The uncertainty models follow the methodology in IPCC Good Practise Guidance (IPCC, 2000). Tier 1 is based on the simplified uncertainty analysis (error propagation method) and Tier 2 is based on Monte Carlo simulations.

Uncertainty estimates are made for total emissions in the base year (only Tier 2), in the latest inventory year and for the emission trend for the corresponding time series. Uncertainty estimates are made for the GHGs separately and summarized.

Input data

The Tier 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. The Tier 2 model is based on activity data and emission factors for the same years and the same uncertainty levels as in Tier 1. Emission data, activity data and emission factors are described in Chapter 3.5.3, 3.5.4 and 3.5.5.

The uncertainty levels used in the uncertainty models are based on different sources, e.g. IPCC Good Practice Guidance, EMEP/EEA Guidebook and reports under the EU ETS. Further, a number of the uncertainty levels are given as NERI 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 3.5.24. Uncertainty levels are given in percentage related.

Table 3.5.24 Uncertainty levels for activity rates and emission factors.

Pollutant	Source	Activity data uncertainty level, %	Emission factor uncertainty level, %
CO_2	Land based activities	2N	40S
CO_2	Offshore activities	2N	30I
CO_2	Gas transmission	15G	2Q
CO_2	Gas distribution	25G, N	10Q, N
CO_2	Venting in gas storage plants	25G, N	2Q
CO_2	Flaring in refineries	11E	2E
CO_2	Flaring offshore	7.5E	2E
CH_4	Petroleum product processing	1E, N	125N
CH_4	Land based activities	2N	40S
CH_4	Offshore activities	2N	30I
CH_4	Gas transmission	15G	2Q
CH_4	Gas distribution	25G, N	10Q, N
CH_4	Venting in gas storage plants	15G, N	2Q
CH_4	Flaring in refineries	11E	15H, N
CH_4	Flaring offshore	7.5E	125G
N_2O	Flaring in refineries	11E	1 000I
N_2O	Flaring offshore	7.5E	1 000I

N: DCE assumption.
I: IPCC Good Practice Guidance (default value).
S: Statistisk Sentralbyrå, Statistics Norway, 2008.
E: EU Emission Trading Scheme (EU ETS).
G: EMEP/EEA Guidebook, 2009.
H: Holst, 2009 and Statoil A/S, 2010.
Q: Annual gas quality, Energinet.dk.

The CO_2 emission factors for flaring offshore 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 CO_2 emission factor for offshore activities is based on standard emission factors from IPCC (2000). Source specific uncertainty levels are not included in IPCC (2000), but it is written that the uncertainty levels must be assumed to be in the range of ±25 % to ±50 % for most gases. 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.

Data from the Danish operators (one year only) indicate that the VOC emissions in the Danish inventory have an uncertainty around 30 %, which has been used as uncertainty level for CH_4 in the uncertainty model. The EMEP/CORINAIR Guidebook (2007) suggests an error of 65 % for the standard equation used to estimate fugitive emissions of VOC from extraction, noting that the error could be much higher when the equation is used for other fields than the ones in USA, which it has been based on. Further the EMEP/EEA Guidebook (2009) says that the uncertainty level of 65 % seems to be in reasonable agreement with estimates for Norway and UK – countries expected to have more similar conditions to Danish than the USA. The EMEP/EEA uncertainty level is in the same order of magnitude as the Danish uncertainty level, which support the assumption that the Danish estimate are applicable for all years in the time series.

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 significantly.

According to IPCC (2000) the emission factor for N_2O is the least reliable. An uncertainty level of 1 000 % is adopted in the Danish uncertainty model.

The Tier 2 uncertainty model is based on Monte Carlo simulations and the input uncertainty levels are given for the 95 % confidence interval assuming a log-normal distribution. The input uncertainty levels are the same as those used in the Tier 1 uncertainty model (Table 3.5.20). For more information on the Tier 2 methodology, please see Chapter 1.7.

Results

The results of the Tier 1 uncertainty model for 2012 are shown in Table 3.5.25. In 2012 N_2O has the largest uncertainty for the total emission followed by CH_4 and CO_2. Due to the emission trend CH_4 has the largest uncertainty followed by N_2O and CO_2. The estimated uncertainty for the total GHG emission is 19 % and the GHG emission trend is -12 % ± 17 %-point.

Table 3.5.25 Uncertainty estimates for total emissions and emission trends from the Tier 1 uncertainty model.

	Emission, Gg CO_2 eqv	Emission, Gg CO_2 eqv	Uncertainty, % Lower and upper (±)	Trend 1990-2012, %	Uncertainty, % Lower and upper (±)
	Base year	2011			
CO_2	325	217	8	-33	6
CH_4	44	106	57	139	128
N_2O	1	1	892	-31	37
GHG	372	327	19	-12	17

Table 3.5.26 show the results from the Tier 2 uncertainty model for 1990 and 2012. The overall emission uncertainty in 2012 is -12/+30 %. The Tier 2 trend estimate is -11 % -20/+29 %-point.

Table 3.5.26 Uncertainty estimates for total emissions in 1990 and 2012 and for the emission trends from the Tier 2 uncertainty model.

	1990			2012			1990-2012		
	Median emission Gg CO_2 eqv	Uncertainty, %		Median emission Gg CO_2 eqv	Uncertainty, %		Median trend, %	Uncertainty, %	
		Lower (-)	Upper (+)		Lower (-)	Upper (+)		Lower (-)	Upper (+)
CO_2	328	15	17	221	7	7	-240	139	116
CH_4	44	19	28	108	34	91	19	11	30
N_2O	1	94	1 193	1	93	1 024	-26	413	26
GHG	374	13	16	330	12	27	-11	20	29

Tier 1 and Tier 2 emissions and uncertainties are shown together in Figure 3.5.14. The figures show that the emissions and median emissions from Tier 2 are very similar. Further, the uncertainty estimates are in the same range for Tier 1 and Tier 2. The N_2O uncertainty is leaved out of Figure 3.5.14 b as the N_2O uncertainties are much higher than for CO_2 and CH_4. It must be noted that the uncertainty models, especially the Tier 1 model, are not suitable for very large uncertainty levels and therefore the uncertainty estimates for N_2O may only be seen as an indicator for a large uncertainties while the values are less accurate. The Tier 2 model has been developed to be more suitable for very large uncertainties, as it is possible to apply truncation for uncertainties. This has been included in the uncertainty calculation for fugitive emissions in case of N_2O, as the uncertainty level for the emission factors is 1 000 %. A truncation of 2 000 % has been applied to ensure that the emission factor interval is within an order of magnitude as given in IPCC Good Practice Guidance.

a) b)

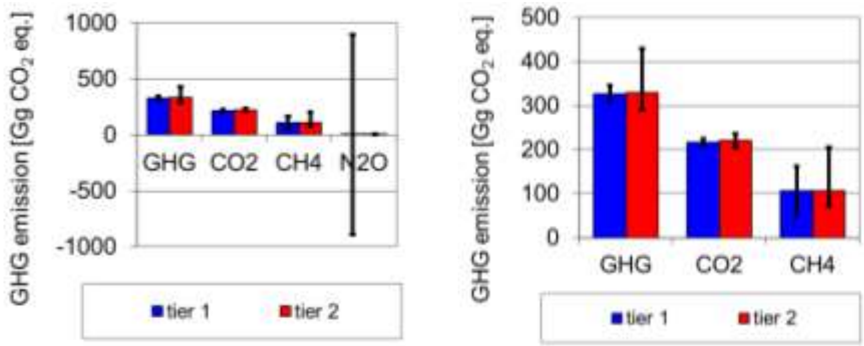

Figure 3.5.14 Emissions and uncertainty estimates from the Tier 1 and Tier 2 models; a) GHG, CH_4, CO_2 and N_2O, b) as figure a, but without N_2O

3.5.7 Source specific QA/QC and verification

The elaboration of a formal QA/QC plan started in 2004 and has recently been updated (Nielsen et al., 2013). The plan describes the concepts of quality work and definitions of sufficient quality, critical control points and a list of Points of Measuring, PM (Figure 3.5.15). Please refer to the general Chapter 1.6 for further information.

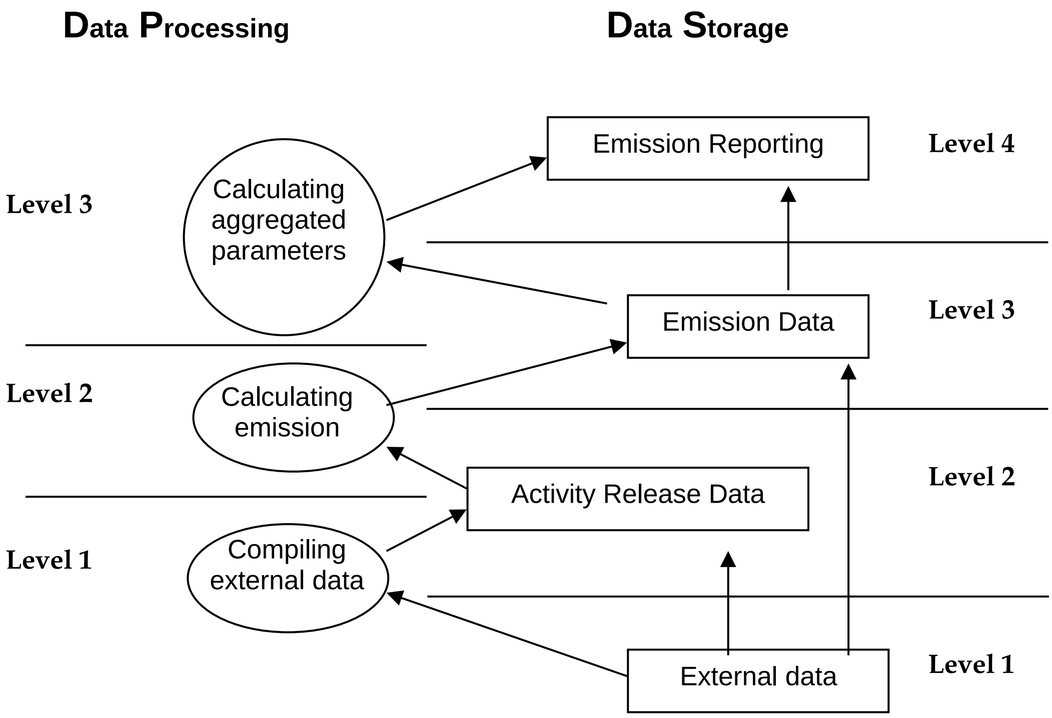

Figure 3.5.15 The general data structure for the Danish emission inventory (Nielsen et al., 2013).

Data storage level 1

Data storage level 1 refers to the data collected by DCE before any processing or preparing. Table 3.5.27 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 3.5.27 List of external data sources.

Category	Data description	Activity data, emission factors or emissions	Reference	Contact(s)	Data agreement/ Comment
Offshore activities	Gas and oil production. Dataset for production of oil, gas and number of platforms. Amounts of offshore loading of ships	Activity data	The Danish Energy Agency	Jan H. Andersen	Not necessary due to obligation by law
Offshore flaring	Flaring offshore in oil and gas extraction	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 from the transmission	Activity data	Energinet.dk	Christian Friberg B.	Not necessary due

	company, sales and losses (meter differences)			Nielsen	to obligation by law
Onshore activities	Amounts of oil transport in pipeline and onshore loading to ships. Emissions from storage of raw oil in the terminal.	Activity data and emission data	DONG Oil Pipes A/S	Stine B. Bergmann	No formal data agreement.
Gas distribution	Natural gas from the distribution company, sales and losses (meter differences)	Activity data	Naturgas Fyn, HMN DONG Energy	Hanne Mochau Erik Wolf-Petersen Finn Adser	No formal data agreement.
Air emissions from refinery	Fuel consumption and emission data.	Activity data and emission data	Statoil A/S, A/S Danish Shell	Anette Holst, Lis Rønnow Rasmussen	No formal data agreement.
Storage and treatment of gas	Environmental reports from plants defined as large point sources (Lille Torup, Stenlille, Nybro)	Activity data	Various plants		Not necessary due to obligation by law
CO_2 emission factors for different sources	Reports according to the CO_2 emission trading scheme (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 chapter regarding emission factors		

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 and Tier 2 uncertainty calculations with short descriptions of the reasoning that underlie 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 Chapter 3.5.6.

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.

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 sources are the Danish Energy Agency, EU ETS reports and annual environmental reports from plants which are obligated to publish environmental reports. Further, annual reports from the gas distribution companies and the raw oil terminal are used. Some environmental reports and annual reports are supplemented with data and information from the given companies.

Only one national data set is found for most fugitive sources, and all data set is expected to be complete and include all activities/emissions form the source. Data on flaring offshore, in refineries and in gas storage and treatment plants 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 supplier. Minor differences may owe to the allocation of fuels, e.g. if pilot gas are included in the flare gas or the fuel gas amount.

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 offshore extraction, offshore flaring 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 fuel consumption and emissions, among other things. 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 data and information are used. All information is compared with previous years.

Reports for the European Union Greenhouse Gas Emission Trading System (EU ETS)
CO_2 emission factors for flaring offshore and in refineries are taken from the EU ETS reports since 2006 when the EU ETS reports became available. EU ETS reports are available for the individual Danish oil/gas production fields and for the refineries.

Emission factors from a wide range of sources
For specific references, see Chapter 3.5.4 regarding emission factors.

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 or databases to ensure that the external data are always available in the original form. Refer to Section 1.3.

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 in this regard. The remaining data are published or delivered by the companies on voluntary basis. See Table. 3.5.26

Data Storage	7.Transparency	DS.1.7.1	Listing of all archived datasets and external

level 1			contacts.

See DS 1.3.1 and Table 3.5.26

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.

Refer to Section 1.7 in the Danish NIR and the QA/QC Section 3.5.7.

Data Processing level 1	2.Comparability	DP.1.2.1	The methodologies have to follow the international guidelines suggested by UNFCCC and IPCC.

The methodologies in the inventory follow the principles in international guidelines by UNFCCC and IPCC.

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 the 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.

More detailed data on emissions from exploration of oil and gas would be preferred, even though emissions calculated by use of the standard IPCC formula is in good agreement with an inventory made by the operators for one emission year. Unfortunately the inventory by the operators is not available for other years.

Regarding the VOC emissions from refineries, more detailed data material would be preferred.

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 Chapter 3.5.

Data Processing level 1	5.Correctness	DP.1.5.2	Verification of calculation results using time series

Time series for activity data on SNAP level as well as emission factors is used to identify possible errors in the calculation procedure.

Data Processing level 1	5.Correctness	DP.1.5.3	Verification of calculation results using other measures

Emissions from offshore activities are compared to an inventory made by the operators and the emissions are found in good agreement.

For the remaining sources only one data set is available for calculation, and no verification using other measures are possible.

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 Chapter 3.5.

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.

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

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

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.

The IEFs for transmission and distribution of natural gas are low compared to other countries as the Danish distribution network is relatively new and made of plastics, leading to negligible fugitive losses under normal circumstances. Only fugitive losses are due to excavations and maintenance and construction work.

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 plants) 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 (offshore fuel and flaring rates).
- 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 NFR and SNAP source categories. Significant dips and jumps are controlled and explained.

The QC work will continue in future years.

National external review

In 2009 a sector report for fugitive emissions from fuels was published (Plejdrup et al. 2009). The report was reviewed by Anette Holst from the Statoil A/S refinery.

3.5.8 Recalculations

The following recalculations regarding fugitive emissions from fuels have been applied for the time series:

Natural gas transmission and distribution

Activity data and IEF for the time series 1990-2011 has been updated for transmission and distribution according to annual environmental reports and the latest national energy statistics, respectively. Further, the CH_4 EFs are updated for one town gas distribution company following an update of the estimated fugitive losses per distribution. The recalculation has changed the CO_2 emission by 0.01 ktonnes and CH_4 emission by (-0.09) - 0.07 ktonnes, corresponding to < 0.003% and (-2) % - 2% of the total fugitive CO_2 and CH_4 emission.

Venting

EFs for CH_4 have been added for the years 1990-1993 for one gas storage plant. In these years the plant is treated as an area source in the national system, while it is treated separately as a point source in the following years. EFs are based on data from annual reports for 1995-1999, as no data are available for the years 1990-1994. Further, a minor error has been applied for venting in 2011, according to the annual report from one of the natural gas storage facilities. The recalculation has changed the CH_4 emission by 0.06 ktonnes, corresponding to 2% of the total fugitive CH_4 emission.

Flaring in gas storage and treatment plants

EFs for CO_2 and CH_4 have been added for the years 1990-1993 for the gas treatment plant. In these years the plant is treated as an area source in the national system, while it is treated separately as a LPS in the following years. EFs are based on data from annual reports for 1995-1999, as no data are available for the years 1990-1994. The recalculation has changed the CO_2 emission by 2.2 ktonnes and the CH_4 emission by 0.01 ktonnes, corresponding to 0.4 % and 0.4 % of the total fugitive CO_2 and CH_4 emission.

Flaring in refineries

The CO_2 EF for one refinery has been updated for the years 1994-2006 and now reflects the average EF from the first five EU-ETS reports (2007-2011). The NO_x EF for two refineries has been changed to the standard EF in the EMEP/EEA Guidebook, as references to the previously applied EFs are outdated or not existing.

The CO_2 EF for a refinery that was shut down in 1996 has been changed for the years 1990-1996 to match the existing refineries, as no better data is available. CO_2 EF for 2010-2011 has been updated and now corresponds to the EU-ETS reporting. The recalculation has changed the CO_2 emission by (-0.05) – 0.49 ktonnes and CH_4 emission by (-0.06) ktonnes, corresponding to (-0.01) – 0.1% and (-2) % of the total fugitive CO_2 and CH_4 emission.

3.5.9 Source specific planned improvements

The following future improvements are suggested.

- **Emissions from storage of fuels in tank facilities:** The current edition of the Danish emission inventory holds emissions from storage and refining of crude oil and from service stations. To make the inventory complete emissions from storage of fuels outside the refineries in tank facilities will be included in the future if data are available. Work is on-going to locate large tank facilities in Denmark and collect the available data. In cases where no emission estimates or measurements are available a set of emission factors have to be set up.

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4 Industrial Processes (CRF sector 2)

4.1 Overview of the sector

4.1.1 Emission overview

The aim of this chapter is to present industrial emissions of greenhouse gases, not related to generation of energy. The data presented in Chapter 4 relates to Denmark only, whereas information for Greenland is included in Chapter 16 and for the Faroe Islands in Annex 8.

An overview of the sources identified is presented in Table 4.1 with an indication of the contribution to the industrial part of the emission of greenhouse gases in 2012. The emissions are extracted from the CRF tables.

Table 4.1 Overview of industrial greenhouse gas sources (2012).

Process	IPCC Code	Substance	Emission ktonne CO_2 eq.	Percent
Cement	2A1		871	48.6
Refrigeration	2F1	HFCs+PFCs	579	32.4
Other (laboratories, double glaze windows)	2F9	SF_6	105	5.84
Foam blowing	2F2	HFCs	66.2	3.70
Lime	2A2		40.2	2.24
Other (lubricants)	2G		31.7	1.77
Limestone and dolomite use	2A3		25.6	1.43
Other (yellow bricks)	2A7		17.5	0.98
Aerosols / Metered dose inhalers	2F4	HFCs	15.8	0.88
Electrical equipment	2F8	SF_6	13.3	0.74
Other (container glass, glass wool)	2A7		9.69	0.54
Other (expanded clay products)	2A7		5.89	0.33
Other (fibre optics)	2F9	HFCs+PFCs	4.31	0.24
Food and Drink	2D2		2.24	0.13
Road paving	2A6		1.77	0.10
Catalysts / fertilisers	2B5		1.41	0.08
Asphalt roofing	2A5		0.019	0.001
Metal production	2C1		NO	NO
Nitric acid	2B2	N_2O	NO	NO
Total			1 791	100

The subsectors *Mineral products* (2A) constitutes 54 %, *Chemical industry* (2B) constitutes below 1 %, *Metal production* (2C) constitutes 0 %, *Consumption of halocarbons and SF_6* (2F) constitutes 44 %, *Other, Food and Drink* (2D) constitutes below 1 %, and *Other, Lubricants* (2G) constitutes 1.8 % of the industrial emission of greenhouse gases. The total emission of greenhouse gases (excl. LULUCF) in Denmark is estimated to 51.6 Mt CO_2 equivalents, of which industrial processes contribute with 1.79 Mt CO_2 equivalents (3.5 %). The emission of greenhouse gases from industrial processes from 1990-2012 are presented in Figure 4.1.

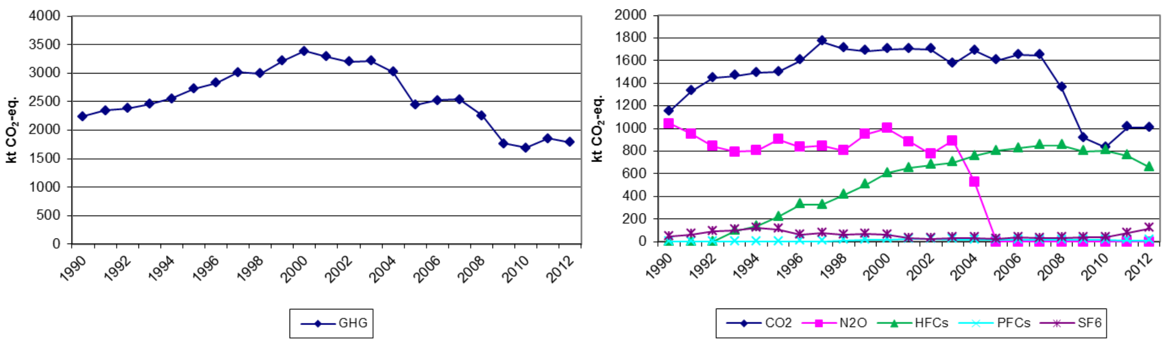

Figure 4.1 Emission of greenhouse gases from industrial processes (CRF Sector 2) from 1990-2012.

The key categories in the industrial processes sector - cement and refrigeration - constitute 1.69 % and 1.12 % of the total emission of greenhouse gases. The trends in greenhouse gases from the industrial sector/subsectors are presented in Table 4.2 and they will be discussed subsector by subsector below. The emissions are extracted from the CRF tables.

Table 4.2 Emission of greenhouse gases from industrial processes in different subsectors from 1990-2012.

Year	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
CO_2 (kt CO_2)										
A. Mineral Products	1 069	1 405	1 616	1 544	1 606	1 320	881	796	972	972
B. Chemical Industry	0.80	0.80	0.79	1.06	1.35	1.20	1.42	2.12	1.39	1.41
C. Metal Production	28.4	38.6	40.7	15.6	NA.NO	NA.NO	NA.NO	NA.NO	NA.NO	NA.NO
D. Food and Drink	4.45	3.91	3.90	4.46	1.72	2.67	1.92	1.56	2.01	2.24
G. Other	49.7	48.8	39.7	37.6	37.9	34.0	31.2	33.2	33.2	31.7
Total	1 152	1 497	1 701	1 602	1 647	1 358	915	833	1 008	1 007
CH_4	-	-	-	-	-	-	-	-	-	-
N_2O (kt N_2O)										
B. Chemical Industry	3.36	2.92	3.24	NO	NO	NO	NO	NO	NO	NO
HFCs (kt CO_2 eqv.)										
F. Consumption of Halocarbons and SF_6	NE	218	607	802	850	853	799	804	759	657
PFCs (kt CO_2 eqv.)										
F. Consumption of Halocarbons and SF_6	NE	0.50	17.9	13.9	15,4	12,8	14,2	13,3	11,1	8,54
SF_6 (kt CO_2 eqv.)										
F. Consumption of Halocarbons and SF_6	44.5	107	58.8	21.8	30,3	31,6	36,7	37,9	73,2	118

4.1.2 Methodology overview

Table 4.3 gives a brief overview over methodologies applied for industrial processes. Further description of the applied methodologies can be found in the following chapters.

Table 4.3 Methodology overview.

			Tier	EF	Key category
Industrial Proc.	2A1 Cement production	CO_2	T3	PS	Yes
Industrial Proc.	2A2 Lime production	CO_2	T2	T1	No
Industrial Proc.	2A3 Limestone and dolomite use	CO_2	T2	T1,PS	No
Industrial Proc.	2A5 Asphalt roofing	CO_2	T1	CS	No
Industrial Proc.	2A6 Road paving with asphalt	CO_2	T1	CS	No
Industrial Proc.	2A7 Glass and Glass wool	CO_2	T2,T3	T1	No
Industrial Proc.	2B5 Catalysts/Fertilizers, Pesticides and Sulphuric acid	CO_2	T2	PS	No
Industrial Proc.	2C1 Iron and steel production	CO_2	T1	T1	No
Industrial Proc.	2D2 Food and Drink	CO_2	T2	T2,PS	No
Industrial Proc.	2G Lubricants	CO_2	T1	T1	No
Industrial Proc.	2B2 Nitric acid production	N_2O	T1	PS	Yes
Industrial Proc.	2F Consumption of HFC	HFC	T1,T2	CS	Yes
Industrial Proc.	2F Consumption of PFC	PFC	T1,T2	CS	No
Industrial Proc.	2F Consumption of SF_6	SF_6	T1,T2	CS	No

4.1.3 Key categories

Key Category Analysis (KCA) for the years 1990 and 2012 as well as for the trend has been carried out. Table 4.4 present the result. A detailed KCA is presented in Chapter 1.5 and Annex 1.

Cement production is identified as key category (level and trend) according to Tier 1 for 1990 and 2012. Nitric acid production is identified as key category in 1990 and the trend is also identified as key according to Tier 1 and 2. Consumption of HFC is identified as key category in 2012 and the trend is also identified as key according to Tier 1 and 2.

Table 4.4 Key Category Analysis for Industrial processes.

			Tier 1			Tier 2		
			1990	2012	1990-2012	1990	2012	1990-2012
Industrial Proc.	2A1 Cement production	CO_2	Level	Level	Trend			
Industrial Proc.	2A2 Lime production	CO_2						
Industrial Proc.	2A3 Limestone and dolomite use	CO_2						
Industrial Proc.	2A5 Asphalt roofing	CO_2						
Industrial Proc.	2A6 Road paving with asphalt	CO_2						
Industrial Proc.	2A7a Glass and Glass wool	CO_2						
Industrial Proc.	2A7b Yellow bricks	CO_2						
Industrial Proc.	2A7c Expanded clay	CO_2						
Industrial Proc.	2B5 Catalysts/Fertilizers, Pesticides and Sulphuric acid	CO_2						
Industrial Proc.	2C1 Iron and steel production	CO_2						
Industrial Proc.	2D2 Food and Drink	CO_2						
Industrial Proc.	2G Lubricants	CO_2						
Industrial Proc.	2B2 Nitric acid production	N_2O	Level		Trend	Level		Trend
Industrial Proc.	2F Consumption of HFC	HFC		Level	Trend		Level	Trend
Industrial Proc.	2F Consumption of PFC	PFC						
Industrial Proc.	2F Consumption of SF_6	SF_6						

4.2 Mineral products (2A)

4.2.1 Source category description

The subsector *Mineral products* (2A) cover the following processes:

- Cement production
- Lime production
- Limestone and dolomite use (for fluegas cleaning at power plants and waste incineration plants and for production of stonewool).
- Asphalt roofing
- Road paving with asphalt
- Production of bricks, tiles and expanded clay products
- Production of container glass/glass wool

Production of cement is identified as a key category; see *Annex 1: Key Category Analyses*.

The time series for the emission of CO_2 from *Mineral products* (2A) are presented in Table 4.5. The emissions are extracted from the CRF tables and the values are rounded.

Table 4.5 Time series for emission of CO_2 (kt) from Mineral products (2A).

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
1. Production of Cement	882	1 204	1 385	1 363	1 407	1 155	764	672	862	871
2. Production of Lime	116	87.7	76.7	63.5	66.9	65.6	43.2	45.6	29.8	40.2
3. Limestone and dolomite use	13.7	53.7	89.7	56.2	49.6	38.7	37.9	45.6	41.7	25.6
5. Asphalt roofing	0.019	0.020	0.032	0.024	0.025	0.025	0.016	0.016	0.021	0.019
6. Road paving	1.76	1.77	1.72	1.84	2.00	1.92	1.64	1.73	1.88	1.77
7. Other										
Glass and Glass wool	17.4	14.1	15.9	12.6	15.0	15.1	10.8	9.33	9.46	9.69
Yellow Bricks	23.0	28.8	32.6	32.2	38.0	28.4	16.5	15.8	20.4	17.5
Expanded Clay	14.9	15.3	14.2	14.0	26.9	16.1	6.48	6.00	6.63	5.89
Total	1 069	1 405	1 616	1 544	1 606	1 320	881	796	972	972

The increase in CO_2 emission is most significant for the production of cement until 2007; however, in the latest years the emission has been decreasing. The overall development in the CO_2 emission from 1990 to 2012 shows a slightly decreasing trend from 882 to 871 kt CO_2, i.e. by 1.3 %. The maximum emission occurred in 2004 and constituted 1 459 kt CO_2; see Figure 4.2.

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 decrease during the latest years may be explained by the decrease in the construction activity.

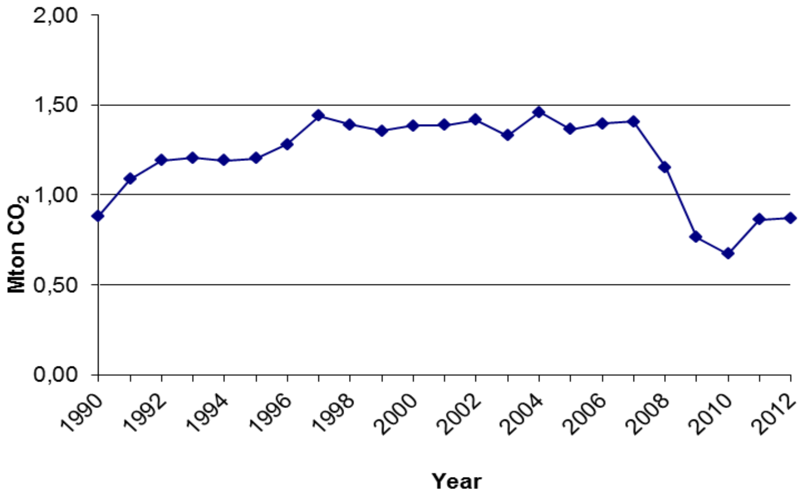

Figure 4.2 Emission of CO_2 from cement production.

4.2.2 Methodological issues

2A1 Cement production

Public statistics for cement production, import and export are presented in Table 4.6. However, the dataset is incomplete probably due to confidentiality in some of the mass flows. The statistics do not add new information to the inventory as information on total amount of produced cement clinker (i.e. clinker for cement production and clinker for sale) is not available. Activity data from Aalborg Portland and implied emission factors for cement production are presented in Table 4.7. Table 4.6 and Table 4.7 show a difference between produced amount of cement (grey and white) according to Statistics Denmark and the amount produced according to Aalborg Portland. This difference may be explained by change in clinker stocks. The most comprehensive activity data is assumed to be the information on yearly produced amount of cement clinker obtained from the Danish producer.

Table 4.6 Production, import, export and supply of cement (Statistics Denmark, 2013).

		1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
Cement clinker[1]	Prod.	NI	NI	102 719	42 691	21 209	16 092	122	3 819	25	24 256
	Import	404	8	NI	31 331	39 776	42 480	32 444	21 391	29 106	24 442
	Export	17 038	186 979	NI	NI	NI	NI	NI	NI	NI	NI
	Supply	-16 634	-186 971	102 719	74 022	60 985	58 572	32 566	25 210	29 131	48 698
Portland cement, white	Prod.	411 653	531 215	551 072	714 626	722 310	607 143	462 377	481 507	514 389	495 886
	Import	NI	24	8 299	15 438	18 670	33 082	29 423	24 152	28 414	24 645
	Export	91 132	NI	NI	NI	NI	NI	NI	NI	NI	NI
	Supply	320 521	531 239	559 371	730 064	740 980	640 225	491 800	505 659	542 803	520 531
Portland cement, grey	Prod.	1 244 256	2 052 705	1 984 976	2 165 928	2 149 092	1 931 679	1 116 237	1 085 117	1 338 415	1 321 447
	Import	115 452	NI	NI	NI	NI	NI	NI	159 923	213 930	182 473
	Export	19 387	332 390	NI	NI	NI	NI	NI	NI	NI	NI
	Supply	1 340 321	1 720 315	1 984 976	2 165 928	2 149 092	1 931 679	1 116 237	1 245 040	1 552 345	1 503 920

1. Cement clinker for sale.
NI No information.

Table 4.7 Activity data, emission factors, and CO_2 emission for cement production.

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
Activity										
Tonnes TCE[6]	1 619 976	2 273 775	2 612 721	2 706 371	2 946 294	2 551 346	1 663 126	1 454 043	1 766 561	1 818 293
Tonnes clinker	NI	NI	2 452 394	2 520 788	2 706 048	2 269 687	1 493 230	1 313 654	1 582 023	1 628 506
Tonnes clinker + white cement[1]	1 406 212	2 353 123	-	-	-	-	-	-	-	-
Emission factors										
EF tonnes CO_2 per tonnes TCE[2]	0.545	0.529	-	-	-	-	-	-	-	-
EF tonnes CO_2 per tonnes TCE[3]	-	-	0.530	-	-	-	-	-	-	-
EF tonnes CO_2 per tonnes TCE[4]	-	-	-	0.504	0.478	-	-	-	-	-
EF tonnes CO_2 per tonnes clinker[4,5]	*0.628*	*0.512*	0.565	0.541	0.520	0.509	0.512	0.512	0.545	0.535
Emission										
Tonnes CO_2	882 402	1 203 777	1 384 742	1 363 000	1 407 086	1 154 749	764 407	672 224	861 805	871 083

1. 1990-1997: Amount of clinker produced has not been measured as for 1998-2008. Therefore, the amount of GLK-, FHK-, SKL-/RKL-clinker and white cement is used as estimate of total clinker production.
2. 1990-1997: EF based on information provided by Aalborg Portland.
3. 1998-2004: EF based on information provided by Aalborg Portland (Aalborg Portland, 2008).
4. 2005-2012: EF based on emissions reported to EU-ETS (Aalborg Portland, 2013a).
5. 1998-2012: EF based on clinker production statistics provided by Aalborg Portland (Aalborg Portland, 2013c).
6. Aalborg Portland (2013b).

NI No information.

1990-1997

The emission factor has been estimated from the loss on ignition determined for the different kinds of clinkers produced, combined with the volumes of grey and white cements produced.

The emission of CO_2 depends on the ratio: white/grey cement and the ratio between three types of clinker used for grey cement: GKL-clinker/FHK-clinker/SKL-RKL-clinker. The ratio white/grey cement is known from 1990-1997 with maximum in 1990 and thereafter decreasing. The ratio: GKL-clinker/FHK-clinker/SKL-RKL-clinker is known from 1990-1997. The production of SKL/RKL-clinker peaks in 1991 and decreases hereafter. FKH-clinker is introduced in 1992 and increase to 35 % in 1997.

$$M_{CO_2} = M_{grey} * \frac{M_{GLK} * EF_{GLK} + M_{FKH} * EF_{FKH} + M_{SKL/RKL} * EF_{SKL/RKL}}{M_{GLK} + M_{FKH} + M_{SKL/RKL}} + M_{white} * EF_{white}$$

Table 4.8 Types of cement and emission factors

M_{grey}	Grey cement	Tonne
M_{white}	White cement	Tonne
M_{GLK}	GLK clinker	Tonne
M_{FKH}	FHK clinker	Tonne
$M_{SKL/RKL}$	SKL/RKL clinker	Tonne
EF_{white}	CO_2 emission factor	0.669 tonne CO_2/tonne white cement
EF_{GLK}	CO_2 emission factor	0.477 tonne CO_2/tonne GLK clinker
EF_{FKH}	CO_2 emission factor	0.459 tonne CO_2/tonne FKH clinker
$EF_{SKL/RKL}$	CO_2 emission factor	0.610 tonne CO_2/tonne SKL/RKL clinker

The company has at the same time stated that data until 1997 cannot be improved as they are not available anymore.

1998-2004

From 1998-2004 carbonate content of the raw materials has been determined by loss on ignition methodology. Determination of loss of ignition takes into account all the potential raw materials leading to release of CO_2 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).

2005-2012

However, from the year 2005 the CO_2 emission determined by Aalborg Portland for EU-ETS is used in the inventory (Aalborg Portland, 2013a). The reporting to EU-ETS also provides detailed information of alternative fuels used in the production of clinker; see Table 4.9.

Table 4.9 Alternative fuels used in production of cement clinker (Aalborg Portland 2013a).

Fuel type	Biomass fraction, %
Cemmiljø fuel	30-56
Paper residues	79
Dry wastewater sludge	100
Meat and bone meal	100
Tyre residues	15
Textile residues from tyres	100
Wood waste	100
Garden waste	100
Glycerine	100

The Aalborg Portland report to EU-ETS applies the EF for the most important raw materials as shown in Table 4.10 (Aalborg Portland, 2013a).

Table 4.10 Emission factors for different raw materials in cement production, 2012.

Raw material	Tonne CO_2 per tonne raw material
Limestone	0.44
Magnesium carbonate	0.522
Sand	0.0088-0.0367
Fly ash	0.140
CKD	0.396-0.525

The EFs for limestone and magnesium carbonate are in accordance with the stoichiometric factors and the EFs for the remaining raw materials and CKD are determined by individual analysis.

2A2 Lime production.

The CO_2 emission from the production of burnt lime (quicklime) as well as hydrated lime (slaked lime) has been estimated from the annual production figures, registered by Statistics Denmark – see Table 4.11 and emission factors.

Table 4.11 Statistics for production of lime and slaked lime (tonnes) (Faxe Kalk, 2013b, Statistics Denmark, 2013).

Year	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
Lime	127 978	100 789	92 002	71 239	75 504	74 981	46 202	50 397	35 824	48 999
Slaked lime	27 686	15 804	8 159	13 839	14 028	12 326	12 842	11 173	13 264	13 388
Produced (burnt) in Denmark	155 664	116 593	100 161	85 078	89 532	87 307	59 044	61 570	49 088	62 387
Imported within company									23 606	20 137
Total amount sold from Danish producers	155 664	116 593	100 161	85 078	89 532	87 307	59 044	61 570	72 694	82 524

The emission factors applied are 0.785 kg CO_2 per kg CaO as recommended by IPCC (IPCC, 1997, vol. 3, p. 2.8) and 0.541 kg CO_2 per kg hydrated lime (calculated from company information on composition of hydrated lime: product purity: 91 % $Ca(OH)_2$ in product (Faxe Kalk, 2003)). One Danish company – Faxe Kalk – is covered by the EU-ETS, however, the company do only account for approximately 75 % of the Danish production of lime and hydrated lime (average from 1998-2012). A number of small companies accounts for the remaining of the Danish production.

The company reporting to EU-ETS apply the following EF: 0.7874867 tonne CO_2 per tonne lime produced (Faxe Kalk, 2013a). This EF is in accordance with the stoichiometric factor.

2A3 Limestone and dolomite use

In the production of stonewool a number of raw materials contributing to CO_2 emission are used: bottom ash from coal-fired CHP, stonewool binder, stonewool waste, limestone, and dolomite. Information on emission of CO_2 has been obtained from confidential company reports to EU-ETS for 2006-2012. For the previous years the emission has been extrapolated.

The CO_2 emission from consumption of limestone for flue gas cleaning has been estimated from statistics on generation of gypsum (wet flue gas cleaning processes) and the stoichiometric relations between gypsum and release of CO_2:

$$SO_2 (g) + ½O_2 (g) + CaCO_3 (s) + 2H_2O \rightarrow CaSO_4{,}2H_2O (s) + CO_2 (g)$$

and the emission factor is: 0.2325 tonnes CO_2 per tonne gypsum.

Statistics on the generation of gypsum from power plants are compiled by Energinet.dk (2008). However, for 2006 - 2012 information on consumption of $CaCO_3$ at the relevant power plants has been compiled (from environmental reports) and used in the calculation of CO_2 emission from flue gas cleaning.

Information on the generation of gypsum at waste incineration plants does not explicitly appear in the Danish waste statistics (Miljøstyrelsen, 2012). However, the total amount of waste products generated can be found in the statistics. The amount of gypsum is calculated by using information on flue gas cleaning systems at Danish waste incineration plants (Illerup et al., 1999; Nielsen & Illerup, 2002) and waste generation from the different flue gas cleaning systems (Hjelmar & Hansen, 2002). However, for 2011 and 2012 information of $CaCO_3$ at the relevant plants has been compiled from environmental reports and used in the calculation of CO_2 emission from flue gas cleaning.

2A5 Asphalt roofing and 2A6 Road paving with asphalt

The indirect emission of CO_2 from asphalt roofing and road paving has been estimated from production statistics compiled by Statistics Denmark and default emission factors presented by IPCC (1997) and EMEP/CORINAIR (2004). The default emission factors, together with the calculated emission factor for CO_2, are presented in Table 4.12.

Table 4.12 Default emission factors for application of asphalt products.

		Road paving with asphalt	Use of cutback asphalt	Asphalt roofing
CH_4	g pr tonnes	5	0	0
CO	g pr tonnes	75	0	10
NMVOC	g pr tonnes	15	64 935	80
Carbon content fraction of NMVOC	%	0.667	0.667	0.8
Indirect CO_2	Kg pr tonnes	0.168	159	0.250

2A7 Other

The category *Other* cover the following processes:

- Production of yellow bricks
- Expanded clay products
- Production of glass
- Production of glass woll

The CO_2 emission from the production of bricks and tiles has been estimated from information on annual production registered by Statistics Denmark, corrected for amount of yellow bricks and tiles. This amount is unknown and, therefore, is assumed to be 50 %; see Table 4.13.

Table 4.13 Statistics for production of yellow bricks and expanded clay products (tonnes) (Statistics Denmark, 2013).

Year	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
Bricks (1000 pieces.)	291 348	362 711	414 791	407 940	348 928	322 137	226 363	212 051	222 144	185 398
Yellow bricks[1]	291 348	362 711	414 791	407 940	348 928	322 137	226 363	212 051	222 144	185 398
Expanded clay products	331 760	340 881	316 174	310 901	504 925	303 948	140 915	157 378	172 263	153 305

1. Assumptions: Brick weight: 2 kg/brick, 50 % yellow bricks.

The content of $CaCO_3$ and a number of other factors determine the colour of bricks and tiles and, in the present estimate, the average content of $CaCO_3$ in clay has been assumed to be 18 % (the $CaCO_3$ content in clay for bricks varies from e.g. 0.5 % in clay for red bricks and 19.8 % in clay for yellow bricks (Tegl Info, 2004). The emission factor for lime (0.44 kg CO_2 per kg $CaCO_3$) has been used to calculate the emission factor for yellow bricks: 0.079 tonne CO_2 per tonne yellow bricks. For verification of this approach, see Figure 4.3.

For 2006-2012 emission factors have been derived from CO_2 emissions reported by the brickworks to EU-ETS (confidential reports from approximately 20 brickworks) and production statistics (Statistics Denmark, 2013). The emission factors for 2006-2012 are calculated to 0.0728-0.1089 tonne CO_2 per tonne yellow bricks (average 0.086).

The company reporting to EU-ETS apply the following EF: 0.44 tonne CO_2 per tonne limestone consumed (different brickworks). This EF is in accordance with the stoichiometric factor.

The CO_2 emission from the production of expanded clay products has been estimated from production statistics compiled by Statistics Denmark and an emission factor of 0.045 tonne CO_2 per tonne product. During the preliminary work to establishment of EU-ETS in Denmark the relevant companies reported energy and process related CO_2 emissions for the years 1998-2002 (DEA, 2004). Based on the process CO_2 emissions and statistical information (Statistics Denmark, 2013) the actual emission factors were determined to respectively 0.0345, 0.0349, 0.0415, 0.0445, and 0.0358 tonne CO_2 per tonne product. As a conservative estimate 0.045 tonne CO_2 per tonne product was chosen as national emission factor.

For 2006-2012 emission factors have been derived from CO_2 emissions reported to EU-ETS (Damolin, 2013; Maxit, 2013) and production statistics (Statistics Denmark, 2012). The emission factors for 2006-2012 are calculated to 0.0381-0.0532 tonne CO_2 per tonne product (average: 0.045).

The companies producing expanded clay products reporting to EU-ETS apply the EF shown in Table 4.14 (different producers):

Table 4.14 Emission factors for production of expanded clay products (multiple producers), 2012.

Raw material	tonne CO_2 per tonne raw material
Bentonite	0.003364
Clay (moler)	0.03002
Clay (moler)	0.02163
Clay, dried (moler)	0.00691
Limestone	0.44
C-source	3.67
C-source	3.14631

The EFs for the clay fractions are determined at the different localities whereas the EFs for limestone and one of the C-sources are in accordance with the stoichiometric factors.

The CO_2 emission from the production of container glass/glass wool has been estimated from production statistics published in environmental reports from the producers (Rexam Glass Holmegaard, 2007; Ardagh Glass Holmegaard, 2013b; Saint-Gobain Isover, 2013b) and emission factors based on release of CO_2 from specific raw materials (stoichiometric determination). For 2006-2012 CO_2 emissions have been derived from company reports to EU-ETS (Ardagh Glass Holmegaard, 2013a; Saint-Gobain Isover, 2013a) combined with information in environmental reports.

The companies producing glass and glass wool reporting to EU-ETS apply the EF shown in Table 4.15 (Ardagh Glass Holmegaard, 2013a, Saint-Gobain Isover, 2013a)

Table 4.15 Emission factors used in glass and glass wool production, 2012.

Raw material	Tonne CO_2 per tonne raw material
Limestone	0.44
Magnesium carbonate	0.522
Dolomite	0.478
Soda ash	0.415
C-source	3.666

The EFs are in accordance with the stoichiometric factors.

EU-ETS (EU Emission Trading Scheme)

Guidelines for calculating company specific CO_2 emissions are developed by the EU (EU, 2007). 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 has to use individual methods to determine the actual composition of raw materials (e.g. purity of limestone or Ca per Mg ratio in dolomite) or the actual CO_2 emission from the specific process.

4.2.3 Uncertainties and time series consistency

The time series are presented in Table 4.5. The methodology applied for the years 1990-2012 is considered to be consistent. 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. Furthermore, the activity data originates from the same company for all years.

For the production of lime and bricks, as well as container glass and glass wool, the same methodology has also been applied for all years. The emission factors are based either on stoichiometric relations or on a standard assumption of $CaCO_3$-content of clay used for bricks. The source for the activity data is, for all years, Statistics Denmark.

The source specific uncertainties for mineral products are presented in Chapter 4.9. The overall uncertainty estimate is presented in Chapter 1.7.

4.2.4 Verification

The estimation of CO_2 release from the production of bricks based on an assumption of 50 % yellow bricks has been verified by comparing the estimate with actual information on emission of CO_2 from calcination of lime compiled by the Danish Energy Agency (DEA) (DEA, 2004). The information from the companies (tile-/brickworks; based on measurements of $CaCO_3$ content of raw material) has been compiled by DEA in order to allocate a CO_2 quota to Danish companies with the purpose of future reductions. The result of the comparison is presented in Figure 4.3. From 2006 the information obtained from the EU-ETS reports was implemented directly.

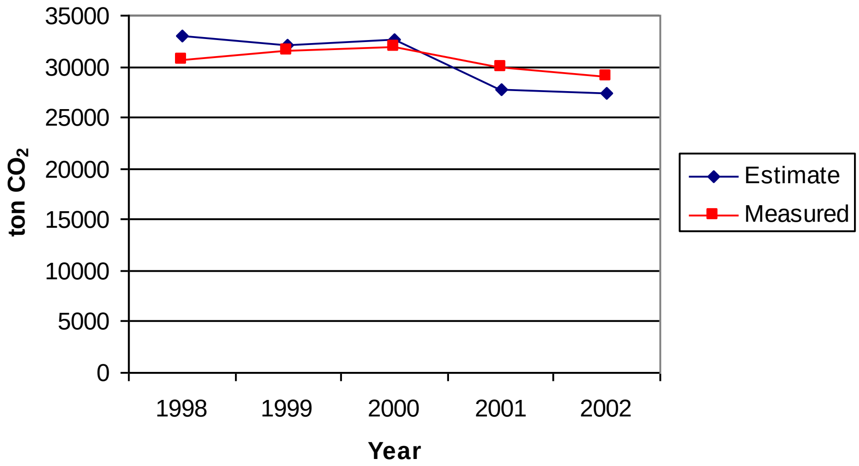

Figure 4.3 Estimated and "measured" CO_2 emission from tile-/brickworks; "measured" means information provided to the Danish Energy Agency by the individual companies (DEA, 2004).

Figure 4.3 shows a reasonable correlation between the estimated and measured CO_2 emission.

The ERT has recommended Denmark to develop a national EF based on the IEF for the years 2006-2010 i.e. emissions based on company reports to EU-ETS. Figure 4.4 presents three scenarios for yellow bricks and expanded clay products:

- Applied methodology from 1990-2005. The EF is based on the assumption that clay for yellow bricks contains 18% $CaCO_3$.
- CO_2 emission based on company reporting to EU ETS for the years 2006-2010.
- Methodology recommended by UNFCCC ERT. The national EF is based on an average of IEF from the years 2006-2011.

Expanded clay products are also a mix of different products with different $CaCO_3$ addition or content. The actual mix is unknown.

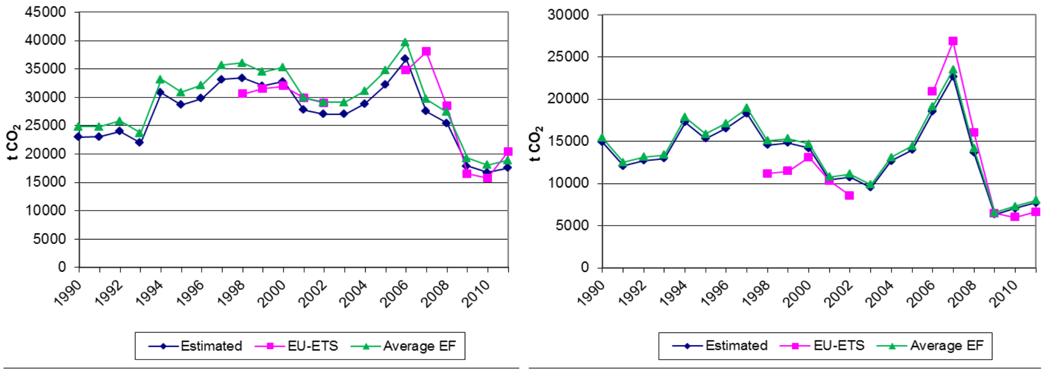

Figure 4.4 CO_2 emission from production of yellow bricks and expanded clay products. The scenarios present the applied methodology (Estimated), available EU-ETS data, and emissions based on a national EF (Average EF).

The recommended methodologies have weaknesses as the (average) EFs are based on actual reported emissions from brickworks and an assumed amount of yellow bricks as well as actual reported emissions from producers of expanded clay products and an assumed product mix. The reliability of the EFs therefore depends on non-verifiable assumptions.

Changes in the methodologies do not change/improve the base year estimates and the best and most precise estimate for the resent years is considered to be the estimates made by the companies for EU-ETS.

4.2.5 Recalculations and improvements

Information on import/export of cement clinker has been included.

4.2.6 Source specific planned improvements

Company specific information on consumption of $CaCO_3$ for flue gas cleaning at waste incineration plants will be included for 2010 and previous years as far as possible. A challenge to solve is to distinguish between limestone and burnt lime as some plants use the term limestone for limestone as well as lime in their environmental reports. The mass balance for production of lime/slaked lime will be investigated as some of the slaked lime may be based on imported lime.

4.3 Chemical industry (2B)

4.3.1 Source category description

The subsector *Chemical industry* (2B) covers the following processes:

- Production of nitric acid/fertiliser.
- Production of catalysts/fertilisers.

Production of nitric acid is identified as a key category due to the trend. However this is due to the closing of the lone plant producing nitric acid in Denmark in 2004.

The time series for emission of CO_2 and N_2O from *Chemical industry* (2B) are presented in Table 4.16.

Table 4.16 Time series for emission of greenhouse gasses from Chemical industry (2B).

2B	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
2. Nitric acid production (kt N_2O)	3.36	2.92	3.24	NO	NO	NO	NO	NO	NO	NO
2. Nitric acid production (kt CO_2 eqv.)	1 043	904	1 004	NO	NO	NO	NO	NO	NO	NO
5. Other (kt CO_2)	0.80	0.80	0.65	3.01	1.35	1.20	1.42	2.12	1.39	1.41
Total (kt CO_2 eq.)	1 044	905	1 004	1.06	1.35	1.20	1.42	2.12	1.39	1.41

The emissions are extracted from the CRF tables and the values are rounded.

The emission of N_2O from nitric acid production is the most considerable source of GHG from the chemical industry. The trend for N_2O from 1990 to 2003 shows a decrease from 3.36 to 2.89 kt, i.e. -14 %, and a 40 % 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.

From 1990 to 2012, the emission of CO_2 from the production of catalysts/fertilisers has increased from 0.80 to 2.12 kt with maximum in 2010, due to an increase in the activity as well as changes in raw material consumption.

4.3.2 Methodological issues

The N_2O emission from the production of nitric acid/fertiliser is based on measurement data for 2002. For the previous years, the N_2O emission has been estimated from annual production statistics from the company and an emission factor of 7.5 kg N_2O per tonne nitric acid, based on the 2002 measurements (Kemira Growhow, 2004). Table 4.17 presents default EF for N_2O emission from nitric acid production.

Table 4.17 Default EF nitric acid production (IPCC, 1997, vol. 3, p. 2.18).

Geographical area	kg N_2O per tonne nitric acid
USA	2 - 9
Norway - modern, integrated plants	< 2
- atmospheric plants	4 - 5
- medium pressure plants	6 - 7.5
Japan	2.2 - 5.7

Specific information on applied technology is not available, however, the EF measured by the Danish nitric acid plant is in accordance with the default emission factors presented by IPCC (1997).

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.

The CO_2 emission from the production of catalysts/fertilisers is based on information in an environmental report from the company (Haldor Topsøe, 2013b), combined with personal communication. In the environmental report, the company has estimated the amount of CO_2 from the process and the amount from energy conversion. Based on information from the company, the emission of CO_2 has been calculated from the composition of raw materials used in the production (for the years 1990 and 1996-2004). The raw materials are e.g.: $CaCO_3$, $CoCO_3$, $CsCO_3$, Cu_2CO_3, K_2CO_3, $MnCO_3$, and $ZnCO_3$; however, the actual composition is confidential. For 2005 the EF is assumed to be the same as in 2004 based on the same activity (produced amount). For the years 1991-1995, the production, as well as the CO_2 emission, has been assumed to remain the same as in 1990.

The producer of catalysts/fertilisers is obliged to report energy related CO_2 emissions to EU-ETS but no the process related emissions. For the years 2006-2012 the process related emissions have been estimates as the difference between the total CO_2 emission reported by the company in yearly environmental reports (Haldor Topsøe, 2013b) and energy related CO_2 emission reported by the company to EU-ETS (Haldor Topsøe, 2013a).

4.3.3 Uncertainties and time series consistency

The time series are presented in Table 4.9. The applied methodology regarding N_2O is considered to be consistent. The activity data is based on information from the specific company. The emission factor applied has been constant for the whole time series and is based on measurements in 2002. The production equipment has not been changed during the period.

The estimated CO_2 emissions from production of catalysts/fertilisers are considered to be consistent as they are based on stoichiometric relations combined with company assumptions for the years 1991-1995.

The source specific uncertainties for the chemical industry are presented in Section 4.9. The overall uncertainty estimate is presented in Chapter 1.7.

4.3.4 Recalculations and improvements

The process related CO_2 emission from production of catalysts/fertilisers has recalculated for the years 2006-2012 by inclusion of available company reports to EU-ETS.

4.3.5 Source specific planned improvements

No improvements are planned for this sector.

4.4 Metal production (2C)

4.4.1 Source category description

The subsector *Metal production* (2C) covers the following process:

- Steelwork

The time series for emission of CO_2 from *Metal production* (2C) is presented in Table 4.18. The emissions are extracted from the CRF tables and the values presented are rounded.

Table 4.18 Time series for emission of CO_2 (ktonne) from Metal production (2C).

2C	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
1. Iron and steel production	28.4	38.6	40.7	15.6	NO	NO	NO	NO	NO	NO

From 1990 to 2001, the CO_2 emission from the electro-steelwork increased from 28 to 47 ktonnes, i.e. by 68 %. The increase in CO_2 emission is similar to the increase in the activity as the consumption of metallurgical coke per amount of steel sheets and bars produced has almost been constant during the period. The electro-steelwork reopened and closed down again in 2005.

4.4.2 Methodological issues

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 tonnes of product) has been almost constant from 1994 to 2001; steel sheets: 0.012-0.018 tonne metallurgical coke per tonne and steel bars: 0.011-0.017 tonne metallurgical coke per tonne. The emission factor (3.6 tonnes CO_2 per tonne metallurgical coke) is based on values in the IPCC-guidelines (IPCC (1997), vol. 3, p. 2.26). The CO_2 emission has been calculated from amounts of final products but related to amount of steel scrap handled at the electro steelwork. Emissions of CO_2 for 1990-1991 and for 1993 have been determined with extrapolation and interpolation, respectively.

4.4.3 Uncertainties and time series consistency

The time series (see Table 4.18) is considered to be consistent as the same methodology has been applied for the whole period. The activity, i.e. amount of steel sheets and bars produced as well as consumption of metallurgical coke, has been published in environmental reports. In 2002, production stopped. For 2005 the production has been assumed to be one third the production in 2001 as the steelwork was operating between 4 and 6 months in 2005.

The source specific uncertainties for the metal production are presented in Section 4.9. The overall uncertainty estimate is presented in Chapter 1.7.

4.4.4 Recalculations and improvements

No source specific recalculations have been performed regarding emissions from the metal production.

4.4.5 Source specific planned improvements

Consumption of reductants in secondary metallurgical processes (e.g. lead) will be investigated.

4.5 Other production (2D)

4.5.1 Source category description

The subsector *Other production*, Food and Drink (2D2) cover the following processes:

- Bread production
- Beer production
- Spirits production
- Sugar production
- Meat (fish etc. frying/curing)
- Margarine and solid cooking fats
- Coffee roasting

Sugar production is the only process contributing to emission of CO_2 whereas all processes contribute to emission of NMVOC. The time series for emission of CO_2 from *Other production, Food and Drink* (2D) is presented in Table 4.19.

Table 4.19 Time series for emission of CO_2 (kt) from Other production, Food and Drink (2D2).

2D	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
2. Food and Drink	4.45	3.91	3.90	4.46	1,72	2,67	1,92	1,56	2,01	2,24

The emissions are extracted from The CRF tables and the values are rounded.

4.5.2 Methodological issues

The CO_2 emission from the refining of sugar is estimated from production statistics for sugar and a number of assumptions: consumption of 0.02 tonne $CaCO_3$ per tonne sugar and precipitation of 90 % CaO resulting in an emission factor at 0.0088 tonne CO_2 per tonne sugar (consumption: 2 % $CaCO_3$ per tonne sugar beets, 10 % sugar in sugar beets). The assumptions are based on environmental reports covering the year 2002. However, from the year 2006-2012 the CO_2 emission compiled by the company for EU-ETS is used in the inventory (Nordic Sugar, 2013). During the preliminary work to establishment of EU-ETS in Denmark the relevant companies reported energy and process related CO_2 emissions for the years 1998-2002 (DEA, 2004). Based on the process CO_2 emissions and statistical information (Statistics Denmark, 2013) the actual emission factors were determined to respectively 0.0048, 0.0038, 0.0046, 0.0039, and 0.0051 tonne CO_2 per tonne product (average: 0.0044).

The time series for sugar production is presented in Table 4.20.

Table 4.20 Production of sugar (tonne) (Statistics Denmark, 2013).

2D	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
Sugar	505 709	444 143	487 107	488 934	329 811	400 261	428 446	262 072	218 065	262 026

4.5.3 Uncertainties and time series consistency

The time series is presented in Table 4.19. The same methodology has been applied for 1990-2005. From 2006-2012 data from EU-ETS has been available and therefore included in the inventory.

The source specific uncertainties for the chemical industry are presented in Section 4.9. The overall uncertainty estimate is presented in Chapter 1.7.

4.5.4 Recalculations and improvements

No source specific recalculations have been performed for the sector *Food and Drink*.

4.5.5 Source specific planned improvements

Implementation of an EF based on information in the company reporting to EU-ETS will be investigated.

4.6 Production of Halocarbons and SF_6 (2E)

There is no production of Halocarbons or SF_6 in Denmark.

4.7 Metal production (2C) and consumption of Halocarbons and SF_6 (2F)

4.7.1 Overview of the sector

The sub-sector *Consumption of halocarbons and* SF_6 (2F) includes the following source categories and the following f-gases of relevance for Danish emissions:

- 2C4: SF_6 used in Magnesium Foundries: SF_6
- 2F1: Refrigeration: HFC-32, -125, -134a, -152a, -143a, PFC (C_3F_8)
- 2F2: Foam blowing: HFC-134a, -152a
- 2F4: Aerosols/Metered dose inhalers: HFC-134a
- 2F8: Production of electrical equipment: SF_6
- 2F9: Other processes (laboratories, double glaze windows, fibre optics): SF_6, HFC-23, CF_4, C_3F_8, C_4F_8

The description of consumption and emission of f-gases given below is based on an inventory published as (Poulsen & Musaeus, 2014). For further details refer to this report.

General trends

A quantitative overview is given below for each of these source categories and each f-gas, showing their emissions in tonnes through the times-series. The data are extracted from the CRF tables that form part of this submission and the data presented are rounded values. 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.

Figure 4.5 present the emission trends for f-gases within the different subsectors.

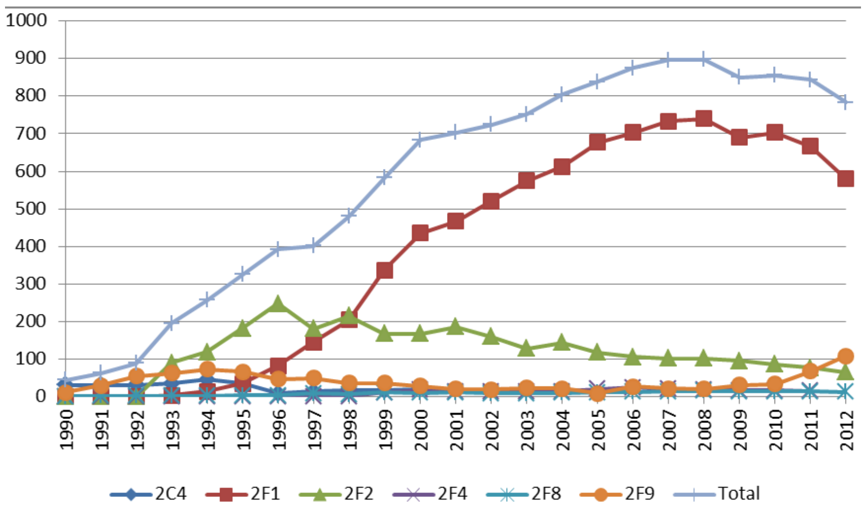

Figure 4.5 Time series for the sub-sectors (ktonne CO_2 equivalents).

The sub-sectors will be described below in the following sections:

- Refrigeration (2F1)
- Foam blowing (2F2)
- Aerosols/metered dose inhalers (2F4)
- Other processes (2C4, 2F8, 2F9)

The emission of SF_6 has been decreasing in recent years due to the fact that activities under Magnesium Foundry no longer exist and due to a decrease in the use of electric equipment. Also, a decrease in "other" occurs until 2010, which for SF_6 is used in window plate production use, laboratories and in the production of running shoes. The increase in 2011 and 2012 is explained in section 4.7.5.

The emission of HFCs increased rapidly in the 1990s and, thereafter, increased more modestly due to a modest 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 they now only increase modestly.

The phase out of f-gasses has in particular been effective within the foam blowing sector and refrigeration installations. With respect to foam blowing, there was a stepwise phase-out of HFC-134a used for foam blowing in hard and soft foam production, during the period 2001-2004. In 2006, all foam production plants in Denmark had substituted HFCs (substitutes have not been included in the inventory). Especially the phase-out of HFCs in soft foam is significant for the GWP emission in this period.

With respect to HFC from refrigeration, it is not possible to determine a stabile decreasing trend yet. Since the introduction of taxes on HFC's in 2001, the consumption decreased in 2002-2003, but then the consumption of HFCs for refrigeration purposes increased again. Especially HFC-404a and HFC-134a increased. This increase is explained with other initiatives in Danish legislation, where new refrigeration systems containing HCFC-22 (ODP) 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. Thus, the consumption of HFCs for refrigeration has changed after 1 January 2007, where new larger HFC installations with stocks exceeding 10 kg are banned. Alternative refrigeration technologies based on CO_2, propane/butane and ammonia is now introduced and available for customers. Butane/propane and ammonia used in refrigeration have not been included in the inventory.

PFCs are emitted in small amounts from refrigeration systems and from optics fibre production, whereas, the consumption as cleaning agent and for new refrigeration systems has been phased out in 2002.

Table 4.21 and Figure 4.6 quantify an overview of the emissions of the gases in CO_2 equivalents. The reference is the trend table as included in the CRF table for year 2011.

Table 4.21 Time series for emission of HFCs, PFCs and SF_6 (kt CO_2 equivalents.).

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
HFCs	-	218	607	802	850	853	799	804	759	657
PFCs	-	0.50	17.9	13.9	15.4	12.8	14.2	13.3	11.1	8.54
SF_6	44.5	107	59.2	21.8	30.3	31.6	36.7	37.9	73.2	118
Total	44.5	326	684	838	896	897	850	855	843	784

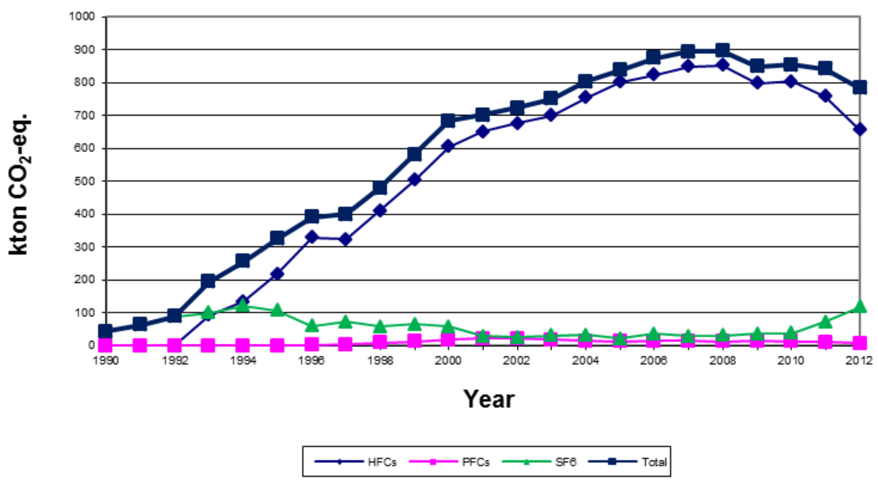

Figure 4.6 Time series for emission of HFCs, PFCs and SF_6 (kt CO_2 equivalents.).

The decrease in the SF_6 emission has brought its emissions in CO_2 equivalents down to the level of PFC. Overall, and for all uses, the most dominant group by far is HFCs. In this grouping, HFCs constitute a key category, both with regard to the level and trend analysis.

General methodology

The data for emissions of HFCs, PFCs, and SF_6 have been obtained in continuation on work on inventories for previous years. The determination includes the quantification and determination of any import and export of HFCs, PFCs, and SF_6 contained in products and substances in stock form. This is in accordance with the IPCC guidelines (IPCC (1997), vol. 3, p. 2.43ff), as well as the relevant decision trees from the IPCC Good Practice Guidance (IPCC, 2000) p. 3.53ff).

For the Danish inventories of f-gases, a Tier 2 bottom-up approach is basically used. As for verification using import/export data, a Tier 2 top-down approach is applied. In an annex to the f-gas inventory report 2011 (Poulsen & Musaeus, 2014)), 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.
- 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 GPG, which are assessed to be applicable in a national context. In case of commercial refrigerants and Mobile Air Condition (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 (MAC, fridge/freezers for household) 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 the annex to the report referred to above.

The Tier 2 bottom-up analysis used for determination of emissions from HFCs, PFCs, and SF_6 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 on the basis of 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 waste products.

Consumption and emissions of f-gases are, whenever possible, 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. However, the continued use of a category for *Other HFCs* has been necessary since not all importers and suppliers have specified records of sales for individual substances.

The potential emissions have been calculated as follows:

Potential emission = import + production - export - destruction/treatment.

Table 4.22 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-407a	23	25	52			
HFC-410a	50	50				
HFC-507a		50		50		

1. The mixtures do also contain substances that do not have GHG potential and therefore, the substances do not sum up to 100 %.

The substances have been accounted for in the 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 schemes, the ratios provided in Table 4.22 have been used.

The national inventories for f-gases are provided and documented in a yearly report (Poulsen & Musaeus, 2014). 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.

4.7.2 2F1 Refrigeration

Source category description

2F1 Refrigeration consists of the following processes:

- Household fridges/freezers
- Commercial refrigeration
- Transport refrigeration
- Mobile air conditioning
- Stationary air conditioning.

Table 4.23 presents the emissions of f-gases from consumption of HFCs and PFC in refrigeration and air conditioning systems.

Table 4.23 Emission of f-gases from consumption of HFCs and PFC in refrigeration and air condition systems (2F1 Refrigeration) (t).

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
HFC-32	NO	0,11	5,75	13,7	15.4	16.8	17.6	17.5	17.1	16.2
HFC-125	NO	2,58	43,1	67,7	73.6	75.3	74.7	72.8	66.7	60.0
HFC-134a	NO	14,3	112	181	198	198	167	187	193	160
HFC-152a	NO	NO	0,58	0,26	0.17	0.14	0.11	0.093	0.077	0.077
HFC-143a	NO	2,43	39,6	60,3	65.6	66.0	64.6	62.5	56.0	49.3
PFC (C_3F_8)	NO	0,072	2,29	1,99	1.51	1.29	1.13	1.00	0.90	0.80

Methodological issues

The data collection is described in the Section 4.7.1 Overview of the sector, General methodology.

The activity data expressed as total amount of HFCs and PFC filled into new products and present in operating systems are presented in Table 4.24 and Table 4.25 respectively.

Table 4.24 Consumption (filled into new products) of HFCs and PFC in refrigeration and air condition systems (2F1 Refrigeration) (t per year).

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
Domestic refrigeration										
HFC-125	NO	0.88	3.96	1.61	1.32	0.86	0.53	0.64	0.79	0.75
HFC-134a	NO	6.16	2.62	65.7	33.6	37.7	17.6	6.82	9.28	9.49
HFC-143a	NO	1.04	4.68	1.90	1.56	1.02	0.62	0.76	0.93	0.89
Commercial Refrigeration[1]										
C_3F_8	NO	1.50	6.30	0.45	0.090	0.06	NO	NO	NO	NO
HFC-125	NO	66.3	118	91.9	91.8	79.5	65.8	67.9	71.0	69.6
HFC-134a	NO	4.68	203	151	106	127	136	106	117	124
HFC-143a	NO	60.8	108	81.4	71.3	55.4	55.4	54.5	53.3	53.4
HFC-152a	NO	NO	1.30	NO	NO	NO	NO	NO	NO	NO
HFC-32	NO	7.00	22.3	21.4	29.6	30.9	17.4	20.2	24.6	22.6
Transport Refrigeration										
HFC-125	NO	1.92	7.92	3.28	0.37	3.24	2.57	2.69	2.90	2.97
HFC-134a	NO	0.12	0.72	0.79	0.44	0.79	0.75	0.74	0.86	0.57
HFC-143a	NO	1.56	9.36	3.87	0.43	3.83	3.04	3.18	3.43	3.51
Mobile Air-Conditioning										
HFC-125	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
HFC-134a	NO	NO	24,0	33,3	35.2	35.7	43.8	67.3	74.1	58.6
HFC-143a	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

1. Including stationary A/C.

Table 4.25 HFCs and PFC present in operating refrigeration and air condition systems (2F1 Refrigeration) (t).

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
Domestic refrigeration										
HFC-125	NO	0.86	25.9	35.1	37.5	38.0	38.1	37.5	36.4	33.8
HFC-134a	NO	165	625	824	854	855	839	811	717	748
HFC-143a	NO	1.02	30.6	41.5	44.3	44.9	45.0	44.4	43.1	40.0
Commercial Refrigeration[1]										
C_3F_8	NO	1.92	25.9	17.6	12.9	11.3	10.0	8.97	8.04	7.18
HFC-125	NO	77.7	414	659	712	707	688	626	580	517
HFC-134a	NO	79.5	690	1 076	1 157	1 109	1 088	1 074	930	901
HFC-143a	NO	71.5	366	580	619	604	582	517	468	410
HFC-152a	NO	NO	5.75	2.12	1.38	1.13	0.93	0.77	0.65	0.65
HFC-32	NO	6.90	70.7	141	164	173	172	167	164	152
Transport Refrigeration										
HFC-125	NO	2.15	26.4	15.7	13.4	14.2	14.3	14.4	14.7	11.3
HFC-134a	NO	0.14	9.87	7.06	5.80	5.57	5.33	5.13	5.08	4.42
HFC-143a	NO	1.84	28.2	17.5	15.2	16.2	16.4	16.6	17.0	13.1
Mobile Air-Conditioning										
HFC-125	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
HFC-134a	NO	NO	149	213	229	231	229	231	230	230
HFC-143a	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

1. Including stationary A/C.

The applied EFs are presented in Table 4.26. The EFs for commercial refrigerators, mobile A/C, and transport refrigeration has been assessed and compared with national conditions (Poulsen, 2002; citation from Poulsen & Musaeus, 2014).

Table 4.26 Applied EF for refrigeration and air condition systems (2F1 Refrigeration) (Poulsen & Musaeus, 2014).

	Assembly, %	Stock, % per annum	Lifetime
Household fridges and freezers	2	1	15 years
Commercial refrigerators	1.5	10	
Mobile air conditioning systems	0.5	33	
Transport refrigeration	0.5	17	6-8 years

Detailed information on the amount of HFCs used for refilling of mobile A/C has been available for 2009 - 2011, and therefore, a new approach has been implemented in the calculation of emissions. HFCs for mobile A/C are only used for refilling, and therefore the amount used for mobile A/C is assumed to be the same as the amount emitted during use (Poulsen & Musaeus, 2014):

Consumption of HFC for MAC = refilled stock = emission

Uncertainties and time series consistency

See Section 4.7.7 Uncertainties and time series consistency.

Recalculations and improvements

No source specific recalculations have been performed regarding emissions from consumption of HFCs and PFC for refrigeration and air conditioning.

Source specific planned improvements

No improvements are planned for this sector.

4.7.3 2F2 Foam blowing

Source category description

2F2 Foam blowing consists of the following processes:

- Hard foam, refrigerators
- System foam, shoes etc.
- Soft foam

Table 4.27 present the emissions of f-gases from consumption of HFCs in foam blowing.

Table 4.27 Emission of HFCs from consumption in foam blowing (2F2) (t).

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
HFC-32	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
HFC-125	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
HFC-134a	NO	136	127	91.2	78.9	78.6	73.2	66.7	59.2	50.4
HFC-152a	NO	43.4	16.2	1.49	2.82	3.39	3.61	4.29	4.07	4.75

Methodological issues

The data collection is described in the Section 4.7.1 Overview of the sector, General methodology.

Table 4.28 and Table 4.29 present the consumption of HFCs in foam blowing and the amount accumulated in stock, respectively.

Table 4.28 Consumption of HFCs in foam blowing (2F2) (t).

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
Hard foam										
HFC-134a	NO	193	220	52.8	94.6	76.1	0.06	0.17	NA	NA
HFC-152a	NO	4.00	1.00	5.50	13.0	15.0	12.0	15.0	8.00	13.0
Soft foam										
HFC-125	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
HFC-134a	NO	105	43.9	11.9	NO	NO	NO	NO	NO	NO
HFC-152a	NO	43.0	15.4	NO	NO	NO	NO	NO	NO	NO
HFC-32	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table 4.29 HFCs present as stock in hard foam (2F2) (t).

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
Hard foam										
HFC-134a	NO	416	1 415	1 258	1 095	1 005	885	762	642	519
HFC-152a	NO	3.60	15.3	24.8	41.9	53.6	62.0	72.7	76.6	84.9

The applied EFs are presented in Table 4.30.

Table 4.30 Applied EFs for foam blowing (2F2) (Poulsen & Musaeus, 2014).

	Consumption; %	Stock, %	Lifetime
Foam in household fridges and freezers	10	4.5 annual	15 years
Soft foam (open cell)	100[1]		
Joint filler	100[1]		
Foaming of polyether (shoe soles)	15	4.5	3 years
System foam	0[2]	-[3]	

1. 100% emission during the first year after production.
2. No emission during production of system foam.
3. System foam is only produced for export.

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.

Uncertainties and time series consistency

See Section 4.7.7 Uncertainties and time series consistency.

Recalculations and improvements

A few corrections have been made in the CRF for consumption of HFC-134a to hard foam – IEF and stock, however, no methodological changes have been implemented.

Source specific planned improvements

No improvements are planned for this sector.

4.7.4 2F4 Aerosols/Metered dose inhalers

Source category description

2F4 Aerosols/Metered dose inhalers consist of HFCs used for:

- Propellant in aerosols
- Medical dose inhalers

Table 4.31 present the emissions of f-gases from consumption of HFCs in aerosols and medical dose inhalers.

Table 4.31 Emissions of HCF-134a from consumption of HFC in aerosols/medical dose inhalers (2F4) (t).

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
HFC-134a	NO	NO	14.5	16.1	16.0	14.3	13.6	12.9	12.5	12.2

Methodological issues

The data collection is described in the section 4.7.1 Overview of the sector, General methodology.

Table 4.32 present the emissions of f-gases from consumption of HFCs in aerosols and medical dose inhalers.

Table 4.32 Consumption of HFC-134a in aerosols/medical dose inhalers (2F4) (t).

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
Metered dose inhalers	NO	NO	1.61	5.63	7.62	7.23	7.07	7.24	6.93	6.84
Aerosols	NO	NO	11.5	15.0	7.00	7.10	6.00	5.23	5.36	5.31

The applied EF is presented in Table 4.33.

Table 4.33 Applied EF for aerosols/medical dose inhalers (Poulsen & Musaeus, 2014).

	Consumption/filling	Stock	Lifetime
Aerosols	0 %	50 % first year 50 % second year	2 years
Medical dose inhalers	0 %	50 % first year 50 % second year	2 years

Uncertainties and time series consistency

See Section 4.7.7 Uncertainties and time series consistency.

Recalculations and improvements

No source specific recalculations have been performed regarding emissions from use of HFC-134a in aerosols and medical dose inhalers.

Source specific planned improvements

No improvements are planned for this sector.

4.7.5 Other processes (2C4, 2F8 and 2F9)

Source category description

Other processes (2C4, 2F8 and 2F9) consist of the following processes:

- Consumption of SF_6 in magnesium foundries; see Table 4.28
- Consumption of SF_6 in electrical equipment; see Table 4.29
- Consumption of SF_6 in running shoes; see Table 4.30
- Consumption of SF_6 in laboratories; see Table 4.30
- Consumption of SF_6 in double glazed windows; see Table 4.30
- Consumption of HFCs and PFCs in fibre optics; see Table 4.30
- Consumption of PCFs as detergent; see Table 4.30

Table 4.34-4.36 presents the emissions of f-gases from consumption of HFCs, PFC and SF_6 in other processes.

Table 4.34 Emissions from SF_6 used in magnesium foundries (2C4) (t).

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
SF_6 used in magnesium foundries	1.30	1.50	0.89	NO	NO	NO	NO	NO	NO	NO

Table 4.35 Emissions from consumption of SF_6 in electrical equipment (2F8) (t).

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
SF_6	0.060	0.16	0.47	0.52	0.63	0.68	0.61	0.59	0.59	0.55

Table 4.36 Emissions from consumption of SF_6, HFCs, and PFCs in other processes (2F9) (t)

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
SF_6	0.50	2.83	1.12	0.39	0.64	0.65	0.93	0.99	2.47	4.38
HFC-23	NO	NO	NO	NO	0.24	0.12	0.24	0.36	0.36	0.12
CF_4	NO	NO	NO	NO	0.14	0.11	0.36	0.36	0.20	0.18
C_3F_8	NO	NO	0.27	NO	NO	NO	NO	NO	NO	NO
C_4F_8	NO	NO	NO	NO	0.45	0.35	0.45	0.45	0.40	0.20

The increase in emission of SF_6 in 2011 is caused by disposal of double glazed windows after 20 years expected lifetime.

Methodological issues

The data collection is described in the Section 4.7.1 Overview of the sector, General methodology. Activity data are presented in Table 4.37-4.38.

Table 4.37 HFCs, PFC and SF_6 consumed in other processes (t).

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
Electrical equipment										
SF_6	1.20	1.40	4.00	3.58	5.11	5.59	3.75	3.18	2.87	1.86
Detergent										
C_3F_8	NO	NO	0.54	NO	NO	NO	NO	NO	NO	NO
Double glaze windows										
SF_6	NO	13.5	4.13	NO	NO	NO	NO	NO	NO	NO
Fibre optics										
c-C_4F_8	NO	NO	NO	NO	0.45	0.35	0.45	0.45	0.40	0.20
CF_4	NO	NO	NO	NO	0.14	0.11	0.36	0.36	0.20	0.18
HFC-23	NO	NO	NO	NO	0.24	0.12	0.24	0.36	0.36	0.12
Laboratories										
SF_6	NO	0.40	NO	NO	0.26	0.27	0.55	0.64	0.74	0.73
Shoes										
SF_6	NO	0.11	0.11	NO	NO	NO	NO	NO	NO	NO
Various										
SF_6	0.10	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table 4.38 SF_6 accumulated as stock in other processes (t).

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
Electrical equipment	9.40	26.2	57.3	67.9	75.5	80.4	83.5	85.5	88.4	89.7
Double glaze windows	NO	25.0	38.4	36.6	75.5	80.4	83.5	85.5	88.4	89.7

The applied EFs are presented in Table 4.39. Special attention has been given to use of SF_6 as insolation in high-voltage plants (Poulsen, 2001; ELTRA, 2004; citation from Poulsen & Musaeus, 2014).

Table 4.39 Applied EFs for other processes (Poulsen & Musaeus, 2014).

	Consumption	Stock	Lifetime
Liquid cleaners/detergents	50 % first year 50 % second year		
Fibre optics production	100 % in the year of production		
Laboratories	100 %		
Insolation gas in double glaze windows	15 %	1% annual	20 years
Insolation gas in high voltage switches	5 %	0.5 % annual 5 % in reuse/ drawing off	?[3]
Shock-absorbing in Nike Air training footwear	-[1]	-[2]	5 years

1. No emission from production in Denmark.
2. Yearly emission has been estimated to 0.11 tonne (Poulsen & Musaeus, 2014).
3. Lifetime unknown.

Uncertainties and time series consistency

See Section 4.7.7 Uncertainties and time series consistency.

Recalculations and improvements

No source specific recalculations have been performed regarding emissions from other use of HFCs, PFCs, and SF_6.

Source specific planned improvements

No improvements are planned for this sector.

4.7.6 QA/QC and verification

Comparison of emissions estimates using different approaches

This comparison of Tier 1 potential emissions has been used for a check on the Tier 2 actual emission estimates. This check was carried out in 1995-1997 and, for all three years, it shows a difference of approximately a factor 3 higher emission by using potential emission estimates.

This comparison of bottom-up estimates has not yet been compared with the top-down Tier 2 approach. This comparison will be developed.

National activity data check

The spreadsheets containing activity data have incorporated several data-control mechanisms, which ensure that data estimates do not contain calculation failures. A very comprehensive QC procedure on the data in the model for the whole time series has been carried out for the 2013 submission in connection with the process which provided, (1) data for the CRF background tables 2(II).F. for the years (1993)-2012 and (2) data for potential emissions in CRF tables 2(I). This procedure consisted of a check of the input data for the model for each substance. As regards the HFCs, this checking was carried out in relation to their trade names. Conversion was made to the HFC substances used in the CRF tables, etc. A QC was that emission of the substances could be calculated and checked comparing results from the substances as trade names and as the "no-mixture" substances used in the CRF.

Emission factors check

Country-specific emission factors are explained and documented for MAC and commercial refrigerants and SF_6 in electric equipment. Separate studies have been carried out and reported; see the previous chapters for references. For other sub-source categories, the country-specific emission factors are assessed to be the same as the IPCC default emission factors.

Emission check

As the f-gas inventory is developed and made available in full in spread sheets, where HFCs data relate to trade names, special procedures are performed to check the full possible correctness of the transformation to the CRF-format through Access databases.

4.7.7 Uncertainties and time series consistency

The time series for actual emissions of halocarbons and SF_6 are presented in Section 4.7.1. The time series are consistent as regards the methodology. The potential emission estimates are only included in the CRF.

Tier 1 and Tier 2 uncertainty estimates have been calculated by use of default uncertainties.

In general, uncertainty in inventories will arise through at least three different processes:

- Uncertainties from definitions (e.g. incomplete, unclear, or faulty definition of an emission or uptake);
- Uncertainties from natural variability of the process that produces an emission or uptake;
- Uncertainties resulting from the assessment of the process or quantity depending on the method used: (i) uncertainties from measuring; (ii) uncertainties from sampling; (iii) uncertainties from reference data that may be incompletely described, and (iv) uncertainties from expert judgement.

Uncertainties due to poor definitions are not expected to be an issue in the f-gas inventory. The definitions of chemicals, the factors, sub-source categories in industries etc. are well defined.

Uncertainties from natural variability are likely to occur over the short-term while estimating emissions in individual years. But over a longer time period, 10-15 years, these variabilities level out in the total emission. This is due to that input data (consumption of f-gases) is known and is valid data, and has no natural variability due to the chemicals stabile nature.

Uncertainties that arise due to imperfect measurement and assessment are probably an issue for the:

- Emission from MAC (HFC-134a).
- Emission from commercial refrigerants (HFC-134a).

Due to the limited knowledge for these sources, the expert assessment of consumption of f-gases can lead to inexact values of the specific consumption of f-gases.

The uncertainty varies from substance to substance. Uncertainty is greatest for HFC-134a due to its widespread application in products that are imported and exported. The greatest uncertainty in application is expected to arise from consumption of HFC-404a and HFC-134a in commercial refrigerators and mobile refrigerators. The uncertainty involved in year-to-year data is influenced by the uncertainty associated with the rates at which the substances are released. This results in significant differences in the emission determinations in the short-term (approximately five years); differences that balance in the long-term.

The source specific uncertainties for consumption of halocarbons and SF_6 are presented in Chapter 4.9. The overall uncertainty estimate is presented in Chapter 1.7.

4.8 Other (2G)

4.8.1 Source category description

The subsector *Other* (2G) covers the following process:

- Oxidation of lubricants during use.

The time series for emission of CO_2 from *Other* (2G) is presented in Table 4.40.

Table 4.40 Time series for emission of CO_2 (kt) from Other (2G).

2G	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
Oxidation of lubricants during use	49.7	48.8	39.7	37.6	37.9	34.0	31.2	33.2	33.2	31.7

The emissions are extracted from the CRF tables and the values are rounded.

The emission of CO_2 from oxidation of lubricants during use is decreasing from 49.7 kt in 1990 to 33.2 kt in 2011.

4.8.2 Methodological issues

The emission of CO_2 from oxidation of lubricants during use is calculated according to the following formula:

$$E_{CO2} = LC \bullet CC_{\text{lubricant}} \bullet ODU_{\text{lubricant}} \bullet 44/12$$

where:

E_{CO2} = emission of CO_2

LC = consumption of lubricants

CC = carbon content of lubricant

ODU = amount of lubricant oxidised during use

In the calculation the following default values have been applied: CC = 20.1 kg C per kg lubricant and ODU = 0.2. The activity data applied are presented in Table 4.41.

Table 4.41 Consumption of lubricant oil (TJ) (Danish Energy Agency).

2G	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
Oxidation of lubricants during use	3 372	3 314	2 693	2 550	2 574	2 307	2 116	2 251	2 251	2 150

4.8.3 Uncertainties and time series consistency

The time series is presented in Table 4.40. The applied methodology has been the same during all the years and is therefore considered to be consistent. The activity data are based on information from Danish Energy Agency. The same emission factor has been used for all the years from 1990 to 2012.

4.8.4 Recalculations and improvements

No source specific recalculations have been performed regarding emissions from the consumption of lubricants.

4.8.5 Source specific planned improvements

No improvements are planned for this sector.

4.9 Uncertainty

4.9.1 Tier 1 uncertainty

The source specific uncertainties for industrial processes are presented in Table 4.42. The uncertainties are based on IPCC guidelines combined with assessment of the individual processes.

The producer has delivered the activity data for production of cement as well as calculated the emission factor based on quality measurements. The uncertainties on activity data and emission factors are assumed to be 1 % and 2 %, respectively.

The activity data for production of lime and bricks are based on information compiled by Statistics Denmark. Due to the many producers and the variety of products, the uncertainty is assumed to be 5 %. The emission factor is partly based on stoichiometric relations and partly on an assumption of the number of yellow bricks. The last assumption has been verified (see Table 4.42). The combined uncertainty is assumed to be 5 %.

The producers of glass and glass wool have registered the consumption of - raw materials containing carbonate. The uncertainty is assumed to be 5 %. The emission factors are based on stoichiometric relations and, therefore, uncertainty is assumed to be 2 %.

The producers have registered the production of nitric acid during many years and, therefore, the uncertainty is assumed to be 2 %. The measurement of N_2O is problematic and is only carried out for one year. Therefore, the 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 and iron and steel production.

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, on the other hand, assumed to be 50 %. The base year for f-gases for Denmark is 1995.

Table 4.42 Uncertainties on activity data and emission factors as well as overall trend uncertainties for the different greenhouse gases.

	Activity data uncertainty	Emission factor uncertainty				
		CO_2	N_2O[2]	HFCs[3]	PFCs[3]	SF_6[3]
Greenhouse gases	%	%	%	%	%	%
2A1. Production of Cement	1	2				
2A2. Production of Lime and Bricks	5	5				
2A3. Limestone and dolomite use	5	5				
2A5. Asphalt roofing	5	25				
2A6. Road paving with asphalt	5	25				
2A7.1 Glass production	5	2				
2A7.2 Yellow bricks	5	2				
2A7.3 Expanded clay	5	2				
2B2. Nitric acid production[2]	2		25			
2B5. Other[1]	5	5				
2C1. Iron and Steel production	5	5				
2D. Food and Drink	5	5				
2F. Consumption of HFC	10			50		
2F. Consumption of PFC	10				50	
2F. Consumption of SF_6	10					50
2G. Other: Lubricants	2	5				
Overall uncertainty in 2012		1.97	-	51.0	51.0	51.0
Trend uncertainty		1.17	-	42.7	240	15.5

1) Production of catalysts/fertilisers.
2) The production closed down in the middle of 2004.
3) The base year for f-gases is for Denmark 1995.

4.9.2 Tier 2 uncertainty

The tier 2 uncertainty for CO_2 emission from industrial processes and consumption of F-gases is presented in Table 4.43 and Table 4.44. The uncertainty estimates are based on the same individual uncertainties as applied for the tier 1 uncertainty estimate.

Table 4.43 Tier 2 uncertainty for industrial processes.

		1990			2012			1990-2012		
		Median Emission	Uncertainty (%) Lower (-)	Upper (+)	Median Emission	Uncertainty (%) Lower (-)	Upper (+)	Median Emission	Uncertainty (%) Lower (-)	Upper (+)
CO_2	ktonnes	2 195	10	13	1 007	2.0	1.9	1 182	9.2	12

Table 4.44 Tier 2 uncertainty for consumption of F-gases.

		1995			2012			1995-2012		
		Median Emission	Uncertainty (%) Lower (-)	Upper (+)	Median Emission	Uncertainty (%) Lower (-)	Upper (+)	Median Emission	Uncertainty (%) Lower (-)	Upper (+)
CO_2 eq.	ktonnes	292	22	33	793	25	37	-414	-60	-33

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. (2012). The present chapter presents QA/QC considerations for industrial processes 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 Tier 1 and Tier 2 level by using default and country specific uncertainty factors. The applied uncertainty factors are presented in Table 4.36.

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.

The applied data sets are presented in Table 4.39.

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.
- 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).

Statistics Denmark is used as source for activity data as they are able to provide consistent data for the period 1990-2012. In the cases where the statistics do not contain transparent data, statistics from industrial organisations are used to generate to required activity data.

For many of the processes, the default emission factors are based on chemical equations and are, therefore, the best choice. In some cases, the default EF has been modified in order to reflect local conditions.

Secondary literature may be used in the interpretation or in disaggregation of the public statistics.

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:

U:\ST_ENVS-Luft-Emi\Inventory\2012\2_Industrial_Processes\Level_1a_Storage.

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 GHG-inventory has been signed. The implementation of this information has been introduced for production of cement, bricks, expanded clay products, flue gas cleaning at CHP and sugar refining.

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 4.45. For the reasoning behind their selection, see DS.1.3.1.

Table 4.45 Applied datasets (archived in: U:\ST_ENVS-Luft-Emi\\LUFT_EMI\Inventory\2012\2_Industrial_Processes\Level_1a_Storage).

\EnvironmentalReports2012\	WasteIncineration (folder)
	AalborgPortland_miljoeredegoerelse_2012
	Ardagh 2012
	Cheminova 2012
	DaniscoGrindsted_GroentRegnskab2012 (folder)
	Faxe Kalk Gl Strandvej ovnanlæg Stubberup 2012
	HaldorTopsøe_GroentRegnskab2012 (folder)
	NordicSugar_Nykøbing_GroentRegnskab2012 (folder)
	Rockwool 2012
	Saint Gobain Isover 2012
\EU-ETS2011\	CHP (folder)
	Industry (folder)
	CO2udledning_og_energiforbrug_EDO_2012
\Statistics2011\	894996651012458366525531977_sugar_production
	1296026454406188864621548830_bread
	1297316516644931165171188125_cattle
	1297326501845340665022549357_pigs
	1297336487270930464880805095_poultry
	1301665535347807555368038512_fats
	201311617158130087722KN8Y62151633712_coffee_IE
	1305175019872105850216162313_beverage
	2013930173742128623422VARER163480203877_cement_lime_production
	201392613847128456841KN8Y47607586821_cement_lime_IE
	1311164389470475343927081523_bricks
	2013111416345130441698VARER159695496883_asphalt 2
	1730176216664248062176998064_asphalt 2_IE
	201311617158130087722KN8Y62151633712_coffee_IE
	894914413900940644148244741_expanded clay
	894996651012458366525531977_sugar_production
	Landbrugsstatistik_1985-90
	Fiskeristatistik 2012

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 Tier 1 as well as Tier 2 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 issue will be investigated further.

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 NIR. 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.

A methodology to verify calculation of results using other measures will be developed.

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 industry (in prep.).

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 industry (in prep.) 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 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.

The IEFs are checked by using a tool developed especially for that purpose and outliers are explained.

Data Storage level 4	4. 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 and Greenland.

The aggregated submission for Denmark and Greenland is checked against the individual submissions for Denmark and Greenland.

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, 2012b). 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, 2007).

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5 Solvent and Other Product Use (CRF sector 3)

5.1 Introduction

This section presents the Danish methodology used for calculating emissions from use of solvents and other product use in industries and households that are related to the source categories Paint application (CRF sector 3A), Degreasing and dry cleaning (CRF sector 3B), Chemical products, manufacture and processing (CRF sector 3C) and Other Use of Solvents and Products (CRF sector 3D). Covered pollutants are; NMVOC, CO_2 and N_2O.

Solvents are chemical compounds that are used on a global scale in industries and as constituents in final products to dissolve e.g. paint, cosmetics, adhesives, ink, rubber, plastic, pesticides, aerosols or are used for cleaning purposes, i.e. degreasing. NMVOCs are main components in solvents - and solvent use in industries and households is typically a dominant source of anthropogenic NMVOC emissions (UNFCCC, 2008; Pärt, 2005; Karjalainen, 2005). In industries 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 solvent ends up in waste or as emissions to water and may finally also contribute to air pollution by evaporation from these compartments. Emission inventories for solvents are based on model estimates, as direct and continuous emissions are rarely measured. In addition to emissions from use of solvents emissions from use of fireworks, tobacco, candles and charcoal for barbeques are included in the source category CRF 3D.

In this section the methodology for the Danish emission inventory for Solvent and Other Product Use is presented and the results for the period 1990 – 2012 are summarised. The method is mainly based on the detailed approach and methodology described in EMEP/EEA (2009) and IPCC (1997 & 2000), and emissions are calculated for industrial sectors, households for the stated CRF sectors, as well as for individual pollutants.

The data presented in Chapter 5 relate to Denmark only, whereas information for Greenland is included in Chapter 16 and for the Faroe Islands in Annex 8.

5.2 Methodology

Emission modelling of solvents can basically be done in two ways: 1) By estimating the amount of (pure) solvents consumed, or 2) By estimating the amount of solvent containing products consumed, taking account of their solvent content (EMEP/EEA, 2009).

In 1) all relevant solvents must be estimated, or at least those together representing more than 90 % of the total pollutant emission, and in 2) all relevant source categories must be inventoried or at least those together contributing more than 90 % of the total pollutant emission. A simple approach is to use a per capita emission for each category, whereas a detailed approach is to get all relevant consumption data (EMEP/EEA, 2009).

The detailed method 1) is used in the Danish emission inventory for solvent use, thus representing a chemicals approach, where each pollutant is estimated separately. The sum of emissions of all estimated pollutants used as solvents equals the pollutant emission from solvent use.

A Tier 1 method is used for determining emissions from fireworks, tobacco, candles and charcoal for barbeques included in CRF 3D, this means a simple multiplication of activity data with emission factors.

5.2.1 Pollutant list

NMVOC is the most abundant chemical group in relation to Solvent and Other Product Use. Additionally there is also some use and/or emissions of NO_2 and CO_2.

The definitions of solvents and VOC that are used in the Danish inventory (Nielsen et al., 2012) 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".

This implies that some NMVOCs, e.g. ethylenglycol, that have vapour pressures just around 0.01 kPa at 20 °C, may only be defined as VOCs at use conditions with higher temperature. However, use conditions under elevated temperature are typically found in industrial uses. Here the capture of solvent fumes is often efficient, thus resulting in small emissions (communication with industries).

The Danish list of NMVOCs comprises approximately 30 compunds or compound groups representing more than 95 % of the total emission from solvent use, cf. Table 5.3. CO_2 conversion factors, where all carbon in a carbon-containing molecule, is converted to CO_2, are also listed in Table 5.3.

Emissions that are emitted from other product use are CO_2, N_2O and NMVOC.

5.2.2 Activity data

For each compound or product a mass balance is formulated:

Consumption = (production + import) – (export + destruction/disposal + hold-up) (Eq. 1)

Data concerning production, import and export amounts of solvents and solvent containing products are collected from StatBank DK (2012), which contains detailed statistical information. Manufacturing and trading industries are committed to reporting production and trade figures to the Danish Customs & Tax Authorities in accordance with the Combined Nomenclature. Import and export figures are available on a monthly basis from 1990 to present and contain trade information from approximately 200 countries world-wide. Production figures are reported quarterly as industrial commodity statistics by commodity group and unit from 1990 to present.

Destruction and disposal of solvents lower the NMVOC emissions. In principle this amount must be estimated for each compound in all industrial activities and for all uses of solvent containing products. At present the solvent inventory only considers destruction and disposal for a limited number of solvents. For some compound it is inherent in the emission factor, and for others the reduction is specifically calculated from information obtained from the industry or literature.

Hold-up is the difference in the amount in stock in the beginning and at the end of the year of the inventory. No information on solvents in stock has been obtained from industries. Furthermore, the inventory spans over several years so there will be an offset in the use and production, import and export balance over time.

In some industries the solvents are consumed in the process, e.g. in the graphics and plastic industry, whereas in the production of paints and lacquers the solvents are still present in the final product. These products can either be exported or used in the country. In order not to double count consumption amounts of pollutants it is important to keep track of total solvent use, solvents not used in products and use of solvent containing products. Furthermore some pollutants may be represented as individual pollutants and also in chemical groups, e.g. “o-xylene”, “mixture of xylenes” and “xylene”. Some solvents are better inventoried as a group rather than individual compounds, due to missing information on use or emission for the individual compounds. The Danish inventory considers single compounds, with a few exceptions.

Activity data for solvents are thus primarily calculated from Equation 1 with input from StatBank DK (2012). When StatBank (2012) holds no information on production, import and export or when more reliable information is available from industries, scientific reports or expert judgements the data can be adjusted or even replaced.

Activity data for Other Product Use in CRF 3D are compiled from StatBank DK.

5.2.3 Emission factors

For each pollutant the emission is calculated by multiplying the consumption with the fraction emitted (emission factor), according to:

Emission = consumption * emission factor

The present Danish method uses emission factors that represent specific industrial activities, such as processing of polystyrene, dry cleaning etc. or that represent use categories, such as paints and detergents. Some pollutants have been assigned emission factors according to their water solubility. Higher hydrophobicity yields higher emission factors, since a lower amount ends in waste water, e.g. ethanol (hydrophilic) and turpentine (hydrophobic).

Emission factors for solvents are categorised in four groups in ascending order: (1) Lowest emission factors in the chemical industry, e.g. lacquer and paint manufacturing, due to emission reducing abatement techniques and destruction of solvent containing waste, (2) Other industrial uses, e.g. graphic industry, have higher emission factors, (3) Non-industrial use, e.g. auto repair and construction, have even higher emission factors, (4) Diffuse use of solvent containing products, e.g. painting, where practically all the pollutant present in the products will be released during or after use.

For a given pollutant the consumed amount can thus be attributed with two or more emission factors; one emission factor representing the emissions occurring at a production or processing plant and one emission factor representing the emissions during use of a solvent containing product. If the chemical is used in more processes and/or is present in several products more emission factors are assigned to the respective chemical amounts.

Emission factors can be defined from surveys of specific industrial activities or as aggregated factors from industrial branches or sectors. Furthermore, emission factors may be characteristic for the use pattern of certain products. The emission factors used in the Danish inventory also rely on the work done in the joint Nordic project (Fauser et al., 2009).

Emission factors for Other Product Use in CRF 3D are compiled from literature searches.

5.2.4 Source allocation

The Danish Working Environment Authority (WEA) is administrating the registrations of chemicals and products to the Danish product register. All manufacturers and importers of products for occupational and commercial use are obliged to register. The following products are comprised in the registration agreement:

- Chemicals and materials that are classified as dangerous according to the regulations set up by the Danish Environmental Protection Agency (EPA).
- Chemicals and materials that are listed with a limit value on the WEA "limit value list".
- Materials, containing 1 % or more of a chemical, which is listed on the WEA "limit value list".
- Materials, containing 1 % or more of a chemical, which are classified as hazardous to humans or the environment according to the EPA rules on classification.

There are the following important exceptions for products, which does not need to be registered:

- Products exclusively for private use.
- Pharmaceuticals ready for use.
- Cosmetic products.

The Danish product register does therefore not comprise a complete account of used pollutants. Source allocations of exceptions from the duty of declaration are done based on information from trade organisations, industries, scientific reports and information from the internet.

Outputs from the inventory are

- a list where the most predominant pollutants are ranked according to emissions to air,
- specification of emissions from industrial sectors and from households,

- contribution from each pollutant to emissions from industrial sectors and households,
- yearly trend in emissions, expressed as total pollutant and single pollutant, and specified in industrial sectors and households.

5.3 Emissions, activity data and emission factors

5.3.1 Solvent Use (NMVOC and CO_2 equivalent emissions)

Table 5.1 and Figure 5.1 show the emissions of NMVOC and CO_2 from 1990 to 2012, where the used amounts of single pollutants have been assigned to specific products and CRF sectors. A general increase is seen for all sectors from 1990 to 1996 followed by a decrease from 1997 to 2006 and stagnation in the period 2007 to 2012. Table 5.2 shows the used amounts of pollutants for the same period. Table 5.1 is derived from Table 5.2 by applying emission factors relevant to individual pollutants and production or use activities. Table 5.2 showing the used amount of products (activity data) is derived by assessing the amount of pollutants that is comprised within products belonging to each of the four source categories. The CO_2 conversion factor for each pollutant is shown in Table 5.3.

In Table 5.3 the emission for 2012 is split into individual pollutants. The most abundantly used solvents are ethanol, turpentine, or white spirit defined as a mixture of stoddard solvent and solvent naphtha and propylalcohol. Ethanol is used as solvent in the chemical industry and as windscreen washing agent. Turpentine is used as thinner for paints, lacquers and adhesives. Propylalcohol is used in cleaning agents in the manufacture of electrical equipment, flux agents for soldering, as solvent and thinner and as windscreen washing agent. Household emissions are dominated by propane and butane, which are used as aerosols in spray cans, primarily in cosmetics. For some pollutants the emission factors are precise but for others they are rough estimates. The division of emission factors into four categories implies that high emission factors are applicable for use of solvent containing products and lower emission factors are applicable for use in industrial use.

The full time series for NMVOC emissions (Table 5.1) and used amount of products (Table 5.2) are presented in Annex 3D; Table 3D-2a, b, c, Table 3D-3 and Table 3D-4, respectively.

Table 5.1 Emission of NMVOC and CO_2-eqv. in Gg pr year.

Total emissions Gg pr year	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
3A Paint Application	5,11	5,90	6,40	5,25	5,18	4,99	4,66	4,32	3,73	3,23	3,38	2,85	2,75	2,87	2,86
3B Degreasing, Dry cleaning and Electronics	7E-05	8E-05	3E-05	1E-05	3E-05	3E-05	2E-05	2E-05	1E-05	2E-05	2E-05	1E-05	1E-05	1E-05	3E-06
3C Chemical Products Manufacturing and Processing	8,14	9,32	6,96	6,28	6,58	4,96	6,06	6,25	6,02	6,12	5,91	4,99	5,05	4,81	4,87
3D Other Use of Solvents and Products	24,7	30.0	27,8	24,8	24,4	22,5	21,4	20,8	20,8	18,0	18,4	19,7	19,4	19,3	19,1
3D3 Other Product Use	0,0831	0,0789	0,0950	0,0855	0,102	0,115	0,102	0,0950	0,109	0,0838	0,0775	0,0804	0,0678	0,0601	0,0817
Total NMVOC	38,0	45,3	41,3	36,4	36,2	32,5	32,3	31,5	30,7	27,5	27,8	27,6	27,3	27.0	27.0
Total CO_2-eqv.	93.5	109	100	88,1	88,4	80,3	78,2	75,7	71,7	64,3	65,7	65,1	63,6	63,4	63,3

Table 5.2 Used amounts of products (activity data) in Gg pr year.

Used amounts of products Gg pr year	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
3A Paint Application	83,2	92,1	105	86,4	86,7	79,8	77,7	75,2	64,7	57,3	58,1	48,7	45,8	43,8	43,3
3B Degreasing, Dry cleaning and Electronics	1,41	1,53	0,586	0,251	0,597	0,578	0,481	0,365	0,292	0,433	0,299	0,263	0,247	0,224	0,054
3C Chemical Products Manufacturing and Processing	406	504	567	551	540	513	634	740	749	814	771	683	641	640	516
3D Other Use of Solvents and Products	197	247	230	206	218	185	182	204	180	162	169	179	170	169	169
3D3 Other Product Use	28,0	31,4	46,5	42.0	56,3	61,8	61,4	63,4	63,6	58,5	51,2	52,2	57,7	49,9	53,6
Total products	716	877	949	886	902	841	956	1083	1058	1093	1049	963	914	903	782

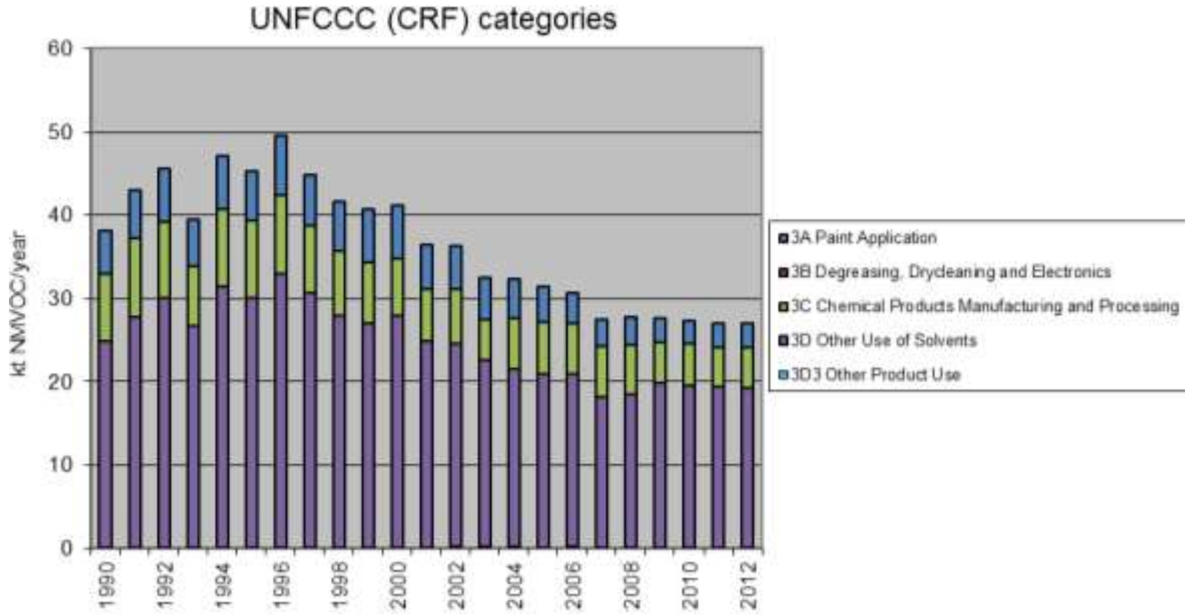

Figure 5.1 Emissions of NMVOC in kt NMVOC per year

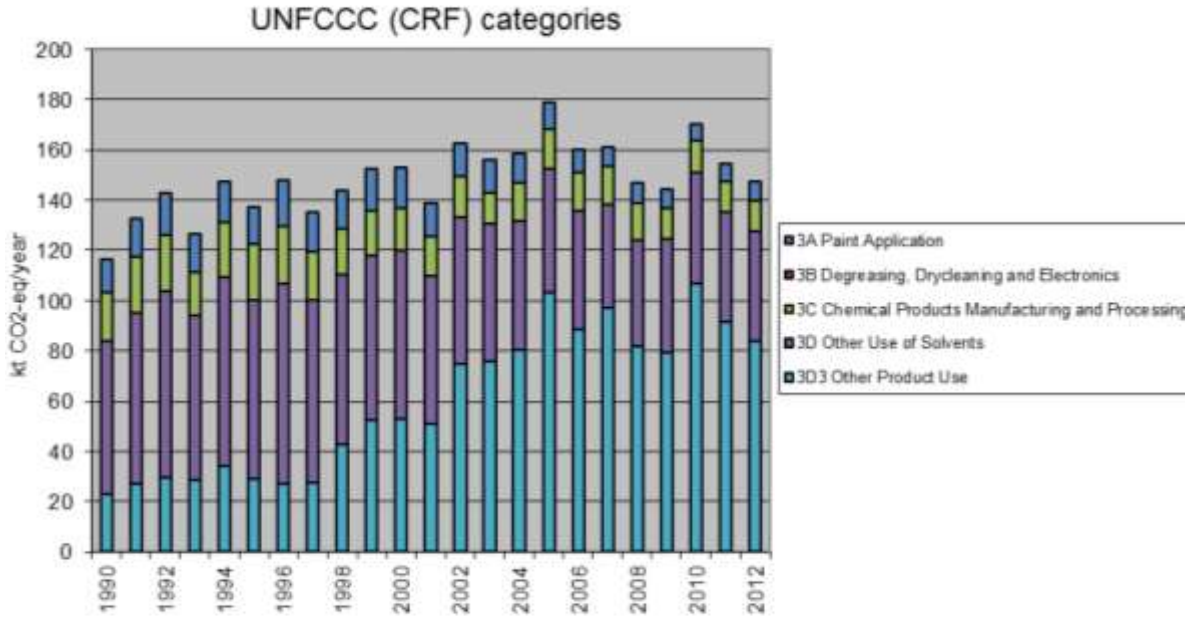

Figure 5.2 Emissions of CO_2-eq in kt CO_2-eq per year.

Table 5.3 NMVOCs with highest emissions 2012, and CO_2 conversion factors assuming that all carbon molecules in the NMVOC molecule are converted to carbon in CO_2.

Pollutant	CAS no	Emissions 2012 (tonnes)	CO_2-conversion factor (g CO_2 pr g NMVOC)
ethanol	64-17-5	7982	1.91
turpentine (white spirit: stoddard solvent and solvent naphtha)	64742-88-7 8052-41-3	6239	2.79
propyl alcohol	67-63-0	2847	2.20
cyanates	79-10-7	2260	1.83
pentane	109-66-0	1650	3.06
methanol	67-56-1	1069	1.38
acetone	67-64-1	861	2.28
propylen glycol	57-55-6	851	1.74
propane	74-98-6	654	2.86
butane	106-97-8	654	2.93
butanone	78-93-3	348	2.45
xylene	1330-20-7 95-47-6 108-38-3 106-42-3	270	3.32
glycol ethers	110-80-5 107-98-2 108-65-6 34590-94-8 112-34-5 and others	251	1.95
ethylen glycol	107-21-1	180	1.42
toluene	108-88-3	141	3.35
cyclohexanones	108-94-1	135	2.69
phenol	108-95-2	130	2.81
styrene	100-42-5	100	3.39
butanoles	78-92-2 2517-43-3 and others	87.5	2.24
formaldehyde	50-00-0	72.3	1.47
acyclic aldehydes	78-84-2 111-30-8 and others	29.4	2.31
ethyl acetate	141-78-6	29.3	2.00
1-butanol	71-36-3	14.7	2.38
butyl acetate	123-86-4	14.0	2.28
tetrachloroethylene	127-18-4	0.45	0.531
acrylic acid	79-10-7	0.043	1.83
Total 2012		26,950	

5.3.2 Other Use of Solvents and Product Use (N_2O, CO_2 and CO_2 equivalent emissions)

3D1 Use of N_2O for Anaesthesia and 3D5 Other Product Use

N_2O is predominantly used as anaesthesia and a small amount is used as fuel in race cars and in chemical laboratories.

Five companies sell N_2O in Denmark and only one company produces N_2O. N_2O is primarily used in anaesthesia by dentists, veterinarians and in hospitals and in minor use as propellant in spray cans, 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. An emission factor of 1 is assumed for all uses, which equals the sold amount to the emitted amount. Sold amounts are obtained from the respective companies and the produced amount is estimated from communication with the company.

Total sold and estimated produced N_2O for sale in Denmark, which equals the emissions, is shown in Table 5.4.

Table 5.4 N_2O emissions. EF = 1, i.e. sale equals emissions, and CO_2-eqv. in Gg per year.

Total emissions Gg per year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
3D1	0,0021	0,0078	0,0086	0,0133	0,0191	0,0342	0,0356	0,0407	0,0330	0,0458	0,0344	0,0420	0.0301
Total CO_2-eqv.	0.65	2.42	2.66	4.12	5.93	10.6	11.0	12.6	10.2	14.2	10.7	13.0	9.33

Table 5.5 and 5.7 presents the emissions, activity data and emission factors for N_2O and CO_2 from the use of fireworks, tobacco, candles and charcoal, which are included in CRF 3D5 Other. Full time series for emissions and activity data can be found in Annex 3D-5 and 3D-6. Activity data are compiled from Statbank (2013).

Table 5.5 Emission of CO_2 and N_2O from the product use of fireworks, tobacco, candles and charcoal.

		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012
CO_2 emission from												
Fireworks	Gg	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Candles	Gg	21.7	26.5	49.3	100.2	85.1	93.4	78.1	75.0	102.7	87.8	81.1
Total	Gg	21.7	26.6	49.5	100.4	85.3	93.6	78.3	75.3	102.9	88.0	81.3
N_2O emission from												
Fireworks	Mg	2.5	5.8	9.4	7.1	8.1	8.7	8.5	10.4	10.5	9.2	6.7
Tobacco	Mg	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5
Candles	Mg	0.2	0.2	0.4	0.8	0.7	0.8	0.6	0.6	0.8	0.7	0.7
Charcoal	Mg	0.2	0.2	0.4	0.4	0.6	0.4	0.3	0.3	0.2	0.2	0.4
Total	Mg	3.7	7.0	10.9	9.1	10.1	10.4	10.0	12.0	12.2	10.6	8.4
Total	Gg CO_2-eqv.	22.9	28.8	52.9	103.2	88.4	96.9	81.4	79.0	106.7	91.3	83.8

Table 5.6 Activity data for the product use of fireworks, tobacco, candles and charcoal.

Year		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012
Fireworks	Gg	1.3	3.0	4.9	3.7	4.2	4.5	4.4	5.4	5.4	4.7	3.5
Tobacco	Gg	12.7	11.4	11.4	10.4	10.3	9.8	9.6	9.4	9.2	8.3	8.2
Candles	Gg	7.4	9.1	16.9	34.4	29.2	32.1	26.8	25.8	35.3	30.2	27.9
Charcoal	Gg	7.2	7.9	13.4	14.9	19.8	12.2	10.4	11.6	7.8	6.7	14.0

Emission factors for use of fireworks, tobacco, candles and charcoal are found from literature studies and are shown in Table 5.7.

Table 5.7 Emission factors for other product use, per Mg.

Compound	Unit	Fireworks	Tobacco	Candles	BBQ
CO_2	Mg	0.043 (a)	NA	2.915 (c)	NA
N_2O	kg	1.935 (a)	0.064 (b)	0.024 (d)	0.030 (e)

(a) Netherlands National Water Board (2008), (b) EFs for wood (111A) in residential plants (1A4b i), SNAP 020200, the energy content used in the calculation is the average of wood pills and wood waste (16.1 GJ/Mg), (c) Shires et al. (2004), (d) Shires et a. (2009), (e) IPCC Guidelines (1997),

5.4 Uncertainties and time series consistency

5.4.1 Solvent Use (NMVOC and CO_2 equivalent emissions)

Tier 1 and 2 uncertainties are expressed as ± 95%-confidence interval limits in percentage relative to the calculated mean emissions for 1990 and 2012, respectively.

Table 5.8 Tier 1 uncertainties for NMVOC and CO_2 equivalents.

Pollutant	Total emission uncertainty, %	Trend 1990-2012, %
NMVOC	23	11
CO_2-eqv.	23	10

Table 5.9 Tier 2 uncertainties for NMVOC and CO_2 equivalents.

Pollutant	1990			2012			Trend 1990-2012		
	Median Emission (Gg)	Lower (%)	Upper (%)	Median Emission (Gg)	Lower (%)	Upper (%)	Median difference (Gg)	Lower (%)	Upper (%)
NMVOC	38	-13	+16	27	-14	+17	11	-3	+4
CO_2-eqv.	94	-14	+16	63	-14	+17	30	-4	+5

Important uncertainty issues related to the mass-balance approach are:

(i) Identification of pollutants that qualify as NMVOCs. Although a tentative list of 650 pollutants from NAEI (2000) has been used, it is possible that relevant pollutants are not included, e.g. pollutants that are not listed with their name in Statistics Denmark (StatBank DK, 2012) but as a product.

(ii) Collection of data for quantifying production, import and export of single pollutants and products where the pollutants are comprised. For some pollutants no data are available in StatBank DK (2012). This can be due to confidentiality or that the amount of pollutants must be derived from products wherein they are comprised. For other pollutants the amount is the sum of the single pollutants *and* product(s) where they are included. The data available in StatBank DK (2012) is obtained from Danish Customs & Tax Authorities and they have not been verified in this assessment.

(iii) Distribution of pollutants on products, activities, sectors and households. The present approach is based on amounts of single pollutants. To differentiate the amounts into industrial sectors it is necessary to identify and quantify the associated products and activities and assign these to the industrial sectors and households. No direct link is available between the amounts of pollutants and products or activities. From the Nordic SPIN database it is possible to make a relative quantification of products and activities used in industry, and combined with estimates and expert judgement these products and activities are differentiated into sectors. The contribution from households is also based on estimates. If the household contribution is set too low, the emission from industrial sectors will be too high and vice versa. This is due to the fact that the total amount of pollutant is constant. A change in distribution of pollutants between industrial sectors and households will, however, affect the total emissions, as different emission factors are applied in industry and households, respectively.

A number of activities are assigned as “other”, i.e. activities that cannot be related to the comprised source categories. This assignment is based on expert judgement but it is possible that the assigned amount of pollutants may more correctly be included in other sectors. More detailed information from the industrial sectors is continuously being implemented.

(iv) Rough estimates and assumed emission factors are used for some pollutants. For some pollutants more reliable information has been obtained from the literature and from communication with industrial sectors. In some cases it is more appropriate to define emission factors for sector specific activities rather than for the individual pollutants. A quantitative measure of the uncertainty has not been assessed. Single values have been used for emission factors and activity distribution ratios etc.

5.4.2 Other Use of Solvents and Product Use (N_2O, CO_2 and CO_2 equivalent emissions)

Tier 1 and 2 uncertainties for CO_2, N_2O and their respective CO_2 equivalents are shown in Table 5.10 and 5.12, respectively.

Table 5.10 Tier 1 uncertainties for CO_2, N_2O and CO_2 equivalents.

Pollutant	Total emission uncertainty, %	Trend 1990-2012, %	Uncertainty trend %-age points
CO_2	100	324	48
N_2O	93	230	79
GHG (CO_2 eqv.)	88	234	73

Table 5.11 Tier 2 uncertainties for CO_2, N_2O and CO_2 equivalents.

Pollutant	1990			2012			Trend 1990-2012		
	Median Emission (Gg)	Lower (%)	Upper (%)	Median Emission (Gg)	Lower (%)	Upper (%)	Median difference (Gg)	Lower (%)	Upper (%)
CO_2	22	-20	+24	81	-20	+24	-60	-67	+55
N_2O	4	-42	+102	19	-22	+55	-15	-180	+73
GHG (CO_2 eqv.)	23	-18	+24	93	-17	+22	-70	-65	+50

The main issue leading to uncertainties is:

- Collection of data for quantifying production, import and export of products. Some data, like private import (cross-border shopping) of tobacco, are not available in StatBank DK (2012).

5.5 Quality assurance/quality control (QA/QC) and verification

Table 5.12 External and internal data for NMVOC emission inventory.

File or folder name	Description	AD or Emf.	Reference	Contact(s)	Data agreement/Comment
"Emissioner NMVOC" folder	Production, import and export data from Statistics Denmark	Activity data	Statistics Denmark		Statistics Denmark are obligated by law to publish the foreign trade statistics and production statistics
NMVOC emissions.xls	Calculations, emission factors, SPIN data. For industrial branches (NACE)	Activity data and emission factors	Statistics Denmark, SPIN, reports, personal communication		
Use Category National.xls	Calculations, emission factors, SPIN data (UCN and NACE) and use amounts from Statbank.	Activity data and emission factors	Statistics Denmark, SPIN, reports, personal communication		
Emission factors solvent use.xls	Emission factors for chemicals in CRF and SNAP sub-categories. CO_2 conversion factors.	Emission factors and CO_2 conversion factors	Scientific reports, personal communication and expert judgement		

The QA/QC procedure is outlined in Section 1.6. In general, Critical Control Points (CCP) has been defined as elements or actions, which need to be addressed in order to fulfil the quality objectives. The CCPs have to be based on clear measurable factors, expressed through a number of Points for Measuring (PM).

Data Storage level 1	1. Accuracy	DS.1.1.1	General level of uncertainty for every data set including the reasoning for the specific values

The sources of data described in the methodology section and in DS.1.2.1 and DS.1.3.1 are used in this inventory. It is the accuracy of these data that define the uncertainty of the inventory calculations. Any data value obtained from StatBank DK (2012) 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 expert 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.

1) Production and import/export data from StatBank DK (2012) for single chemicals can be directly compared with data from Eurostat (2012) for other countries. This has been done for a few chosen chemicals and countries. Furthermore, chosen Danish data from Eurostat (2012) have been validated with

data from StatBank DK (2012) in order to check the consistency in data transfer from national to international databases.

2) 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.

3) A joint Nordic project funded by the Nordic Council of Ministers has been used on methodological issues and for emission factors.

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.

A number of external data sources form the basis for calculating emissions of single chemicals. The general methodology in the emission inventory is described above.

1) StatBank DK (2012) is used as the main database for collecting data on production, import and export of single chemicals, chemical groups and for some products. 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. The database covers all sectors and is regarded as complete on a national level.

2) 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.

3) 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, i.e. 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 industrial branches may give valuable information on specific chemicals and/or products and industrial activities. By considering both sources a verification as well as optimum reliability and accuracy is obtained.

4) 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.

Data are predominantly extracted from the internet (StatBank 2012 and SPIN). These 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 conditions of delivery

As stated in DS.1.4.1 most data are obtained from the internet. 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.

Datasets are archived as stated in Table 5.5. External contacts are stored in e-mail and documents.

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

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. 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.

In "Uncertainties and time series consistency" important uncertainty issues related to missing quantitative knowledge is stated. To summarise; (i) identification and inclusion of all relevant chemicals (and products) Identification of chemicals that qualify as NMVOCs. The definition in the solvent directive (Directive 1999/13/EC) is used. Here 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". A tentative list of 650 chemicals from the "National Atmospheric Emission Inventory" (NAI 2000) has been used, it is possible that relevant chemicals are not included. (ii) Collection of data for quantifying production, import and export of single chemicals. For some chemicals no data are available in StatBank DK (2012). This can be due to confidentiality or that the amount of chemicals must be derived from products wherein they are comprised. (iii) Distribution of chemicals on products, activities, sectors and households. No direct link is available between the amounts of chemicals and products or activities. From the Nordic SPIN database it is possible to make a relative quantification of products and activities used in industry, and combined with estimates and expert judgement these products and activities are differentiated into sectors. More detailed information from the industrial sectors may still be required. (iv) Emission factors for single chemicals, products and industrial and household activities. For many industrial and household activities involving solvent containing products no estimates on emission factors are available. Large variations occur between industry and product groups. And given the large number of chemicals more specific knowledge regarding industrial processes and consumption is needed.

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.

Any changes in calculation procedures are noted for each year's inventory.

Data Processing level 1	5.Correctness	DP.1.5.1	Verification of calculation results using time series

No detailed guidelines or calculations are accessible for time series. These are therefore not used for verification.

Data Processing level 1	5.Correctness	DP.1.5.2	Verification of calculation results using other measures

Calculations performed by IIASA using RAINS codes, which are based on a different methodological approach gives total emission values that are similar to the emissions found in the present approach.

Data Processing level 1	7.Transparency	DP.1.7.1	The calculation principle, the equations used and the assumptions made must be described.

See methodological approach.

Data Processing level 1	7.Transparency	DP.1.7.2	Clear reference to dataset at Data Storage level 1

See methodological approach.

Data Processing level 1	7.Transparency	DP.1.7.3	A manual log to collect information about recalculations.

This is stated in documents listed in Table 5.5.

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.

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.

See DP.1.5.1 and DP.1.5.2.

5.6 Recalculations

Improvements and additions are continuously being implemented due to the comprehensiveness and complexity of the use and application of solvents in industries and households. The main improvements in the 2012 reporting include the following:

- Minor changes in the activity data for tobacco, fireworks, barbeques and candles due to changes updated values from StatBank DK (2013).

5.7 Planned improvements

- Emissions of N_2O used as propellant and solvent in canned whipped cream will be estimated. It has not been possible to get access to sales data and/or use data of number of cans from manufacturers and distributors. If these activity data cannot be compiled an expert estimate will be made.

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6 Agriculture (CRF sector 4)

The data presented in Chapter 6 relates to Denmark only, whereas information for Greenland is included in Chapter 16 and for the Faroe Islands in Annex 8.

The emission of greenhouse gases from agricultural activities includes:

- CH_4 emission from enteric fermentation and manure management.
- N_2O emission from manure management and agricultural soils.
- NMVOC emission from agricultural soils.
- Emission of CH_4, N_2O, NMVOC, CO and NO_x from burning of straw on field.

Emissions from rice production and burning of savannahs do not occur in Denmark and consequently these categories have been reported as Not Occurring.

6.1 Overview of sector

In CO_2 equivalents, the agricultural sector contributes with 19 % of the overall greenhouse gas emission (GHG) in 2012 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 2012 with 90 % and 77 % respectively of the total Danish emissions of N_2O and CH_4.

From 1990 to 2012, the emissions decreased from 12.5 million tonnes CO_2 equivalent to 9.6 million tonnes CO_2 equivalent, which corresponds to a 23 % reduction (Table 6.1). N_2O is the largest contributor to the overall agricultural greenhouse gas emission, in 2012 accounting for 56 % in CO_2 equivalents. The decrease in the agricultural emission is caused by a decrease in N_2O emission, while the CH_4 emission is nearly unaltered.

Table 6.1 Emission of GHG in the agricultural sector in Denmark 1990 – 2012

	1990	1995	2000	2005	2008	2009	2010	2011	2012
CH_4, Gg CO_2 eqv.	4 234	4 227	4 036	4 043	4 106	4 095	4 165	4 151	4 203
N_2O, Gg CO_2 eqv.	8 292	7 344	6 417	5 804	5 832	5 499	5 445	5 517	5 396
Total, Gg CO_2 eqv.	12 526	11 571	10 453	9 847	9 938	9 594	9 609	9 668	9 599

The major part of the emission is related to livestock production, which in Denmark is dominated by the production of cattle and swine.

Figure 6.1 shows the distribution of the greenhouse gas emission across the main agricultural sources. The total N_2O emission from 1990-2012 has decreased by 35 % 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 twenty five years to prevent loss of nitrogen from agricultural soil to the aquatic environment. These measures includes among other things a ban on manure application during autumn and winter, strict requirements to storage and application of manure, increasing area with winter-green fields to catch nitrogen, a maximum number of animals per hectare (ha) and maximum nitrogen application rates for agricultural crops. A combination of these increasing environmental requirements and the efforts to obtain economic advantage, the farmers has been forced to improve the utilisation of nitrogen in manure. An improvement of feed efficiency has been one of the most important drivers to reach the objectives. This has led to a halving of nitrogen use in synthetic fertiliser and a decrease of emission per produced kg meat, which all has reduced the overall GHG emission.

The CH_4 emissions from 1990 to 2012 shown in Figure 6.1 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. By coincidence, the decrease and the increase almost balance each other out and the total CH_4 emission from 1990 to 2012 has decreased by 1 %.

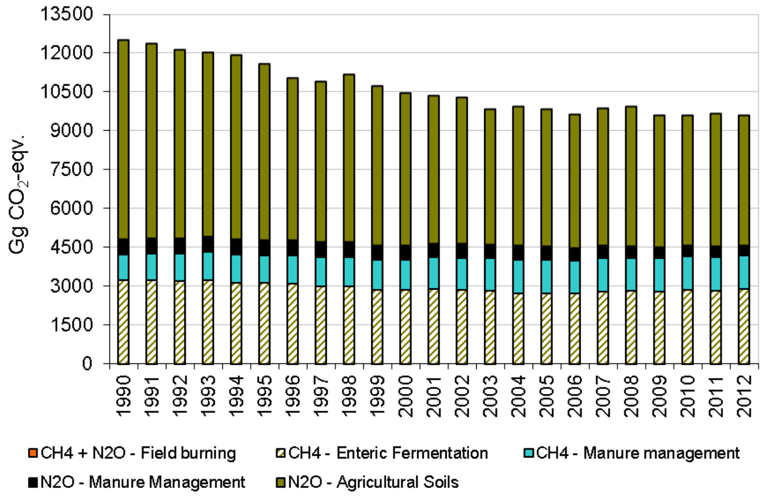

Figure 6.1 Danish greenhouse gas emissions 1990 – 2012.

6.1.1 Key category identification

The key category analysis (KCA) divides the agriculture emissions into 14 subcategories, refer Annex 1. In Table 6.2 is listed KCA covering Tier 1 and Tier 2. Tier 1 only gives key source identification based on the quantitative emission, while the Tier 2 analyse also include information on uncertainties estimates (refer to Chapter 1.5). In 1990, 9 of the 14 agricultural sources are registered as key categories and 11 sources are key categories if uncertainties are taken into account (Tier 2). In 2012, 5 of the sources are listed as key categories according to level and trend for Tier 1 and 8 sources in Tier 2. For the methodological choice Denmark uses the key categories identified using both tier 1 and tier 2 for the latest year as well as key categories identified for the trend from 1990 to the latest year.

The three most important agriculture key categories are CH_4 from enteric fermentation and N_2O emissions from nitrogen leaching and run-off and synthetic fertilisers.

Table 6.2 Key category identification Tie1 and Tier 2 from the agricultural sector 1990 and 2012.

CRF table	Compounds	Emission source	Key category identification	
2012			Tier 1	Tier 2
4.A	CH_4	Enteric fermentation	Level/trend	Level/trend
4.B(a)	CH_4	Manure management	Level/trend	Level/trend
4.F	CH_4	Field burning of agri. residues	-	-
4.B(a)	N_2O	Manure management	Level	Level
4.D1.1	N_2O	Synthetic fertilisers	Level/trend	Level/trend
4.D1.2	N_2O	Animal manure applied to soils	Level/trend	Level/trend
4.D1.3	N_2O	N-fixing crops	Level	Level/trend
4.D1.4	N_2O	Crop residue	Level	Level/trend
4.D1.5	N_2O	Cultivation of histosols	Level	Level
4.D1.6	N_2O	Sewage sludge and industrial waste	-	-
4.D2	N_2O	Pasture, range and paddock	Level	Level
4.D3.1	N_2O	Atmospheric deposition	Level	Level/trend
4.D3.2	N_2O	Nitrogen leaching and run-off	Level/trend	Level/trend
4.F	N_2O	Field burning of agri. residues	-	-
1990				
4.A	CH_4	Enteric fermentation	Level	Level
4.B(a)	CH_4	Manure management	Level	Level
4.F	CH_4	Field burning of agri. residues	-	-
4.B(b)	N_2O	Manure management	Level	Level
4.D1.1	N_2O	Synthetic fertilisers	Level	Level
4.D1.2	N_2O	Animal manure applied to soils	Level	Level
4.D1.3	N_2O	N-fixing crops	-	Level
4.D1.4	N_2O	Crop residue	Level	Level
4.D1.5	N_2O	Cultivation of histosols	-	Level
4.D1.6	N_2O	Sewage sludge and industrial waste	-	-
4.D2	N_2O	Pasture, range and paddock	Level	Level
4.D3.1	N_2O	Atmospheric deposition	Level	Level
4.D3.2	N_2O	Nitrogen leaching and run-off	Level	Level
4.F	N_2O	Field burning of agri. residues	-	-

6.2 Data references

The calculated emissions are based on methods described in the IPCC Reference Manual (IPCC, 1997) and the IPCC Good Practice Guidance (IPCC, 2000).

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, the Danish Agricultural Advisory Service, the Danish AgriFish Agency and the Danish Environmental Protection 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 6.3 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		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
The Danish Agricultural Advisory Service	http://www.vfl.dk	DAAS	- housing type (until 2004) - grazing situation - manure application time and methods - estimation of extent of field burning of agricultural residue
Danish Environmental Protection Agency	www.mst.dk	EPA	- sewage sludge used as fertiliser (until 2004) - industrial waste used as fertiliser
The Danish AgriFish Agency	http://naturerhverv.fvm.dk	DAFA	- synthetic 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 used in 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 6.2, is implemented in great detail and is used to cover emissions of air pollutants and greenhouse gases. Thus, there is a direct coherence between the NH_3 emission and the emission of N_2O.

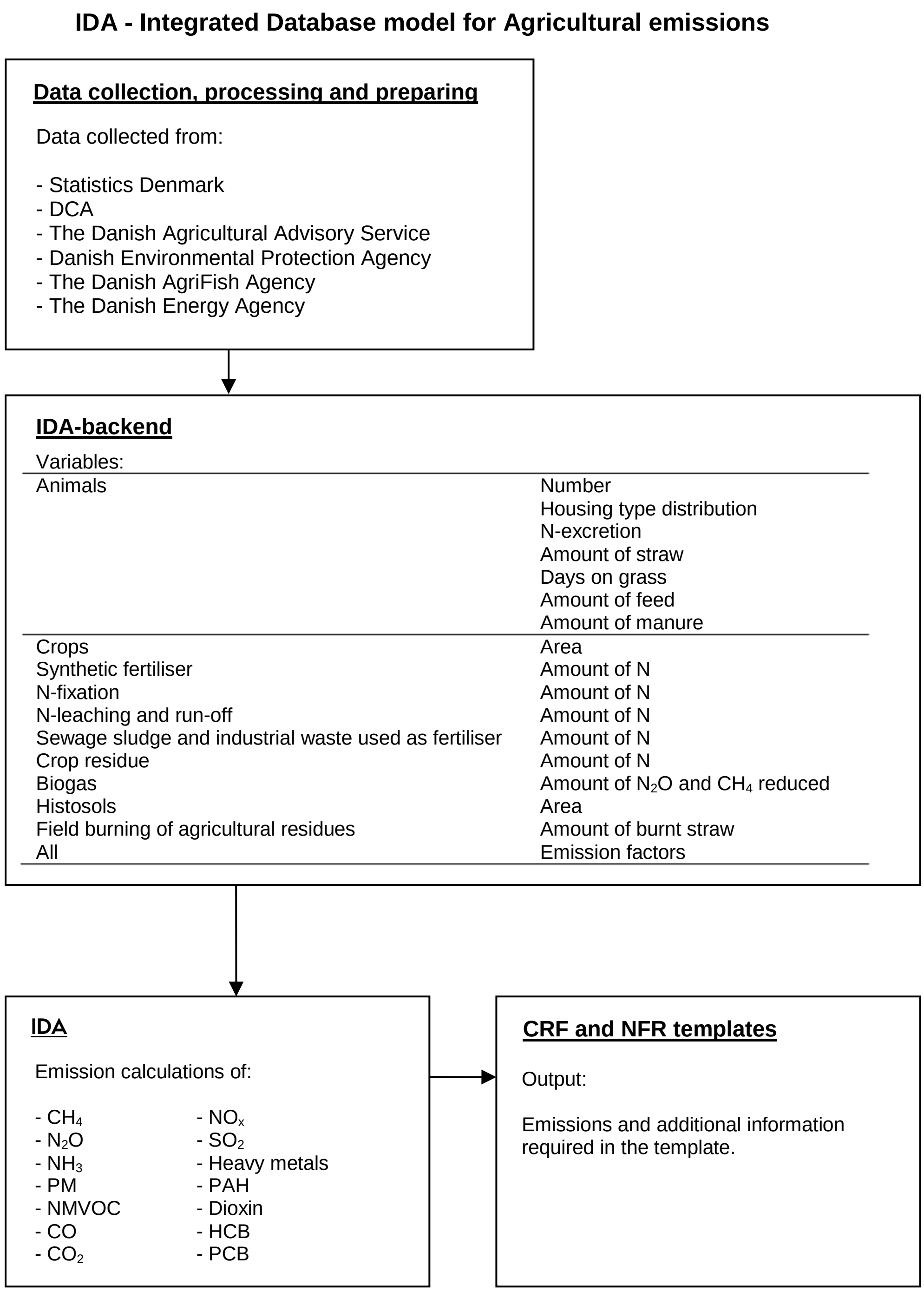

Figure 6.2 IDA - Integrated Database model for Agricultural emissions

Most emissions relate to livestock production, which basically 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 38 different livestock categories, according to livestock type, weight class and age. These categories are subdivided into housing type and manure type, which results in 252 different combinations of livestock subcategories and housing types (see Annex 3E-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 6.4 Livestock categories and subcategories.

CRF 4B	Aggregated livestock categories as given in IPCC	Includes	No. of subcategories in IDA, animal type/housing system
4B 1a	Dairy Cattle[1]	Dairy Cattle	34
4B 1b	Non-dairy Cattle[1]	Calves (<½ yr), heifers, bulls, suckling cattle	120
4B 3	Sheep	Including lambs	1
4B 4	Goats	Including kids (meet, dairy and mohair)	3
4B 6	Horses	<300 kg, 300 - 500 kg, 500 - 700 kg, >700 kg	4
4B 8	Swine	Sows, weaners, fattening pigs	36
4B 9	Poultry	Hens, pullets, broilers, turkeys, geese, ducks	42
4B 13	Other	Fur animals[2], deer, ostriches, pheasant	12

1) For all subcategories, large breed and jersey cattle are distinguished from each other.

2) Fur farming: Mink and foxes

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.

6.2.1 Number of animals

Livestock production is primarily based on the agricultural census from Statistics Denmark (DSt). The emission from bulls, fattening pigs and poultry is based on slaughter data. A certain numbers of horses, goats and sheep on small farms are added to the number in DSt because Statistics Denmark does not include farms less than 5 ha, where many of these animals are placed. Statistics Denmark is the source for the database kept by FAO (Food and Agriculture Organization of the United Nations) and Eurostat. This explains why the number of sheep, goats and horses in FAO and the Danish emission inventory differ. The largest difference is found for horses. In the agricultural census for 2012, the number of horses is estimated to be around 68 000. Including horses on small farms and riding schools, however, the number of horses rises to approximately 155 000 (Clausen, 2012). Data on the number of sheep and goats are based on the Central Husbandry Register (CHR), which is the central register of farms and animals administrated by the Ministry of Food, Agriculture and Fisheries.

Information on the number of deer, ostriches and pheasants are not included in Statistics Denmark. While the number of deer and ostriches are based on the CHR, the number of pheasants is based on expert judgement from DCE and the pheasant breeding association.

In Annex 3E-2 is provided number of animals allocated on all livestock subcategories for selected years 1990-2011, for all years see http://envs.au.dk/videnudveksling/luft/emissioner/reportingsectors/agriculture/.

6.2.2 Housing type

From 2005, all farmers have to report to the Danish AgriFish Agency (DAFA) information concerning the use of housing type. Annex 3E-1 shows the housing type for each livestock category for selected years 1990 – 2011.

Before 2005 there exist no official statistics which cover the distribution of animals according to housing type. The distribution is, therefore, based on an expert judgement from the Danish Agricultural Advisory Service (DAAS) and DCA. Approximately 90-95 % of Danish farmers are members of DAAS, which regularly collects statistical data from the farmers on different issues, as well as making recommendations with regard to farm buildings. Hence, DAAS has a good understanding of which housing types that are currently in use and also the changes over time.

6.2.3 Feed consumption and 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 (Poulsen et al., 2001, Poulsen et al., 2013). 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 3E-3 and 4.

The Danish normative standards are based on practical farming and thus reflect the actual Danish agricultural production conditions. DCA receive data from the Danish Agricultural Advisory Service (DAAS), which is the central office for all Danish agricultural advisory services. DAAS 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 the Danish Agricultural Advisory Service, 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-miljoe/normtal/ (17.01.2014).

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 normative data is adjusted over time but the methodology is the same.

6.3 CH_4 emission from enteric fermentation (CRF sector 4A)

6.3.1 Description

The major part of the agricultural CH_4 emission originates from digestive processes. In 2012, this source accounts for 30 % of the total GHG emission from agriculture. The emission is primarily related to ruminants and, in Denmark, particularly to cattle, which, in 2012, contributed with 86 % of the emission from enteric fermentation. The emission from pig 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 %).

6.3.2 Methodological issues

The methodology for estimating emissions from enteric fermentation is based on the Revised 1996 IPCC Guidelines (IPCC, 1997) and the IPCC Good Practice Guidance (IPCC, 2000). 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 not applicable based on country-specific information (Hansen, 2010). 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 and heifers, where a national Y_m is used for all years. In the Danish inventory sheep and goats includes lamb and kids - an average of Y_m values for mother animal and lamb/kid is used.

Tier 1

Emission factors used for poultry, ostrich and pheasants are based on the emission factors given by Wang & Huang (2005) (see Table 6.5). 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 for laying hens 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.

Table 6.5 EF for poultry in mg CH_4 per head per lifecycle.

	CH_4 emission factor
Broilers, 42 days	15.87
Taiwan country chicken, 91 days	84.82
Pullets, 140 days	3 561
Laying hens, 365 days	10 610

Source: Wang & Huang, 2005.

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) for each livestock category – see below. 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 and heifers which have sugar beets in the feed. The parts of the equation concerning sugar beet will be left out for the remaining animal categories.

$$EF = EF_{winter} + EF_{summer}$$

$$EF_{winter} = FU \cdot ((\frac{GE_{FU\,winter}}{55.65}) \cdot Y_{m\,excl\,sugarbeet} \cdot (1 - \frac{grazing\ days}{365} - \frac{days\ with\ sugar\ beet}{365}) + (\frac{GE_{FU\,winter}}{55.65}) \cdot Y_{m\,incl\,sugarbeet} \cdot \frac{days\ with\ sugar\ beet}{365})$$

$$EF_{summer} = FU \cdot (\frac{GE_{FU\,summer}}{55.65}) \cdot Y_{m\,grazing} \cdot \frac{grazing\ days}{365}$$

Where:
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

Thus, to calculate the total gross energy (GE) intake, the GE per feed unit – defined as GE_{FU} – 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 % (Statistics Denmark, yearbook 2010). For other cereals e.g. wheat and rye one feed unit is 0.97 kg and 1.05 kg, respectively.

Gross energy intake

The calculation of $GE_{FU,\,winter}$ and $GE_{FU,\,summer}$ 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 DAAS 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:

The principle for estimation of $GE_{FU,\,winter}$ and $GE_{FU,\,summer}$ is the same, why the following equation only is defined as GE_{FU}.

$$GE_{FU} = \frac{MJ/day}{FU/day}$$

$$FU/day = \frac{kg\ dm}{day} \cdot \frac{FU}{kg\ dm}$$

$$MJ/day = \frac{kg\ dm}{day} \cdot \frac{MJ}{kg\ dm}$$

$$MJ/kg\,dm = \%_{Crude protein} \cdot E_{Crude protein} + \%_{Raw\,fat} \cdot E_{Raw\,fat} + \%_{Carbonhydrates} \cdot E_{Carbonhydrates}$$

$$\%_{Carbonhydrates} = 100 - (\%_{Crude protein} + \%_{Raw\,fat} + \%_{Raw\,ashes})$$

In Annex 3E-5 and 6 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 3E-7 and 8 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.

For dairy cows, the energy intake comes out at 18.3 MJ pr. FU in a standard winter feed regardless of whether the animal grazes or not, which is based on information from DCA. For bull calves (< ½ year), as well as bulls older than ½ year, the same energy content value is used, as for dairy cows.

For horses, heifers, suckling cattle, sheep and goats an average winter feed plan is provided based on information from DCA and DAAS 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.

Table 6.6 GE per feeding unit, MJ per FU.

	GFU_{winter}	GFU_{summer}
Dairy cattle	18.3	18.3
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 3E-9a, the annual average feed intake given in GE as MJ per day is shown, from 1990 to 2012, for each CRF livestock category and Annex 3E-9b shows the GE for each subcategory for non-dairy cattle and swine.

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 6.3.4.

Methane conversion rate (Y_m)

Investigations from DCA have shown a change in fodder practice from use of sugar beet to maize (whole cereal). Sugar beet feeding gives a higher methane production rate compared to grass and maize due to the high content of easily convertible sugar. The development in fodder practice reflects the change in the average Y_m for dairy cattle and heifer from 6.39 in 1990 to 5.94 and 5.97 in 2012, respectively.

The estimation of the national values of Y_m is based on model "Karoline" developed by DCA based on average feeding plans for 20 % of all dairy cows in Denmark obtained from the Danish Agricultural Advisory Service DAAS (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 and for 1990 and 2003 to 2012 by extrapolation where the actual sugar beet area is taken into account. Data for actual sugar beet area are shown in Table 6.7. 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. The value of the estimated average Y_m for 1991 and 2002 are, when adjusted for winter/summer, 6.35 and 5.96, respectively (see Table 6.8).

Table 6.7 Area grown with sugar beets and maize for feeding 1990-2012, ha.

Area	1990	1995	2000	2005	2008	2009	2010	2011	2012
Sugar beet for feeding	102 347	52 927	17 577	4 974	5 206	5 257	4 118	3 985	4 562
Maize for feeding	18 735	36 583	61 493	131 027	159 030	168 917	172 168	173 693	183 570

Table 6.8 CH_4 conversion rate (Y_m) – national factor used for dairy cattle and heifers > ½ year 1990 – 2012, %.

Dairy cattle + Heifers > ½ year	1990	1991	1995	2000	2002	2005	2008	2009	2010	2011	2012
$Y_{m\ excl.\ sugar\ beet}$	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92
$Y_{m\ incl.\ sugar\ beet}$	6.78	6.70	6.36	6.06	6.00	5.96	5.96	5.96	5.95	5.95	5.95
$Y_{m\ grazing}$	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	6.00	6.00	6.00
Average Y_m											
Dairy cattle	6.39	6.35	6.16	6.00	5.94	5.94	5.94	5.94	5.94	5.94	5.94
Heifers	6.39	6.35	6.16	6.00	5.94	5.94	5.94	5.94	5.97	5.96	5.97

Implied emission factor

Table 6.9 shows the implied emission factors (IEFs) for all IPCC livestock categories. IEFs vary across the years for dairy cattle, non-dairy cattle, swine, goats and poultry due to changes for feed intake, distribution of animals in subcategories and number of grazing days. For goats new subcategories are introduced in 2005 and therefore the IEF differs from the other years. For sheep, horses, deer, ostrich and pheasants the IEF is constant. The emission from fur farming is considered to be not applicable (Hansen, 2010).

Table 6.9 Implied emission factors – Enteric Fermentation 1990 – 2012, kg CH_4 per head per year.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
1. Cattle									
a. Dairy	116.62	119.45	117.16	128.12	130.67	133.76	134.35	132.91	133.91
b. Non-Dairy	34.77	34.96	35.01	36.98	40.82	40.12	39.82	40.38	40.00
3. Sheep	17.17	17.17	17.17	17.17	17.17	17.17	17.17	17.17	17.17
4. Goats	13.15	13.15	13.15	12.87	13.04	13.06	13.06	13.07	13.08
6. Horses	21.81	21.81	21.81	21.81	21.81	21.81	21.81	21.81	21.81
8. Swine	1.09	1.08	1.11	1.07	1.12	1.10	1.07	1.11	1.10
9. Poultry	0.004	0.003	0.003	0.004	0.004	0.003	0.003	0.003	0.003
10. Other									
Fur farming	NA	NA	NA	NA	NA	NA	NA	NA	NA
Deer	11.30	11.30	11.30	11.30	11.30	11.30	11.30	11.30	11.30
Ostrich	NO	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Pheasant	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003

NO = Not occurring.

NA = Not applicable.

The IEF for dairy cattle has increased from 117 kg CH_4 per cow per year in 1990 to 134 kg CH_4 in 2012. The IEF depends on milk yield and feed intake – see Figure 6.3. From 1990 to 2000 the IEF is almost unchanged but increased significant from 2000 to 2012. 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 increased feed efficiency; an improvements of the feed utilization.

The milk yield has in average increased from 6 000 litre per cow in 1990 to approximately 8 400 litre per cow in 2012 (Statistics Denmark).

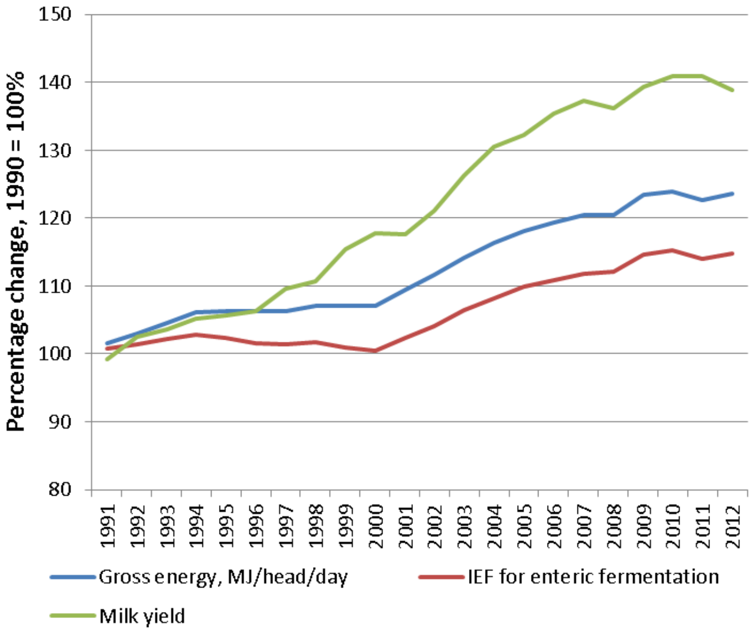

Figure 6.3 Comparison of feed intake, milk yield and IEF for dairy cattle (1990 = 100 %).

A comparison with IPCC Tier 2 calculation in Chapter 6.3.4 shows that the IEFs for the Danish inventory are lower. However, the national IEFs are considered more accurate because the differences can be explained by the improvement in feed efficiency, which has taken place in Danish agriculture from 2000.

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 in subcategories can be reflected in the IEF. The development 1990 - 2008 shows a slight increase due to a higher feed consumption for heifers. From 2008 – 2012 the IEF seems stabile.

The Danish IEF for non-dairy cattle is lower than the Tier 1 default value given in the IPCC Reference Manual (IPCC, 1997). This is due to a combination of lower Y_m value for heifers and lower weight/lower feed intake (Table 6.10). In Chapter 6.3.4 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 6.10 Subcategories for Non-Dairy Cattle 2012 – 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	132 893	61.67	4.00	16.18
Calves, heifer (0-6 month)	150 kg	162 286	102.23	6.00	39.69
Bulls (6 month to slaughter)	large breed: 440 kg sl. weight jersey: 330 kg sl. weight	132 849	116.24	4.00	29.54
Heifers (6 month to calving)	325 kg	494 417	130.21	5.97[a]	50.91
Suckling cattle	Up to 800 kg	97 193	163.55	6.00	63.91
Average - Non-Dairy Cattle			111.5		40.0
IPCC – default value			128.0		48.0

[a] Average Y_m

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 3E-7 and 9b).

In Table 6.11 the IEFs for swine subcategories are shown. 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 6.11 Subcategories for Swine 2011 – 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 7.4 kg)	1 010 516	73.79	0.60	2.87
Weaners (7.4 – 32 kg)	5 847 458	14.25	0.60	0.44
Fattening pigs (32 – 107 kg)	5 472 905	40.55	0.60	1.49
Average - Swine		25.9		1.10
IPCC – default value		38	0.60	1.5

It is important to point out that the IEF for sheep and goats includes emission from lambs and kids due to the Danish normative data. This explains why the Danish IEFs are nearly twice as high as the IPCC default values. A comparison with IPCC Tier 2 which includes lamb indicates that the Danish estimates can be comparable with the IPCC default, see Chapter 6.3.4.

Activity data

In Table 6.12, the development in the number of animals from the agricultural statistics (Statistics Denmark), DAAS and CHR from 1990 to 2012 is presented (for subcategories see Annex 3E-2). The agricultural census does not include farms less than 5 ha. In the Danish emission inventory, the decision has been made to add number of sheep, goats and horses on small farms and deer, pheasants and ostriches based on information from DAAS and CHR (see Chapter 6.2.1).

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.

Table 6.12 Number of animals from 1990 to 2012, 1000 head.

CRF Table 4.A, 4.B (a) and 4.B (b)	1990	1995	2000	2005	2008	2009	2010	2011	2012
IPCC livestock categories:									
Dairy Cattle	753	702	636	564	558	563	568	565	587
Non-Dairy Cattle	1 486	1 388	1 232	1 006	1 006	977	1 003	1 003	1 020
Sheep*	92	81	112	126	117	116	111	94	90
Goats*	7	7	8	11	14	16	16	13	13
Horses*	135	143	150	175	190	178	165	155	155
Swine	9 497	11 084	11 922	13 534	12 738	12 369	13 173	12 932	12 331
Poultry	16 249	19 619	21 830	17 632	15 406	19 676	18 731	19 319	18 991
Other;									
Fur farming	2 264	1 850	2 199	2 552	2 810	2 721	2 699	2 757	2 948
Pheasant**	1 063	1 063	1 063	1 063	1 063	1 063	1 063	1 063	1 063
Deer**	10	10	10	10	10	9	10	8	7
Ostrich**	NO	3	9	4	0.5	0.4	0.4	0.2	0.2

* Including animals on small farms (less than 5 ha), which are not covered by Statistics Denmark.

** Not included in Statistics Denmark.

NO = Not occurring.

6.3.3 Time series consistency

The CH_4 emission from enteric fermentation is given in Table 6.13. From 1990 to 2012, the emission has decreased by 13 %, which is primarily related to a decrease in the number of cattle. The number of swine has increased from 9.5 million in 1990 to 12.3 million in 2012, but this increase is only of minor importance in relation to the total CH_4 emission from enteric fermentation.

Table 6.13 Emission of CH_4 from Enteric Fermentation 1990 – 2012, Gg CH_4.

CRF 4.A	1990	1995	2000	2005	2008	2009	2010	2011	2012
Dairy Cattle	87.83	83.91	74.46	72.29	72.91	75.32	76.34	75.11	78.63
Non-Dairy Cattle	51.66	48.52	43.14	37.20	41.08	39.21	39.93	40.49	40.79
Sheep	1.58	1.39	1.92	2.17	2.02	1.98	1.91	1.61	1.55
Goats	0.10	0.09	0.11	0.15	0.18	0.20	0.21	0.16	0.17
Horses	2.94	3.11	3.27	3.82	4.14	3.87	3.60	3.38	3.38
Swine	10.33	12.02	13.17	14.53	14.27	13.66	14.14	14.34	13.61
Poultry	0.06	0.07	0.06	0.07	0.06	0.06	0.06	0.07	0.06
Other;									
Fur farming	NA	NA	NA	NA	NA	NA	NA	NA	NA
Deer	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.09	0.08
Ostrich	NO	#	#	#	#	#	#	#	#
Pheasant	#	#	#	#	#	#	#	#	#
Total, Gg CH_4	154.62	149.22	136.25	130.33	134.78	134.42	136.28	135.25	138.28
Total, Gg CO_2 eqv.	3 247	3 134	2 861	2 737	2 830	2 823	2 862	2 840	2 904

NO = Not occurring.
NA = Not applicable.
# - emission ≤ 0.0003.

6.3.4 Tier 2/Country Specific compared to IPCC Tier 2 method

A comparison between IPCC Tier 2 and Denmark's Tier2/Country Specific (CS) calculation method for enteric fermentation is made. In the IPCC Guidelines default values are given for dairy cattle, non-dairy cattle and sheep, therefore a comparison is made for these three groups. The comparison is not done annually and the current comparison is based on 2008 data.

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 6.14) shows that the Danish method gives a value for dairy cattle that is up to 7 % lower than the IPCC Tier 2 method. For non-dairy cattle the result is up to 5 % higher. To compare the IEF for sheep the calculation includes lamb. The Danish method gives a 7 % lower value than the IPCC with default values for Y_m (Y_m = 0.07), but a 9 % higher value than IPCC with an average Y_m of values for mother sheep and lamb (Y_m = 0.06).

Table 6.14 IEFs for enteric fermentation calculated by different methods, 2008.

kg CH_4 per animal per year	Tier 2 (IPCC Y_m)	Tier 2 (DK Y_m)	Tier 2/CS
Dairy cattle	140.3	137.9	130.7
Non-dairy cattle	38.8	38.3	40.8
Sheep (incl. lambs)	18.4	15.8	17.2

The three different Tier 2 calculations for non-dairy cattle all show an IEF between 38.3-40.8 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 48 kg per head per year given in the Reference Manual, Table 4.-4 (IPCC, 1997), which can be explained by a combination of lower Y_m for heifers and lower animal weight/lower feed intake.

The calculation of IEF for sheep indicate that the value used in the Danish inventory are reasonable. A Tier 2 calculation, where the productions of lamb are included, based on IPCC Y_m shows an IEF at the same level.

The lower value for the IEF for dairy cattle is mainly due to a lower value for GE (Table 6.15). The Danish values for feed consumption are based on the Danish normative figures and the normative data are based on actual efficacy feeding controls or actual feeding plans at farm level, more info on GE calculations is included in Chapter 6.3.2.

Table 6.15 GE for dairy cattle calculated by different methods, 2008.

MJ per animal per day	Tier 2 (IPCC Y_m and DK Y_m)	Tier 2/CS
Dairy cattle	356.4	335.3

According to Statistics Denmark dairy cattle produce 22.5 kg milk in average per animal per day in 2008. Table 6.16 shows the needed energy intake to achieve this milk production calculated by two different methods. By using the Tier 2 calculation given in the Reference Manual (IPCC, 1997) 15.8 MJ is needed to produce 22.5 kg milk per animal per day. National data for feed intake, which reflect the actual Danish agricultural conditions, show a lower need of energy intake corresponding to 14.9 MJ. This is a result of improved feeding efficiency.

Table 6.16 MJ per kg milk produced 2008.

	Kg milk per animal per day	MJ per kg milk Tier 2	MJ per kg milk Tier 2/CS
Dairy cattle	22.5	15.8	14.9

In Figure 6.4 is shown the Danish trend of MJ per kg milk for dairy cattle. It is seen that the energy intake per kg milk have overall decreased from 1996 to 2008. Around 1999 the Danish level of MJ per kg milk was at the same level as given in the IPCC Tier 2 method. Since then, feeding efficiency has continued to rise due to the structural development, i.e. bigger farms and more intensive production. This explains the lower IEF for dairy cattle based on the Danish methodology.

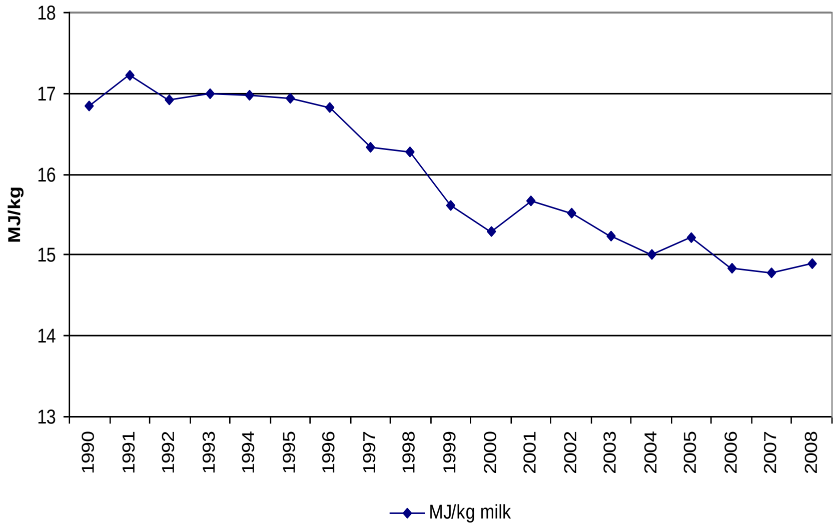

Figure 6.4 The Danish trend for MJ per kg milk produced for dairy cattle, 1990-2008.

6.4 CH_4 and N_2O emission from manure management (CRF sector 4B)

6.4.1 Description

This source contributes with 18 % of the total greenhouse gas emission from the agricultural sector in 2012. The major part of the emission originates from the production of cattle (48 %) followed by swine production (39 %). The remaining part is mainly from poultry and fur farming (13 %).

6.4.2 Methodological issues

CH_4 emission

The IPCC Tier 2/CS 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 IPCC Reference manual (IPCC, 1997). Default values for maximum methane producing capacity (B_0) and methane conversion factor (MCF) given by the IPCC are used. The calculation of volatile solids (VS) is based on national data.

Table 6.17 CH_4 – Manure management – use of national parameters and IPCC default values.

CH_4 – Manure management	National parameters	IPCC default value
Volatile solids, VS	Based on amount of manure (Annex 3E-10a and 10b)	
Maximum methane producing capacity, B_0		IPCC 1997
Methane conversion factor, MCF		IPCC 1997

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:

$$CH_{4_{manure}} = CH_{4_{housing}} + CH_{4_{grazing}}$$

$$CH_{4housing} = VS_{housing} \cdot MCF \cdot 0.67 \cdot B_0$$

$$CH_{4grazing} = VS_{grazing} \cdot MCF \cdot 0.67 \cdot B_0$$

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 from 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.

$$VS_{housing} = \frac{m}{365} \cdot DM_M \cdot VS_{DM} \cdot (365 - g_1) + s \cdot DM_S \cdot (1 - \frac{\%\,ash}{100}) \cdot (365 - g_2)$$

$$VS_{grazing} = \frac{m}{365} \cdot DM_M \cdot VS_{DM} \cdot g_1$$

Where:	VS	= volatile solids, kg animal^{-1} yr^{-1}
	m	= amount of manure excreted, kg animal^{-1} yr^{-1}
	DM	= dry matter of M manure or S straw, pct.
	VS_{DM}	= volatile solids of dry matter, pct.
	g_1	= feeding days on grass, days yr^{-1} [1]
	g_2	= actual days on grass, days yr^{-1}
	s	= amount of straw, kg animal^{-1} yr^{-1}
	% ash	= ash content in straw

The ash content in straw is set to 4.5 % (DAAS, 2005). The VS of dry matter is 78 % for cattle, horses, sheep, goats and deer. For swine, poultry and fur animals the VS of dry matter is 75 % (Møller, 2003). The number of days on grass is shown in Annex 3E-8. The amount of manure excreted and straw used depends on housing type and is given in the normative figures table (Poulsen, 2013).

The VS daily excretion in average for all main livestock categories and cattle subcategories is shown in Annex 3E-10a and 10b.

MCF used for slurry

Default values provided in the IPCC guidelines for the methane production B_0 and MCF are used. For liquid systems, the MCF of 10 % in the Reference Manual (IPCC, 1997) is used.

The Revised 1996 IPCC guidelines (IPCC, 1997) provide a default MCF of 10 % for liquid/slurry, which is based on research of Hashimoto & Steed (1993) and Woodbury & Hashimoto (1993). This MCF value was changed to 39 % in the IPCC Good Practice Guidance (IPCC, 2000), without any scientific argumentation, documentation or specific references. It has to be remarked that the 2006 IPCC Guidelines (IPCC, 2006) return to a MCF value of 10 % for Danish conditions referenced to "Judgement of IPCC Expert Group in

[1] Actual days on grass are the number of days that heifers is 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.

combination with Mangino et al. (2001) and Sommer et al. (2000)" (IPCC, 2006).

The methane emission from liquid systems is very sensitive to temperature effects. Basically most of the manure is stored in Denmark under cold conditions (<5-10 degrees Celsius). The CH_4 formation practically stops at 4 °C and therefore there are no plausible arguments that 39 % of total CH_4 capacity should be released under Danish conditions. Danish studies confirm this assumption (Husted, 1994 and Sommer et al., 2000). Furthermore, investigations based on measurements in Canada, where conditions are similar to Denmark, support this value (Massé et al., 2003). Support of the value of 10 % is also found from a Swedish review (Dustan, 2002), taking into account both the cold climate and the fact that the slurry containers in Scandinavia usually have a surface cover.

Considering the agricultural conditions in Denmark and the present scientific knowledge as described above a MCF of 10 % for liquid/slurry is more appropriate under the Danish conditions. The Danish decision of using a MCF of 10 % is as demonstrated above backed by several scientific papers as well as both the Revised 1996 IPCC Guidelines (IPCC, 1997) and the 2006 IPCC Guidelines (IPCC, 2006). Therefore, Denmark intends to continue using a MCF value of 10 % until new scientific knowledge is published contradicting the above mentioned references.

It has to be remarked that countries with comparable climate use a MCF for liquid/slurry at the same level as default recommended in the Revised IPCC 1996 Guidelines (IPCC, 1997). Finland use the same value as Denmark, i.e. a MCF of 10 %, Germany uses 14 %, Belgium uses 19 % and Norway and the Sweden use a MCF below 10 %.

A lower CH_4 emission from biogas treated slurry

A study indicates a lower CH_4 emission from slurry treated in biogas plants (Sommer et al., 2001). No description on how to include biogas treated slurry in the inventories is provided in the IPCC guidelines. Therefore, the Danish inventory uses data based on a Danish study (Sommer et al., 2001).

The Danish Energy Agency (DEA) provides annually the Danish energy statistics, which for 2012 shows that the produced energy from biogas corresponds to 4383 TJ (DEA, 2013). The majority of this production (2969 TJ) takes place on biogas plants and uses agricultural products which mainly are animal manure (slurry). In Denmark exist around 80 biogas plants and the largest twenty plants produce 70 % of the total agricultural biogas production.

Table 6.18 Number of biogas plants and production of energy

Production size, TJ per year	No. of biogas plants	Energy production, TJ
<10	22	94
10-50	33	780
50-100	12	848
100-200	10	1246
Total	77	2969

The energy potential very much depends on the type of biomass input; the combination of manure and other agricultural biomasses, the storage time and the technology on the different biogas DEA assume an average energy potential where 0.83 million tonnes of slurry produce 1 PJ biogas. This means that in 2012 around 2.5 million tonnes of slurry has been treated in biogas plants.

It is assumed that of the total amount of biogas treated slurry, cattle slurry makes up 45 % and pig slurry 55 % (Tafdrup, 2010). In 2012, the amount of biogas treated slurry is equivalent to approximately 6 % of total slurry in housing.

The lower CH_4 emission as a consequence of biogas treated slurry is calculated as the difference between non-treated slurry and treated slurry.

$$CH_{4,lower} = CH_{4,\text{non-treated slurry}} - CH_{4,\text{treated slurry}}$$

The calculation is based on the amount of volatile solids (VS) calculated as the VS percentage of dry matter (DM) which is 80 % for both cattle and pig slurry. The dry matter content is based on the Danish normative figures (Poulsen et al., 2001 and Poulsen, 2013).

The CH_4 emission from treated and non-treated slurry is calculated as:

$$CH_{4,\text{non-treated slurry}} = VS \cdot B_o \cdot MCF \cdot 0.67$$

$$CH_{4,\text{treated slurry}} = VS \cdot B_o \cdot MCF \cdot 0.67 \cdot E_{lower}$$

Where; $CH_{4,\text{non-treated slurry}}$ and $CH_{4,\text{treated slurry}}$ are the emission of non-biogas treated slurry and biogas treated slurry, respectively. VS express the total amount of volatile solid in non-biogas treated slurry and biogas treated slurry, B_0 is the maximum methane forming capacity, MCF is the methane conversion factor and the factor 0.67 express the conversion from m^3 to kg. E_{lower} is the lower emission of biogas treated slurry compared to untreated slurry.

Based on results from Sommer et al. (2001) it is assumed that the emission from treated cattle slurry is reduced by 23% compared with untreated slurry. This leads to an E_{lower} for cattle of 0.77. Likewise, results from treated pig slurry show a 40 % lower emission than for untreated slurry, which leads to an E_{lower} at 0.60 (Sommer et al., 2001). Refer to Annex 3E-11.

All key model parameters for estimating the lower CH_4 emission in 2012 as a result of biogas plants are listed in Table 6.19. Data for 1990 to 2012 are shown in Annex 3E-12a.

Table 6.19 Key model parameters used to calculate the lower CH_4 emission due to biogas treated slurry, 2012.

	Slurry, biogas treated	DM[a]	VS of DM[b]	VS in treated slurry	MCF[c]	B_0[c]	E_{lower}[d]	CH_4 emission in untreated slurry	CH_4 emission in biogas treated slurry	Lower CH_4 emission
	1000 Gg	Pct.	Pct.	10^6 kg VS	Pct.	m^3 CH_4 per kg VS		Gg CH_4	Gg CH_4	Gg CH_4
Cattle slurry	1.10	10.3	80	90.85	10	0.24	0.77	1.46	1.11	0.34
Pig slurry	1.35	6.1	80	65.76	10	0.45	0.60	1.98	1.19	0.80
Lower emission										1.14

[4a] Poulsen et al., 2001 and Poulsen, 2013.

[b] Møller, 2003.

[c] IPCC default.

[d] Sommer et al., 2001.

Due to biogas treated slurry, the total emission of CH_4 in 2012 is lowered by 1.14 Gg CH_4 (Table 6.19), which correspond to a 2 % reduction of the total CH_4 emission from manure management in 2012. Calculations for the lower CH_4 emission for all years 1990 – 2012 are listed in Table 6.20.

The lower emission is subtracted in the emission related to manure management from dairy cattle and fattening pigs, which are the main sources of the production of slurry.

Table 6.20 Lower CH_4 emissions as a result of biogas treated slurry 1990 – 2012.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
Amount of treated slurry, Mt									
- cattle	0.09	0.29	0.52	0.87	0.99	1.08	1.12	1.08	1.10
- swine	0.10	0.35	0.64	1.06	1.20	1.31	1.37	1.31	1.35
VS total in treated slurry									
- cattle	0.01	0.02	0.04	0.07	0.08	0.09	0.09	0.09	0.09
- swine	0.01	0.02	0.03	0.05	0.06	0.06	0.07	0.06	0.07
Total reduced emission, Gg CH_4	0.09	0.30	0.54	0.90	1.02	1.11	1.16	1.11	1.14

CH_4 implied emission factors

Table 6.21 shows the development in the implied emission factors from 1990 to 2012. Variations between the years for dairy cattle, non-dairy cattle, poultry, swine and fur farming reflect changes in feed intake, distribution of animals in subcategories, grazing situation and changes in housing type system.

The IEFs for poultry, ostriches, pheasants and deer are unaltered because of very few changes in feed intake and grazing days. A more detailed division in subcategories for goats and horses is implemented from 2007 and 2003, respectively, and explains the small changes in IEFs.

The IEF for sheep and goats includes lambs and kids and the housing systems for these categories are defined as deep litter with a MCF of 10 %. This explains why the Danish IEF is considerably higher than the IPCC default value, which is provided for sheep and goats housed in solid storage systems. IEF for sheep and goats change in 2012 due to change in amount of manure excreted and dry matter content.

Table 6.21 Implied emission factors – Manure Management 1990 – 2012, kg CH_4 per head per year.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
1a. Dairy Cattle	21.06	22.87	27.55	34.25	32.18	33.09	33.20	32.73	33.60
1b. Non-Dairy Cattle	5.71	6.73	7.40	9.23	9.71	9.66	9.49	9.72	9.19
3. Sheep	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.71
4. Goats	2.44	2.44	2.44	2.45	2.45	2.45	2.45	2.45	2.37
6. Horses	2.96	2.96	2.96	2.95	2.95	2.95	2.95	2.95	2.95
8. Swine	2.12	2.19	2.22	2.22	2.27	2.29	2.24	2.31	2.30
9. Poultry	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.03
10. Other									
Fur farming	0.57	0.59	0.65	0.79	0.92	0.97	0.99	1.03	1.04
Deer	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Ostrich	NO	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47
Pheasant	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

IEF for dairy cattle has increased as a result of increasing milk yield, but also because of changes in housing types. Annex 3E-1 shows the changes in housing types from 1990 to 2012. Old-style tethering systems with solid manure have been replaced by loose-housing with slurry-based systems. The MCF for liquid manure is ten times higher than that for solid manure. For non-dairy cattle the same development in IEF is seen, but here it is mainly because an increasing proportion of bull-calves are raised in housings with deep litter, where the MCF is also high.

For pigs and fur farming, there has been a similar development as for dairy cattle with a move from solid manure to slurry-based systems.

As shown in Table 6.22 the national IEF for dairy cattle is particularly high compared to the IPCC default value, which is mainly due to the fact that more cattle are housed on slurry based system than given in the IPCC assumptions. Furthermore, VS used for Danish dairy cattle are higher due to higher milk yield.

For non-dairy cattle the national VS value is nearly the same as the default, but a high proportion of the animals are housed in deep litter or liquid/slurry systems, 39 % and 31 % in 2012 respectively, which both have a MCF at 10 %.

Table 6.22 Cattle – important parameters for calculation of the average implied emission factor for manure management 2012.

	IPCC			DK		
	VS kg dm per hd per day	Liquid/slurry %	IEF kg CH_4 per hd per yr	VS kg dm per hd per day	Liquid/slurry %	IEF kg CH_4 per hd per yr
Dairy	5.1	40	14	6.2	88	34
Non-dairy (average)	2.7	50	6	2.7	31	9
Calves, bull				1.5	0	0
Calves, heifer				1.8	0	0
Bulls > ½ yr				3.9	40	16
Heifer > ½ yr				2.8	50	9
Suckling cattle				4.3	7	12

The category of swine in the Danish inventory operates with three subcategories. The IEF is lower compared with the IPCC default value due to a lower VS value probably because of the relatively high share of weaners. In the Reference Manual (IPCC, 1997) an average feed intake of 38 MJ per head per day is used, which is significantly higher than the average feed intake for Danish weaners and fattening pigs.

Table 6.23 Swine – important parameters for calculation of the average implied emission factor for manure management 2012.

	IPCC				DK			
	VS kg dm per hd per day	Feed intake MJ per hd per day	Pit > 1 month %	IEF Kg CH_4 per hd per year	VS kg dm per hd per day	Feed intake MJ per hd per day	Liquid/slurry %	IEF kg CH_4 per hd per year
Swine	0.5	38	73	3.0	0.2		98	2.3
Sows (incl. piglets until 7 kg)					0.5	74		6.9
Weaners (7-32 kg)					0.1	2		0.2
Fattening pigs (32-107 kg)					0.3	10		0.8

In Table 6.24 are shown the emission of CH_4 from manure management from 1990 to 2012. The main part of the emission originates from cattle and swine. The emission is increased from 1990 to 2012 and this is mainly due to a change in housing systems to a higher share of slurry based systems.

Table 6.24 Emission of CH_4 from Manure Management 1990 – 2012, Gg CH_4.

CRF 4.A	1990	1995	2000	2005	2008	2009	2010	2011	2012
Dairy Cattle	15.86	16.07	17.51	19.33	17.96	18.63	18.86	18.50	19.73
Non-Dairy Cattle	8.48	9.34	9.12	9.28	9.77	9.44	9.52	9.74	9.37
Sheep	0.26	0.23	0.31	0.36	0.33	0.33	0.31	0.26	0.25
Goats	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.03	0.03
Horses	0.40	0.42	0.44	0.52	0.56	0.52	0.49	0.46	0.46
Swine	20.13	24.26	26.41	30.01	28.90	28.34	29.44	29.94	28.38
Poultry	0.47	0.54	0.52	0.53	0.49	0.51	0.53	0.51	0.50
Other;									
Fur farming	1.29	1.09	1.44	2.01	2.57	2.64	2.68	2.85	3.05
Deer	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.002	0.002
Ostriches	NO	0.005	0.013	0.005	0.001	0.001	0.001	0.0003	0.0003
Pheasants	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Total, Gg CH_4	46.91	51.98	55.80	62.07	60.63	60.45	61.88	62.30	61.77
Total, Gg CO_2 eqv.	985	1 092	1 172	1 303	1 273	1 270	1 300	1 308	1 297

No = Not occurring.

N_2O emission

The N_2O emission from manure management is based on the amount of nitrogen in the manure in housings. The emission from manure deposited on grass is included in “Pasture, Range and Paddock Manure” (Chapter 6.5.2). The IPCC default emission factors are applied, see Table 6.25.

Table 6.25 Emission factors for N_2O from manure management.

		Emission factor
	Unit	IPCC – default values
Handling of manure:		
Solid manure, poultry	kg N_2O-N per kg N	0.005
Solid manure, other	kg N_2O-N per kg N	0.02
Slurry and urine	kg N_2O-N per kg N	0.001
Deep litter	kg N_2O-N per kg N	0.02
Deep litter, farmyard manure < 1 month[1]	kg N_2O-N per kg N	0.005

[1] Farmyard manure, which is faeces and urine mixed with large amounts of bedding (usually straw) on the floors of cattle or swine housing.

The total amount of nitrogen in manure has decreased by 12 % from 1990 to 2012 (Table 6.26), despite a significant increase in the production of pigs and poultry. This reduction is due to improvements in fodder efficiency, especially for fattening pigs. A decrease in total amount of nitrogen also means a decrease for the N_2O emission. Another reason for the decreased N_2O emission is a change from the previous more traditional tethering systems with solid manure to slurry based systems due to the lower emission factor for liquid manure than for solid manure. For example for dairy cattle 70 % is placed on slurry based housing system in 1990, which is increased to 88 % in 2012. It is important to point out that the N-excretion rates shown in Table 6.26 are values weighted for the subcategories (Table 6.4). N-excretion reflects nitrogen excreted per animal per year (per AAP). The variations in N-excretion in the time series reflect changes in feed intake, fodder efficiency and distribution of animals in subcategories.

Table 6.26 Nitrogen excretion, annual average 1990 – 2012, kg N per head per year (AAP).

CRF Table 4.B(b)	1990	1995	2000	2005	2008	2009	2010	2011	2012
Livestock category									
Dairy cattle	129.49	125.23	125.31	133.30	137.98	138.12	138.63	138.47	138.03
Non-dairy	35.59	36.26	36.39	40.88	45.53	44.81	43.15	44.11	43.39
Sheep	21.18	21.90	16.95	16.95	16.95	16.95	16.95	16.95	16.95
Goats	21.18	21.90	16.95	15.83	16.32	16.37	16.40	16.43	16.55
Swine	11.84	9.70	9.61	9.19	8.63	8.33	7.81	7.98	8.01
Poultry	0.63	0.62	0.55	0.73	0.74	0.55	0.60	0.55	0.54
Horses	44.15	39.56	39.56	39.56	39.56	39.56	39.56	39.56	39.56
Fur farming	4.90	4.65	4.62	5.38	5.29	5.51	5.82	5.65	5.44
Deer	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Ostrich	NO	15.61	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
N-excretion, total, Gg N per year	292	274	270	277	269	260	261	260	258
N-excretion, housing, Gg N per year	258	239	235	251	246	237	239	239	237

NO – Not occurring.

Table 6.27 shows the N_2O emission from manure management distributed on the main livestock categories. The total emission decreased from 1.94 Gg N_2O in 1990 to 1.32 Gg N_2O in 2012 and this trend is particularly determined by the emission from cattle and swine. The main reason is change in housing types towards more animals on slurry based system. For swine is seen the same development as for cattle where the share of slurry based system has increased from 89 % in 1990 to 98 % in 2012. Furthermore, the N-excretion from fattening pigs and weaners has decreased significantly.

Table 6.27 Emission of N_2O from manure management 1990-2012, Gg N_2O.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
Dairy Cattle	0.57	0.50	0.42	0.31	0.31	0.29	0.30	0.27	0.28
Non-Dairy Cattle	0.38	0.38	0.37	0.39	0.43	0.41	0.41	0.41	0.40
Sheep	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01
Goats	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002
Swine	0.54	0.46	0.46	0.46	0.31	0.26	0.26	0.24	0.22
Poultry	0.26	0.33	0.35	0.36	0.32	0.31	0.32	0.30	0.29
Horses	0.09	0.09	0.09	0.11	0.12	0.11	0.10	0.10	0.10
Fur farming	0.08	0.06	0.06	0.05	0.03	0.03	0.02	0.02	0.03
Deer	IE	IE	IE	IE	IE	IE	IE	IE	IE
Ostriches	NO	0.0013	0.0035	0.0014	0.0002	0.0001	0.0001	0.0001	0.0001
Pheasants	IE	IE	IE	IE	IE	IE	IE	IE	IE
Total excl. biogas	1.94	1.84	1.76	1.70	1.53	1.43	1.43	1.36	1.32

NO – Not Occurring.

IE - Included Elsewhere. Deer and pheasants are at pasture 365 days a year and the emissions are reported under 4.D.2 Pasture, Range and Paddock.

A lower N_2O emission from biogas treated slurry

Studies indicate a lower N_2O emission from biogas treated slurry compared to untreated slurry (Sommer et al., 2001 and Sommer et al., 2004). The lower emission is a result of displacement in allocation between the fraction of degradable and non-degradable VS. Biogas treated slurry increase the fraction of non-degradable VS, which promote the oxygen content in soil. These conditions will reduce the potential for N_2O emission, because N_2O emission takes place in environments without oxygen or with very low concentrations of oxygen (Sommer et al., 2001).

In practice this effect of a lower N_2O emission will take place in the manure applied on soil. However, it is chosen, in the inventory, to account for the lower N_2O emission by subtracting it from the manure management emission. The biogas treatment is taken place, before the slurry is applied to soil.

No methodology is provided in the IPCC Reference Manual or GPG on how to account for this reduction. The estimation is based on a Danish study (Sommer et al., 2001). The reduced N_2O emission is calculated as:

$$N_2O\text{-}N_{lower} = N_2O\text{-}N_{non\text{-}treated\ slurry} - N_2O\text{-}N_{treated\ slurry}$$

The N_2O emission from treated and non-treated slurry is calculated as:

$$N_2O\text{-}N_{non\text{-}treated} = N_{slurry\ non\text{-}treated} \cdot N_{content} \cdot EF_{N_2O}$$

$$N_2O\text{-}N_{treated} = N_{slurry\ treated} \cdot N_{content} \cdot E_{N_20} \cdot EF_{lower}$$

Where; $N_2O\text{-}N_{non\text{-}treated}$ slurry and $N_2O\text{-}N_{treated}$ slurry are the emission of non-biogas treated slurry and biogas treated slurry, respectively. $N_{content}$ express the nitrogen content in slurry. N_{slurry} is the total amounts of N in slurry, EF_{N2O} express the N_2O emission factor based on IPCC default (1.25 %). E_{lower} is the lower emission of biogas treated slurry compared to untreated slurry.

Based on result in Sommer et al. (2001) it is assumed that the emission from treated cattle slurry is 36 % lower compared to untreated slurry, which lead to an E_{lower} of 0.64. Result from Sommer et al. (2001) concerning the pig slurry shows a 41 % lower N_2O emission from treated slurry, which results in a E_{lower} of 0.59. Refer to Annex 3E-11.

All key model parameters for estimating the lower N_2O emission in 2012 as a result of biogas treatment of manure are listed in Table 6.28.

Table 6.28 Key model parameters used to calculate the lower N_2O emission due to biogas treated slurry, 2012

	Slurry, biogas treated	Total N in treated slurry[a]	E_{lower}[b]	N_2O emission, untreated slurry	N_2O emission, biogas treated slurry	Lower N_2O emission
	1000 Gg	Pct.		Gg N_2O	Gg N_2O	Gg N_2O
Cattle slurry	1.10	0.538	0.64	0.074	0.047	0.027
Pig slurry	1.35	0.541	0.59	0.091	0.054	0.037
Lower emission						0.064

[a] Poulsen et al., 2001

[b] Sommer et al., 2001.

Data for 1990 to 2012 are shown in Annex 3E-12b.

Due to the biogas treatment, the emission of N_2O in 2012 is reduced by 0.06 Gg N_2O (Table 6.29) which corresponds to a 4 % reduction of the N_2O emission from manure management in 2012.

Table 6.29 Lower N_2O emissions from manure management as a result of biogas-treated slurry 1990 – 2012.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
Amount of treated slurry, Mt									
- cattle	0.09	0.29	0.52	0.87	0.99	1.08	1.12	1.08	1.10
- swine	0.10	0.35	0.64	1.06	1.20	1.31	1.37	1.31	1.35
Total reduced emission, Gg N_2O	0.01	0.02	0.03	0.05	0.06	0.06	0.06	0.06	0.06
Total N_2O emission incl. biogas, Gg N_2O	1.93	1.83	1.73	1.65	1.47	1.36	1.36	1.30	1.26

6.4.3 Time series consistency

In Table 6.30, the national emission from manure management from 1990 to 2012 is shown. The N_2O emission has decreased by 35 %. The national emission from manure management has, nevertheless, increased by 7 % in CO_2 equivalents due to the increase in the CH_4 emission.

Table 6.30 Emissions of N_2O and CH_4 from Manure Management 1990 – 2012.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
N_2O emission									
Liquid manure, Gg N_2O	0.30	0.27	0.25	0.26	0.26	0.24	0.24	0.25	0.25
Solid manure, Gg N_2O	1.01	0.81	0.64	0.50	0.36	0.30	0.29	0.24	0.23
Other manure, Gg N_2O	0.62	0.75	0.84	0.89	0.86	0.82	0.83	0.81	0.79
Total, Gg N_2O	1.93	1.83	1.73	1.65	1.47	1.36	1.36	1.30	1.26
Total, Gg CO_2 eqv.	600	566	537	512	457	423	422	403	391
CH_4 emission									
Total, Gg CH_4	46.91	51.98	55.80	62.07	60.63	60.45	61.88	62.30	61.77
Total, Gg CO_2 eqv.	985	1 092	1 172	1 303	1 273	1 270	1 300	1 308	1 297
Total Manure Management, Gg CO_2 eqv.	1 585	1 657	1 709	1 816	1 730	1 693	1 722	1 711	1 688

Incl. the reduction from biogas treated slurry.

6.5 N_2O emission from agricultural soils (CRF sector 4D)

6.5.1 Description

The emissions from agricultural soils, contribute, in 2012 with 93 % of the N_2O emission from the agricultural sector. Figure 6.5 shows the distribution and the development from 1990 to 2012 according to different N_2O sources. The emission has overall decreased 39 %. The increase from 2007 to 2008 was due to a rise in the use of synthetic fertiliser, which can mainly be explained by stockpiling due to expectations of rising prices. In 2009 the emission has decreased again and since then nearly no changes have taken place.

The main part of the emission originates as direct emission. The largest sources are manure and synthetic fertiliser applied on agricultural soils. Another large source is the indirect N_2O emission, of which the emission from nitrogen leaching is the major part.

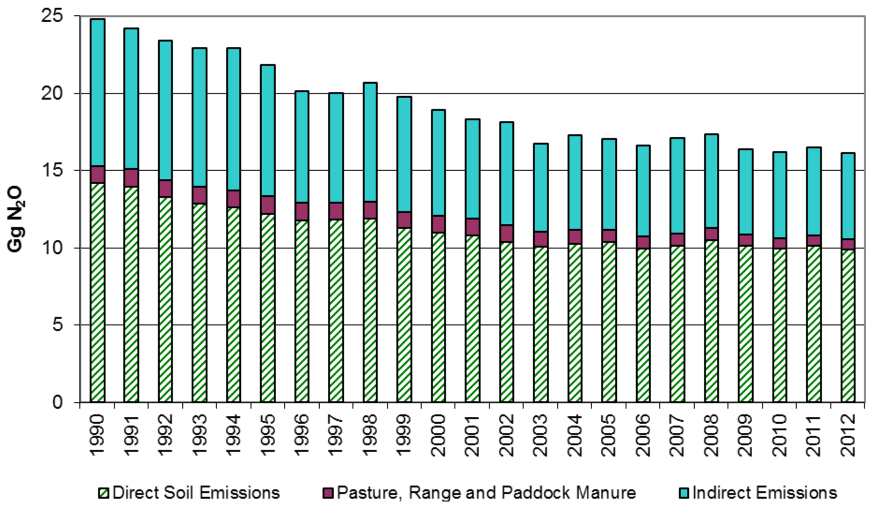

Figure 6.5 N_2O emissions from agricultural soils 1990 - 2012.

6.5.2 Methodological issues

To calculate the N_2O emission the IPCC Tier 1b methodology is used in combination with a country specific method (CS). Tier 1b is used in calculation of emission from N-fixing crops, crop residue and atmospheric deposition.

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 great detail in Mikkelsen et al. (2011) and Denmark's annual inventory report to the UNECE Convention on Long-Range Transboundary Air Pollution (Nielsen et al., 2013b). For the calculation of the N_2O emission from nitrogen leaching and runoff a national model is used.

In the calculation of N_2O from agricultural soils the N_2O emission factors for all sources are based on the default values given by the IPCC (2000). A NH_3 and N_2O emission factor overview is presented in Table 6.31. The estimated emissions from the different sub-sources are described in the text, which follows.

Table 6.31 Emission factors – NH_3 and N_2O from agricultural soils 1990 – 2012.

	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
1. Direct Soil Emissions		
Synthetic Fertiliser Applied to Soils	0.02	0.0125
Animal Wastes Applied to Soils	0.21*	0.0125
N-fixing Crops		0.0125
Crop Residue		0.0125
Cultivation of Histosols		8**
Industrial Waste Used as Fertiliser		0.0125
Sewage Sludge Used as Fertiliser	0.02	0.0125
2. Pasture, range and paddock	0.07	0.02
3. Indirect Soil Emissions		
Atmospheric Deposition		0.01
Nitrogen Leaching and Run-off		0.025***

*Varies from year to year, has decreased from 0.28 in 1990.

**Unit: kg N_2O-N pr ha.

***Groundwater = 0.015, rivers = 0.0075 and estuaries = 0.0025.

Direct emissions

Synthetic fertilisers

The amount of nitrogen (N) applied to soil by use of synthetic fertilisers is estimated from sales estimates from the Danish AgriFish Agency, the source for the FAO database. Table 6.32 shows the consumption of each fertiliser type. Furthermore, the NH_3 emission factor for each fertiliser is given, based on the values from the EMEP/EEA Guidebook, which has been updated in 2013. The NH_3 emission depends on fertiliser type and the major part of the Danish emission is related to the use of calcium ammonium nitrate and NPK fertiliser, where the emission factor is 0.02 and 0.04 kg NH_3-N per kg N, respectively. The Danish FracGASF 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 6.32 Synthetic fertiliser consumption 2012 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		
Calcium and boron calcium nitrate	0.11	0.1
Ammonium sulphate	0.01	5.9
Calcium ammonium nitrate and other nitrate types	0.02	90.8
Ammonium nitrate	0.04	8.1
Liquid ammonia	0.01	7.8
Urea	0.24	0.8
Other nitrogen fertiliser	0.04	22.8
Magnesium fertiliser	0.11	0.0
NPK-fertiliser	0.04	43.0
Diammonphosphate	0.11	0.9
Other NP fertiliser types	0.11	4.7
NK fertiliser	0.04	2.1
Total consumption of N in synthetic fertiliser		187.0
National emission of NH_3-N, Gg	5.82	
Average NH_3-N emission (FracGASF)	0.03	

[1]) EMEP/EEA (2013).

[2]) The Danish AgriFish Agency (2013).

The use of synthetic fertiliser includes fertiliser used in parks, golf courses and private gardens. 1 % of the synthetic fertiliser can be related to these uses outside the agricultural area.

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 synthetic fertiliser has more than halved from 1990 to 2012 (Table 6.33). From 2007 to 2008 the consumption increased which is due to stockpiling based on an expectation of rising prices and therefore the consumption decreased again in 2009 to 2012.

Table 6.33 Nitrogen applied as fertiliser to agricultural soils 1990 – 2012.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
N content in synthetic fertiliser, Gg N	400	316	251	206	220	200	190	197	187
NH_3-N emission, Gg NH_3-N	14	13	8	6	7	6	6	6	6
N in fertiliser applied on soil, Gg N	365	303	243	200	214	194	184	191	181
N_2O emission, Gg N_2O	7.17	5.96	4.78	3.92	4.20	3.82	3.62	3.75	3.56

Manure applied to soil

The amount of nitrogen applied to soil is estimated as the N-excretion in housings minus the NH_3 emission, which occur in housings, under storage and in relation to the application of manure. These values are based on national estimations and are calculated in the NH_3 emission inventory (Table 6.34). Emission factors for NH_3 from the housing unit and storage are given in Annex 3E-3 and 4. The total N-excretion in housings from 1990 to 2012 has decreased by 8 %. Despite this reduction in N-excretion, the amount of nitrogen applied to soil has increased slightly, which is caused by a reduction in NH_3 emission and especially from application of manure.

Table 6.34 Nitrogen applied as manure to agricultural soils 1990 – 2012.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
N-excretion, housing, Gg N	258	239	235	251	246	237	239	239	237
N ab Storage, Gg N	214	200	197	212	213	206	208	208	207
NH_3-N emission from application, Gg NH_3-N	31	26	23	17	17	17	17	16	16
N in manure applied on soil, Gg N	183	175	174	195	196	190	191	192	191
N_2O emission, Gg N_2O	3.59	3.43	3.42	3.83	3.84	3.73	3.75	3.77	3.75

The FracGASM express the fraction of total N-excretion (N ab animal) that is volatilised as NH_3 emission in housings, storage and application. The FracGASM has decreased from 0.25 in 1990 to 0.19 in 2012 (Table 6.35). This is the result of an active strategy to improve the utilisation of the nitrogen in manure.

Table 6.35 FracGASM 1990 – 2012.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
Total N-excretion, Gg N	292	274	270	277	269	260	261	260	258
NH_3-N emission from manure, Gg NH_3-N	44	42	42	42	43	43	43	43	43
FracGASM	0.25	0.23	0.22	0.20	0.19	0.19	0.19	0.19	0.19

N-fixing crops

To estimate the emission from N-fixing crops, IPCC Tier 1b is applied. The emission calculated is based on nitrogen content, the fraction of dry matter and the yield for each harvest crop type. Data for crop yield is based on data from Statistics Denmark. For nitrogen content in the plants, the data are taken from Danish feedstuff tables (Danish Agricultural Advisory Centre). The estimates for the amount of nitrogen fixed in crops are made by the DCA (Kristensen, 2003, Høgh-Jensen et al., 1998, Kyllingsbæk, 2000).

$$N_2O\text{-}N_{N\text{-}fix} = \sum (DM_{i,\,yield} \cdot N_{i,\,pct} \cdot (1 + N_{i,\,pct\,in\,root\,and\,stubble}) \cdot A_{pct\,fix}) \cdot EF_{N2O}$$

Where:

$DM_{i,\,yield}$	= dry matter yield, kg per ha for crop type *i*
$N_{i,\,pct}$	= nitrogen percentage in dry matter
$N_{i,\,pct\,root\,+\,stubble}$	= nitrogen percentage in root and stubble
$A_{pct\,fix}$	= percentage of nitrogen which is fixed
EF_{N2O}	= emission factor, IPCC standard value of 1.25 pct.

The Danish inventory includes emissions from clover-grass, despite the fact that this source is not mentioned in the IPCC GPG. Area with grass and clover covered approximately 20 % of the total agricultural area in 2012 and, for this reason, represents an important contributor to the national emission from N-fixing crops.

In Table 6.36 and Annex 3E-13 and 14 the background data for estimating the N-fixing is listed. The emission from N-fixing crops decreases from 1990-2012, largely due to a reduction in agricultural area (Annex 3E-15).

Table 6.36 Emissions from N-fixing crops 2012.

	Crop yield, 1000 t	N-fixing, kg N per tonnes crop yield	N-fixing total, t N fix	N_2O emission, Gg N_2O
Legumes to maturity[a]	26.5[b]	37.3	988	0.019
Lucerne	281.2	7.7	2 154	0.042
Crops for silage	206.4[e]	6.1	1 253	0.025
Legumes/marrow-stem kale	NO	6.1	NO	NO
Grass and clover in rotation	4 166.8[e]	8.2	34 126	0.670
Grass not in rotation	173.7[e]	8.2	1 422	0.028
Fields with catch crop	115.7[e]	8.2	947	0.019
Peas for conservation[a]	9.6	37.3	359	0.007
Seeds of leguminous grass crops			825	0.016
- Red clover	441.6[c]	200[d]		
- White clover	4 017.8[c]	180[d]		
- Black medic	76.2[c]	180[d]		
Total N-fixed			42 075	
Total N_2O emission				0.826

[a] Dry matter content for straw is 0.87 and the N-fraction is 0.010.

[b] Yield of seed, yield of straw is 60 % of yield of seed.

[c] Area, ha.

[d] kg N per ha.

[e] Crop yield given by DSt adjusted to only amount of N-fixing crops

Crop residue

To estimate the emission from crop residue, IPCC Tier 1b is applied. N_2O emissions from crop residues are calculated as the total aboveground quantity of crop residue returned to soil. For cereals, the aboveground residues are calculated as the amount of straw plus stubble and husks. The total amount of straw is given in the annual census and reduced by the amount used for feeding, bedding and bio fuel in power plants. Straw for feed and bedding is subtracted because this quantity of removed nitrogen returns to the soil via manure.

$$N_2O - N_{crop\ residue,j} = \sum_1^N ha_{i,j} \cdot (N_{i,stubble} + N_{i,husks} + N_{i,tops} + N_{i,leafs}) \cdot EF_{N_2O}$$

Where:

i = crop type

j = year

ha = on which the crop is grown

N_i = nitrogen derived from husks, stubble, plant tops and leaf debris, kg ha^{-1}

EF_{N2O} = emission factor, IPCC standard value of 1.25 %

National values for nitrogen content are used provided by the DCA (Djurhuus and Hansen 2003). It is calculated based on relatively few observations, but is at present the best available data. Data for yield and area cultivated are collected from Statistics Denmark. Background data is given in Annex 3E-16 and 17.

The national emission from crop residues has decreased 14 % from 1990 to 2012 (Table 6.37). This decrease is a result of a fall in cultivated area of beets for feeding, which has been replaced by cultivation of green maize. Another reason is a fall in the agricultural area and a greater part of the straw is harvest – 52 % in 1990 and 63 % in 2012.

Table 6.37 Emissions from crop residue 1990 – 2012.

Crop residue	1990	1995	2000	2005	2008	2009	2010	2011	2012
Stubble	18.9	18.2	18.2	17.6	17.9	17.5	17.9	18.1	17.8
Husks	11.4	11.6	12.0	12.3	11.9	12.4	12.5	12.5	11.7
Top of beets and potatoes	7.1	5.8	5.3	4.9	4.4	4.3	4.3	4.5	4.7
Leafs	6.8	10.3	9.0	9.4	7.9	7.0	7.4	7.1	7.4
Straw	15.1	10.4	10.8	10.2	8.1	10.0	9.7	9.7	9.6
Crop residue, total, Gg N	59.3	56.2	55.3	54.4	50.1	51.2	51.8	51.8	51.1
N_2O emission, Gg	1.17	1.10	1.09	1.07	0.98	1.01	1.02	1.02	1.00
$Frac_R$	0.86	0.85	0.85	0.85	0.86	0.87	0.86	0.86	0.87
$Frac_{NCRO}$	0.018	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
$Frac_{NCRBF}$	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04

Frac values

The fractions $Frac_{NCRO}$, $Frac_{NCRBF}$ and $Frac_R$ are calculated for all years by using the definitions given in the IPCC Reference Manual pp 4.92 – 4.94.

The $Frac_{NCRO}$ and $Frac_{NCBRF}$ are calculated as the N-content in harvest crops divided with the total amount of dry matter in harvest crops. $Frac_{NCBRF}$ covers all N-fixing crops and $Frac_{NCRO}$ all the non N-fixing crops. In Table 6.38 the national calculated fraction values are compared to default values given in the Reference Manual (IPCC, 1997). The national values differ slightly during the years. For all Frac values the Danish values are higher than the IPCC default values. For N-fixing crops the explanation could be that Denmark includes fields with clover grass, which has a high N-content. The higher national $Frac_{NCRO}$ could be a consequence of the relatively large part of straw that is harvested and used for feeding, bedding and fuel. As provided by Statistics Denmark nearly 63 % of the straw in 2012 is harvested (see Annex 3E-18).

For the fractions $Frac_R$, the unit kg N per kg crop-N is used, as given in the Reference Manual (IPCC, 1997). The fraction is calculated as N-content in the whole above ground crop biomass that is removed from the field as a crop product divided with total N-content in all parts of plants above ground.

The national $Frac_R$ is significantly higher than the IPCC default. The national value express, that 84 % to 87 % of the total N in crops above ground is removed from the field. The remaining is the N-content in straw and tops from beets and potatoes, which are left on the field. From 1990 to 2012 the $Frac_R$ is increased as a consequence of a fall in cultivated area of feeding beets.

Table 6.38 Frac values.

Fractions	Text in CRF Table 4.Ds2 – additional information	Unit	IPCC default values	National Values 1990-2012
$Frac_{NCRO}$	Fraction of residue dry biomass that is N (all other crops than N-fixing crop)	kg N per kg dm	0.015	0.017-0.018
$Frac_{NCRBF}$	Fraction of total above-ground biomass of N-fixing crop that is N	kg N per kg dm	0.03	0.04
$Frac_R$	Fraction of N in the hole above ground crop biomass that is removed from the field as a crop product	kg N per kg crop-N	0.50[a]	0.84-0.87

a) IPCC, 2000.

Cultivation of histosols

N_2O emissions from histosols are based on the area with organic soils multiplied by the default emission factor given by the IPCC, 8 kg per ha and constant for all years 1990-2012. The area of histosols is shown in Table 6.39. The area of histosols has decreased from 1990 to 2012, see more in Chapter 7.4.1.

Table 6.39 Area of histosols in ha, 1990-2012.

Year	1990	1995	2000	2005	2008	2009	2010	2011	2012
Area, ha	74 473	69 282	64 092	58 901	55 786	54 748	53 710	52 687	50 886

Other Direct Emissions

The category, "Other", includes emission from sewage sludge and sludge from industries applied to agricultural soils as fertiliser. Information about industrial waste and sewage sludge applied on agricultural soil and the content of nitrogen is obtained from a series of reports published by the Danish Environmental Protection Agency. From 2005 the amount of sewage sludge and N content is based on the information registered in the fertiliser accounts controlled by The Danish AgriFish Agency. The recent official figures regarding the amount of sludge from the industrial waste are data covering year 2002 (Petersen & Kielland, 2003). Data covering year 2008 and 2009 are received from Econet AS (Petersen, 2011) and will be included in an EPA report under preparation. Based on these data the amount in 2003-2007 is interpolated.

It is assumed that 1.9 % of N-input applied to soil volatises as NH_3, which is based on information from the Danish Environmental Protection Agency (Bielecki, 2002). In Table 6.40 are shown N, emission of NH_3-N and emission of N_2O from sewage sludge and sludge from industries applied to agricultural soils.

Table 6.40 Emission from sludge applied on agricultural soils 1990 – 2012.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
Nitrogen in sewage sludge, t N	3 115	4 635	3 625	2 173	2 394	2 979	2 692	2 592	2 470
Nitrogen in industrial waste, t N	1 529	4 500	5 147	5 509	4 185	3 993	3 942	3 942	3 942
NH_3-N emission, t NH_3-N	58	87	68	41	45	56	50	49	46
N applied as fertiliser to the soil, t N	4 586	9 048	8 705	7 641	6 534	6 916	6 583	6 485	6 365
N_2O emission, Gg N_2O	0.09	0.18	0.17	0.15	0.13	0.14	0.13	0.13	0.13

Pasture, Range and Paddock Manure

The amount of nitrogen deposited on grass is based on estimations from the NH_3 inventory. Grazing days is based on expert judgement from the Danish Agricultural Advisory Service. N-excretion on grass has decreased due to a reduction in the number of dairy cattle. Under review by ESD it has been recommended that the emission of NH_3 from grazing animals is not subtracted before calculation of N_2O.

Table 6.41 Nitrogen excreted on grass 1990 – 2012.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
N-excretion, grass, Gg N	34	36	34	26	23	22	22	21	22
N_2O emission, Gg	1.08	1.12	1.08	0.82	0.74	0.70	0.69	0.67	0.68
FracGRAZ	0.12	0.13	0.13	0.09	0.09	0.09	0.08	0.08	0.08

$Frac_{GRAZ}$ is estimated as the volatile fraction from grazing animals compared with the total excreted nitrogen (N ab animal) (Table 6.41). The decrease in $Frac_{GRAZ}$ is due to a decrease in number of dairy cattle and a decrease in grazing days for dairy cattle and heifers.

Indirect emissions

Atmospheric deposition

To estimate the emission from atmospheric deposition, IPCC Tier 1b is applied. Atmospheric deposition includes all agricultural NH_3 emission sources included in the Danish NH_3 emission inventory (Nielsen et al., 2013b). This includes the emission from livestock manure, use of synthetic fertiliser, growing crops, NH_3-treated straw used as feed, field burning of crop residues and sewage sludge plus sludge from industrial production applied to agricultural soils.

The emission from atmospheric deposition has decreased from 1990 – 2012 as a result of the reduction in the total NH_3 emission, from 101 901 tonnes of NH_3-N in 1990 to 60 475 in 2012.

Table 6.42 NH_3 emission 2012.

NH_3 emission	2012
	t NH_3-N
Manure, housing	48 564
Manure, grazing	1 515
Synthetic fertilisers	5 817
Crops	4 448
NH_3 treated straw	0
Burning of agricultural residues	85
Sewage sludge and industrial sludge	46
Emission total	60 475
N_2O emission, Gg	0.95

Nitrogen leaching and Run-off

Nitrogen, which is transported through the soil, can be transformed to N_2O. The IPCC recommends an N_2O emission factor of 0.025 used, of which 0.015 is for leaching to groundwater, 0.0075 for transport to watercourses (in IPCC definition called rivers) and 0.0025 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:

$$N_2O_{leaching} = (N_{leach\text{-}ground} \cdot EF_{ground} + N_{leach\text{-}rivers} \cdot EF_{rivers} + N_{leach\text{-}estuatires} \cdot EF_{estuatires}) \cdot \frac{44}{28}$$

In the Action Plans for the Aquatic Environment, nitrogen leaching to groundwater, rivers and estuaries has been estimated, see Table 6.43. 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 3E Figure 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). The SKEP/Daisy model has estimated the total N leached from 2003-2007 to be 172-159 thousand tonnes N, whereas N-LES model has estimated the total N leached to be 163-154 thousand tonnes in the same period. An average of the results from the two models is used in the emission inventory.

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 Bioscience, Aarhus University (Windorf et al., 2011). 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 have been going on from the early 1990's.

Table 6.43 N leaching to groundwater, rivers and estuaries in Gg, 1990-2012.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
Groundwater	267	235	179	160	163	154	151	153	149
Rivers	102	104	95	67	80	59	68	73	74
Estuaries	100	91	81	56	65	49	55	59	59

Figure 6.6 shows leaching from groundwater estimated in relation to the nitrogen applied to agricultural soils as livestock manure, synthetic fertiliser and sludge. The average proportion of nitrogen leaching from groundwater has decreased from around 39 % in the middle of the nineties to around 33 % in 2012. 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 synthetic fertiliser, which has been reduced by 50 % from 1990 to 2012.

The proportion of N input to soils lost through leaching and runoff ($Frac_{LEACH}$) used in the Danish emission inventory is higher than the default value of the IPCC (30 %). The high values are partly due to the humid Danish climate, with the precipitation surplus during winter causing a downward movement of dissolved nitrogen. $Frac_{LEACH}$ has decreased from 1990 and onwards. At the beginning of 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. The data based on model estimates from DCA and DCE reflect the Danish conditions and are considered the best estimate.

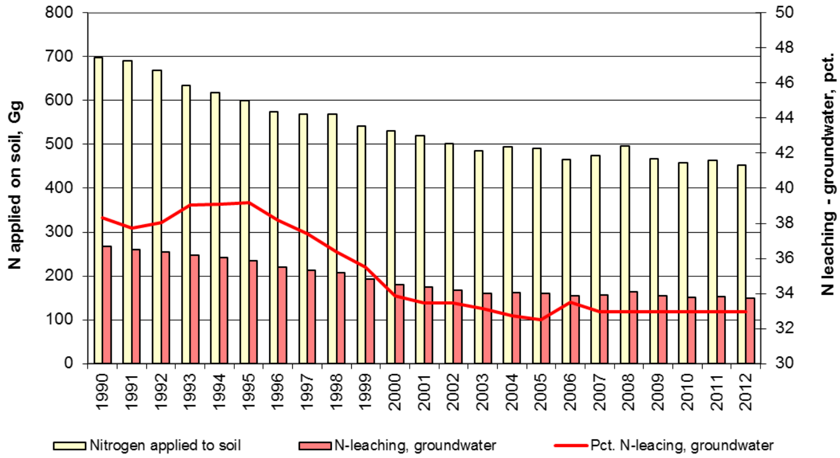

Figure 6.6 Nitrogen applied to agricultural soils and N-leaching, groundwater 1990-2012.

6.5.3 Activity data

The calculation of the N_2O emission is based on the amount of nitrogen applied to agricultural soils, which is the activity data. Table 6.44 provides an overview on activity data from 1990 to 2012 used to calculate the N_2O emission from agricultural soils. The amount of nitrogen applied to agricultural soil has decreased from 1 081 Gg N to 702 Gg N, corresponding to a 35 % reduction, which results in a lower N_2O emission.

Table 6.44 Activity data - agricultural soils 1990 – 2012, Gg N.

CRF – Table 4.D	1990	1995	2000	2005	2008	2009	2010	2011	2012
Total amount of nitrogen applied on soil	1 081	937	810	746	752	721	708	719	702
1. Direct Emissions									
Synthetic Fertilizers	387	303	243	200	214	194	184	191	181
Animal Manure Applied to Soils	183	175	174	195	196	190	191	192	191
N-fixing Crops	44	37	38	34	35	41	39	42	42
Crop Residue	59	54	55	54	50	51	52	52	51
Industrial Waste	2	5	5	6	4	4	4	4	4
Sewage Sludge	3	5	4	2	2	3	3	3	2
2. Pasture, Range and Paddock	34	36	34	26	23	22	22	21	22
3. Indirect Emissions									
Atmospheric Deposition	102	88	77	69	65	62	62	62	60
Nitrogen Leaching and Run-off	267	235	179	160	163	154	151	153	149

6.5.4 Time series consistency

The N_2O emissions from agricultural soils have been reduced by 35 % from 1990 to 2012. This is largely due to a decrease in the use of synthetic fertiliser and a decrease in N-leaching as a result of national environmental policy, where action plans have focused on decreasing the nitrogen losses and on improving the nitrogen utilisation in manure.

Table 6.45 Emissions of N_2O from Agricultural Soils 1990 – 2012, Gg N_2O.

CRF – Table 4.D	1990	1995	2000	2005	2008	2009	2010	2011	2012
Total N_2O emission	24.81	21.86	18.96	17.07	17.34	16.37	16.20	16.50	16.14
1. Direct Emissions	14.24	12.23	11.02	10.39	10.54	10.18	9.96	10.16	9.90
Synthetic Fertilisers	7.59	5.96	4.78	3.92	4.20	3.82	3.62	3.75	3.56
Animal Manure Applied to Soils	3.59	3.43	3.42	3.83	3.84	3.73	3.75	3.77	3.75
N-fixing Crops	0.87	0.73	0.75	0.67	0.69	0.80	0.77	0.83	0.83
Crop Residue	1.17	1.06	1.09	1.07	0.98	1.01	1.02	1.02	1.00
Cultivation of Histosols	0.94	0.87	0.81	0.74	0.70	0.69	0.68	0.66	0.64
Industrial Waste	0.03	0.09	0.10	0.11	0.08	0.08	0.08	0.08	0.08
Sewage Sludge	0.06	0.09	0.07	0.04	0.05	0.06	0.05	0.05	0.05
2. Pasture, Range and Paddock	1.08	1.12	1.08	0.82	0.74	0.70	0.69	0.67	0.68
3. Indirect Emissions	9.50	8.51	6.86	5.86	6.06	5.49	5.55	5.66	5.56
Atmospheric Deposition	1.60	1.38	1.21	1.09	1.01	0.97	0.98	0.97	0.95
Nitrogen leaching and Run-off	7.89	7.13	5.66	4.77	5.04	4.52	4.57	4.70	4.61

6.6 Field burning of agricultural residues (CRF sector 4F)

Field burning of agricultural residues has in Denmark 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. 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 the Danish Agricultural Advisory Service. The total amounts are based on data from Statistics Denmark.

From field burning is seen emissions of a series of different compounds and related to GHG emissions of the following compounds are estimated CH_4, N_2O, NO_x, CO, CO_2, SO_2 and NMVOC. For emission of NMVOC see Chapter 6.7. The emission of NO_x and CO is given CRF Table 4s2. Emission of CO_2 (biogenic) and SO_2 is estimated, but not reported because this is not possible in CRF tables in the present format. Equation for calculating emission of various compounds:

$$E = BB \cdot \frac{EF}{1\,000\,000} \cdot FO$$

$$BB = CP \cdot FB \cdot FR_{dm}$$

E = emission of compounds, Gg
BB = total burned biomass, Gg 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

Table 6.46 Factors for estimating emissions of CH_4 and N_2O, 2012.

		Crop production	Fraction burned in fields	Dry matter (dm) fraction of residue	Total Biomass burned	EF	Fraction oxidized	Emission
		t			Gg dm	g per kg dm		Gg
CH_4	Mixed cereals	5 803 600	0.001	0.85	4 933	2.7	0.90	0.012
CH_4	Straw from seeds of grass	334 675	0.15	0.85	42 671	2.7	0.90	0.104
N_2O	Mixed cereals	5 803 600	0.001	0.85	4 933	0.07	0.90	0.0003
N_2O	Straw from seeds of grass	334 675	0.15	0.85	42 671	0.07	0.90	0.003
Total CO_2 eqv								3.36

The emission of CH_4, N_2O, NO_x, CO, CO_2 and SO_2 from field burning contributes with less than 1 % of the national emission.

The fraction value $Frac_{BURN}$ is calculated by using the definitions as given in IPCC Reference Manual pp. 4.92 – 4.94. $Frac_{BURN}$ is calculated as the amount of N in burned straw divided with the total amount of N in crop residue and the fractions are given in kg N per kg crop-N. For all years the value of $Frac_{BURN}$ is around 0.01 kg N per kg crop-N, which is low, compared to IPCC default value. This is due to the prohibition of field burning in Denmark.

6.7 NMVOC emission

Around 3 % of the total NMVOC emission originates from the agricultural sector, which, in the Danish emission inventory, includes emission from agricultural soils, such as arable land crops and grassland, and field burning of agricultural residue. Activity data are obtained from Statistics Denmark. The emission factor for agricultural soils is for land with arable crops 393 g NMVOC per ha and for grassland, 2120 g NMVOC per ha (Fenhann & Kilde, 1994 and Priemé & Christensen, 1991). The IPCC default value for the emission factor for field burning of agricultural residue is used. The emission from agricultural soils contributes with 88 % and field burning with 12 % of the agricultural NMVOC emission in 2012.

No significant changes from 1990 to 2012 have taken place. A decrease in the area of arable crops offsets an increase in the area of grassland.

Table 6.47 Area and NMVOC emission from agricultural soils 1990 – 2012.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
Arable crops, 1000 ha	2 322	2 064	2 043	2 086	2 107	2 103	2 096	2 102	2 102
Grassland, 1000 ha	466	446	413	446	490	498	521	516	527
NMVOC emission, Gg	1.90	1.76	1.68	1.77	1.87	1.88	1.93	1.92	1.94

Table 6.48 NMVOC emission from field burning of agricultural residue 1990 – 2012.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
NMVOC emission, Gg	0.20	0.24	0.30	0.33	0.27	0.32	0.23	0.23	0.27

6.8 Uncertainties

Uncertainties are calculated using both a Tier 1 and a Tier 2 approach; see Chapter 1.7 for a description of the Tier 2 methodology. The same uncertainty values for activity data and emission factors are used for both Tier 1 and Tier 2.

6.8.1 Uncertainty values

Uncertainties regarding animal production, such as number of animals, feeding consumption, normative figures etc., are very small. The number of animals is estimated by Statistics Denmark and all cattle, sheep and goats have their own ID-number (ear tags) and, hence, uncertainty with regard to their numbers is almost non-existing. Statistics Denmark has estimated the uncertainty in the number of swine to be less than 1 %.

The Danish Normative System for animal excretions is based on data from the Danish Agricultural Advisory Service (DAAS), which is the central office for all Danish agricultural advisory services. DAAS engages 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".

The normative figures (Poulsen et al. 2001) are comprised of arithmetic means. Based on feeding plans, the standard deviation in N-excretion rates between farms can be estimated to ±20 % for all animal types (Poulsen, DCA). 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.

Data for hectares under cultivation is estimated by Statistics Denmark and the uncertainties are based on their estimates. For the most common crops the uncertainties are below 5 %.

In the 2011 submission the uncertainty estimates for both activity data and emission factors were re-evaluated and some adjustments were made. For CH_4 emission from animals (CRF category 4.A and 4.B) the uncertainties for activity data are lowered due to the combined effect of low uncertainty in actual animal numbers, relatively low uncertainty for feed consumption and excretion rates, this gives a relatively low uncertainty in the activity data as a whole – between 2% and 22%. The uncertainties for the emission factors for CH_4 emission form animals are adjusted based on default values from the IPCC (1997 and 2000).

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, 2013b). Uncertainties related to the N_2O emission factor are based on the IPCC Good Practice Guidance. See Table 6.49 for uncertainty values for the agricultural sector.

Table 6.49 Uncertainties values for activity data and emission factors for CH_4 and N_2O.

CRF category		Emission factor	Uncertainties value for activity data, %	Uncertainties value for emission factor, %
4.A Enteric Fermentation		CH_4	2	20
4.B Manure Management		CH_4	5	20
		N_2O	22	100
4.D Agricultural Soils				
4.D1 Direct soil emissions				
	Synthetic Fertilisers	N_2O	25	100
	Animal Manure Applied to Soils	N_2O	30	100
	N-fixing Crops	N_2O	20	100
	Crop Residue	N_2O	20	100
	Cultivation of Histosols	N_2O	20	100
	Sewage sludge used as fertiliser	N_2O	20	100
	Industrial waste used as fertiliser	N_2O	20	100
4.D2 Pasture, range and paddock		N_2O	25	100
4.D3 Indirect soil emissions				
	Atmospheric Deposition	N_2O	19	100
	N-Leaching and Run-off	N_2O	20	100
4.F Field Burning of Agricultural Residue				
		CH_4	25	50
		N_2O	25	50

6.8.2 Result of the uncertainty calculation

Table 6.50 shows the result of the Tier 1 and Tier 2 uncertainty calculation for 2012. A calculation of 1990 gives nearly the same uncertainty values as for 2012, for all emission sources. The overall uncertainty calculation for the agricultural sector based on Tier 1 is estimated to ±25 %. Tier 2 calculation shows an uncertainty interval from -19 % to +32.

For most of the emission sources the uncertainty level based on Tier 2 are nearly at the same level as for Tier 1, see Figure 6.7. The two calculations can be considered as consistent. The lowest uncertainties are seen for CH_4 emission from enteric fermentation and manure management and the highest for emission form grazing animals and this pattern is reflected in both calculations.

The biggest difference between the Tier 1 and Tier 2 uncertainty calculations is seen for N_2O from manure management.

Table 6.50 Comparison between Tier 1 and Tier 2 uncertainty calculation, 2012.

Uncertainty		Tier 1 Emission, Gg CO_2 eqv	Uncertainty, % Lower and upper (±)	Tier 2 Median emission, Gg CO_2 eqv	Uncertainty, % Lower (-)	Upper (+)
4 Agriculture total	CH_4 and N_2O	9 599	25	10 132	19	32
4.A Enteric Fermentation	CH_4	2 904	20	2 911	12	14
4.B Manure Management	CH_4 and N_2O					
	CH_4	1 297	21	1 302	11	13
	N_2O	391	102	424	20	27
4.D Agricultural soil:	N_2O					
4.D1 Direct soil emissions	N_2O	3 069	56	3 305	40	76
4.D2 Pasture, Range and Paddock Manure	N_2O	211	103	212	62	161
4.D3 Indirect soil emissions	N_2O	1 724	86	1 766	54	130
4.F Field Burning of Agricultural Residues	CH_4 and N_2O					
	CH_4	2	56	2	42	70
	N_2O	1	56	1	42	70

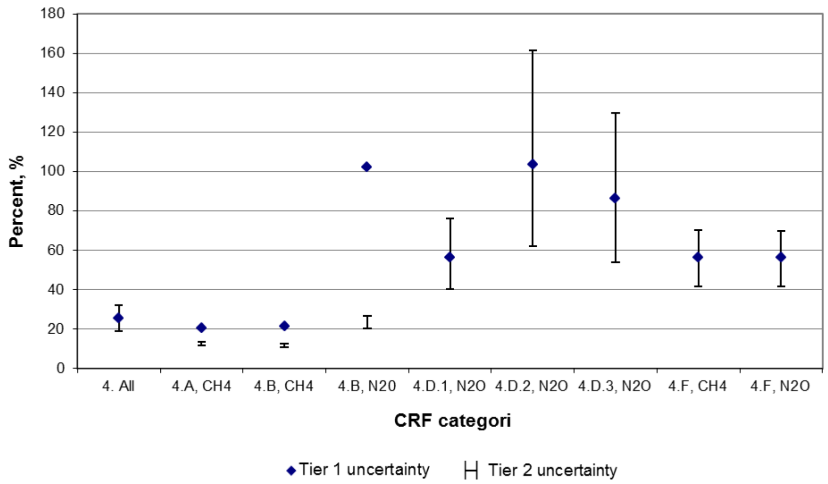

Figure 6.7 Tier 1 and Tier 2 uncertainties for the agricultural sector, 2012.

6.9 Quality assurance and quality control (QA/QC)

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, 2013a). For more detailed information of the structure in the general QA/QC plan refers 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 6.9.2 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. This year a more detailed set up for stage I, II and III are developed – refer to Annex 3E-19.

The QA/QC procedure is divided in six stages as listed below:

Table 6.51 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 (2012)
	- 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 AgriFish 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 AgriFish Agency: distribution of housing systems and the use of nitrogen in synthetic 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 2013. In the case where an error cover 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 1990-2012 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, which could be compared with the survey given in the emission inventory. Another possibility to check some of the IDA estimations is the information in the fertiliser accounts controlled by The Danish AgriFish Agency. Farmers with more than 10 animal units have to be 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 2012 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 (Mikkelsen et al., 2011). 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 3E-19.

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. total N-excretion in manure calculated of DCA. Furthermore, some comparisons with the Register of Fertilisation administrated by the Danish AgriFish Agency can be provided.

Stage VI is implemented. Two reports describing the methodology in calculation of agricultural emissions in details are published (Mikkelsen et al., 2006 and Mikkelsen et al., 2011). Both reports have been reviewed by experts not involved with the preparation of the emission inventory. The 2011 report was reviewed by: Nicholas J. Hutchings from the DCA, Aarhus University and Johnny M. Andersen from the Faculty of Life Sciences, University of Copenhagen. The reviewers have reviewed all sections of the report. In the next updated version is it planned to contact relevant reviewers to focus on specific subject areas. An updated version of the methodology report is planned to take place in 2013/2014.

6.9.1 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 agricultural sector, in more details see Table 6.2:

- Data from the annual agricultural census made by Statistics Denmark.
- DCA, Aarhus University.
- The Danish AgriFish Agency.
- Danish Agricultural Advisory Service (DAAS).
- 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 DAAS 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 AgriFish Agency

Total area with the various agricultural crops is provided to the Danish AgriFish 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-mineral accounting on a farm and field level with the N-excretion data from DCA. Data at farm level is reported annually to the Danish AgriFish Agency. The N figures also include the quantities of synthetic fertilisers bought and sold. Suppliers of synthetic fertilisers are required to report all N sales to commercial farmers to the Agency. The total sold to farmers is very close to the amount imported by the suppliers, corrected for storage. The total amount of synthetic fertiliser in Denmark is, therefore, a very precise estimate for the synthetic fertiliser consumed. This is also valid for N-excretion in animal manure.

The Danish AgriFish 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 AgriFish Agency provides data for distribution of housing type.

Danish Agricultural Advisory Service (DAAS)

DAAS is the central office for all Danish agricultural advisory services. DAAS 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 DAAS 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 waste water 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 to be a precise estimate for the Danish agricultural efficacy level.

Regarding uncertainties for the remaining emission sources see Chapter 6.8.

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 6.8 and Table 6.50.

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 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 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):

Mrs. Hanne Damgaard Poulsen (hannedamgaard.poulsen@agrsci.dk)

Mr. Nick Hutchings (nick.hutchings@agrsci.dk)

Mr. Christen Duus Børgesen (christen.Borgesen@agrsci.dk)

The Danish Agricultural Advisory Centre:

Mr. Ole Aaes (oes@vfl.dk)

Mr. Eric F. Clausen (efc@vfl.dk)

Mr. Barthold Feidenshans'l (baf@vfl.dk)

Danish AgriFish Agency:

Mr. Troels Knudsen (tkn@pdir.dk)

Mrs. Mette Thomsen (mth@pdir.dk)

The Danish Energy Agency:

Mr. Søren Tafdrup (st@ens.dk)

The Danish Environmental Protection Agency:

Mrs. Linda Bagge (bagge@mst.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 Tier 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. A Tier 2 calculation is provided, please refer to Chapter 6.8.

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) and an updated version in Mikkelsen et al. (2011). The first report has been reviewed by the Statistics Sweden, who is responsible for the Swedish agricultural inventory and the updated report has been 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. 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. As a consequence, 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 Reference Manual and the Good Practice Guidance.

Implied emission factors for CH_4 from enteric fermentations are, in general, lower than the IPCC default values, which is due to the professional way farms are managed in Denmark. There has been an increase in emission from the enteric fermentation of CH_4 due to increase in milk production. The IEF is in line with Canada, the Netherlands, Sweden and Finland, who all have agricultural conditions comparable to Denmark.

The IEF for CH_4 from manure management is, in general, higher compared with the default IPCC values for Western Europe because of the higher percentage handled as slurry. However, due to the high efficiency at farm level, energy intake is lower per head and the subsequent CH_4 emission from slurry is, thereby, lower. Denmark uses an MCF factor of 10 % as provided in the 1996 guidelines and not the 39 % in the revision to the 1996 guidelines. For further explanation, see Chapter 6.4.2.

$Frac_{LEACH}$ is higher than the default IPCC values. $Frac_{LEACH}$ has decreased from 1990 and onwards. In the beginning of 1990s, manure was often applied in autumn. The high values are partly due to the humid Danish climate, with the precipitation surplus during winter causing a downward moment of dissolved nitrogen. The decrease in $Frac_{LEACH}$ over time is caused by sharpened environmental requirements, banning manure application after harvest. As a result, most manure application occurs during spring and summer, where there is a precipitation deficit. The generally accepted leaching values in Denmark are 0.3 for mineral nitrogen and 0.45 for organic-bound nitrogen. These values are based on a series of leaching studies.

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 Reference Manual and the Good Practice Guidance.

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 1.7.

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, 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 6.3.4.

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 and the documentation report (Mikkelsen et al., 2011).

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 (Mikkelsen et al., 2011).

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 (Mikkelsen et al., 2011).

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 1.7.

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 check-list 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 check-list is under development for correctness of data import to level 2.

6.10 Recalculation

Below follows an overview of improvements and recalculations implemented since the 2013 submission.

Recalculations

Some changes in calculation of agricultural emissions 1990-2011 have taken place. The recalculation has contributed to a decrease in the total agricultural emissions for the years 1990-2011 of up to 0.2 % given in CO_2 equivalent (Table 6.52).

Table 6.52 Changes in GHG emission in the agricultural sector compared with the CRF reported last year.

	1990	1995	2000	2005	2008	2009	2010	2012
Previous inventory, Gg CO_2 eqv.								
4.A Enteric Fermentation	3 247	3 134	2 861	2 737	2 830	2 823	2 862	2 840
4.B Manure Management	1 593	1 669	1 722	1 816	1 730	1 693	1 723	1 711
4.D Agricultural Soils	7 702	6 787	5 885	5 295	5 379	5 079	5 026	5 118
4.F Field Burning of Agricultural Residues	3	3	4	4	3	4	3	3
Recalculated, Gg CO_2 eqv.								
4.A Enteric Fermentation	3 247	3 134	2 861	2 737	2 830	2 823	2 862	2 840
4.B Manure Management	1 585	1 657	1 709	1 816	1 730	1 693	1 722	1 711
4.D Agricultural Soils	7 692	6 777	5 879	5 290	5 374	5 075	5 022	5 114
4.F Field Burning of Agricultural Residues	3	3	4	4	3	4	3	3
Change in Gg CO_2 eqv.								
4.A Enteric Fermentation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
4.B Manure Management	-8.0	-11.6	-12.4	0.0	0.0	0.0	-1.6	-0.2
4.D Agricultural Soils	-10.5	-9.8	-6.1	-4.8	-4.6	-3.5	-3.7	-3.7
4.F Field Burning of Agricultural Residues	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Change in pct.								
4.A Enteric Fermentation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.B Manure Management	-0.5	-0.7	-0.7	0.0	0.0	0.0	-0.1	0.0
4.D Agricultural Soils	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
4.F Field Burning of Agricultural Residues	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Change in total, Gg CO_2 eqv.	-18	-21	-19	-5	-5	-4	-5	-4
Change in total, pct.	-0.15	-0.19	-0.18	-0.05	-0.05	-0.04	-0.06	-0.04

The most significant inventory changes are mentioned below:

The amount of straw used for bedding for heifers has been changed for 1990-2002 and this affects the emission of CH_4 from manure management. The number of geese has been changed for all years and the number of weaners and fattening pigs has been changed for 2011, this affects both emissions from enteric fermentation, manure management and agricultural soils.

The amount of biogas treated manure has been changed in 2010 and this decreases the emission of manure management.

The main change in emission from agricultural soils is due to change in EF for NH_3 from synthetic fertilisers, which has been changed for all years due to the updated version of the EEA/EMEP Guidebook in 2013. This increases the emission of N_2O from atmospheric deposition due to the increase in emission of NH_3 from synthetic fertilisers while the emission of N_2O directly from synthetic fertilisers decreases.

6.11 Planned improvements

The Danish emission inventory for the agricultural sector meets the requirements given in the IPCC Good Practice Guidance. In the years to come and based on the ERT recommendations, two specific improvements have to be mentioned.

For next submission it is planned to update some of the emission calculations to follow the IPCC 2006 guidelines. The global warming potential for CH_4 and N_2O will be changed from 21 and 310 to 25 and 298, respectively. Emission factors for N_2O from agricultural soils will be revised. Furthermore will the types of housing systems be revised in proportion to the systems given in IPCC 2006.

First step is taken to improve the documentation of the biogas treated slurry. The Energy Statistics got information of the total produced biogas production in Denmark and from another statistic; Energy production census it is possible to get plant specific information regarding the energy production. We still got the challenge with the energy potential in manure – how many tonnes of slurry are used to produce the total energy as given in the Energy Statistics. Present a conversion factor based on an expert judgment from the Danish Energy Agency is used. Next step is to find information which can verify the expert judgment or even better improve the conversion factor. We still investigate the opportunity to use the register for fertilization where all farmers have to register the amount of nitrogen, but it requires a calculation from amount of nitrogen to amount of manure, which differ significant between the different animal types. Data revived from the Danish Biogas Plant Association could also be helpful to check the information of the amount of biogas treated slurry for the largest biogas plants.

Another issue which has to be investigated are improvements of the documentation regarding the emission reduction potential. This is planned to be done by a literature study. Other countries e.g. Germany also use biogas treated slurry and could have some available interesting data. Based on this knowledge it is hopefully possible to do some improvements in near future.

Besides the biogas issue, further work to document the comprehensive QC procedures is planned. Further focus will in particular be addressed to compare the calculations from our database IDA with estimates from other institutions as far as available data makes it possible (refer to "Stage V" in the QA/QC plan – see Chapter 6.9.1).

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7 LULUCF (CRF sector 5)

7.1 Overview of the sector

This chapter covers only the territory of Denmark without the Faroe Islands and Greenland. Greenland is submitting a separate NIR and the corresponding CRF tables for the Greenlandic territory to UNFCCC. This can be found as Chapter 16 in this NIR.

Denmark (Capital: Copenhagen) is situated around 56°N and 13°E and covers 43,098 km^2. No permanent ice is occurring and only very small insignificant areas with rocks. The climate is according to IPCC GPG 2003 cold and wet. Denmark is an intensive agricultural country where most of the area is affected by agriculture. The average temperature in the standard 30 year, 1961-1990 was 7.7 °C with a minimum temperature in February of 0.3 °C and a maximum in July of 17.0 °C. Year 2012 had an average mean temperature of only 8.3 °C which is 0.6 °C above the average. 2012 was slightly cooler than 2011. 2011 was the ninth warmest recorded year since 1873 and slightly cooler than 2008, which had an average temperature of 9.4 °C (www.dmi.dk).

All land is classified into Forest, Cropland, Grassland, Wetlands, Settlements or Other Land.

7.1.1 Abbreviations

The following abbreviations are used in accordance with definitions in the IPCC guidelines:

A: Afforestation, areas with forest established after 1990 under article 3.3.
R: Reforestation, areas which have temporarily been unstocked for less than 10 years - included under article 3.4.
D: Deforestation, areas where forests are permanently removed to allow for other land use, included under article 3.3.
FF: Forest remaining Forest, areas remaining forest after 1990.
FL: Forest Land meeting the definition of forests.
CL: Cropland.
GL: Grassland.
SE: Settlements.
OL: Other land, unclassified land.
FM: Forest Management, areas managed under article 3.4.
CM: Cropland Management, areas managed under article 3.4.
GM: Grazing land Management, areas managed under article 3.4.

The LULUCF sector differs from the other sectors in that it contains both sources and sinks of carbon dioxide. Removals are given as negative figures and emissions are reported as positive figures according to the guidelines. For 2012 emissions from LULUCF were estimated to be a net sink of approximately 838 Gg CO_2 equivalents or 1.7 % of the total reported Danish emission.

7.1.2 Methodology overview

Tier

The type of emission factor and the applied tier level for each emission source are shown in Table 7.1 below. The tier level has been determined based on the 1996 Guidebook (IPCC 1997).

Distinguishing between tier level 2 and 3 have been based on the emission factor. The tier levels 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 either a few emission measurements or IPCC tier 2 emission factors.
- Tier 3: Based on models which include carbon stock changes methodologies.

Table 7.1 shows which of the source categories are key in any of the key source analysis[1] (including LULUCF, tier 1/tier 2, level/trend).

Table 7.1 Methodology and type of emission factor.

		Tier	EF	Key category
5.A.1 Forest	CO_2	Tier 3, Tier 1	CS, D	Yes
5.A.2 Forest	CO_2	Tier 3, Tier 1	CS, D	No
5(II) Forest Land.	N_2O	Tier 2	CS	No
5.B Cropland, Living biomass	CO_2	Tier 2	CS	No
5.B Cropland, Mineral soils	CO_2	Tier 3	CS, D	Yes
5.B Cropland, Organic soils	CO_2	Tier 2	CS, D	Yes
5(III) Disturbance, Land converted to cropland	N_2O	Tier 2	CS, D	No
5.C Grassland, Living biomass	CO_2	Tier 2	CS, D	Yes
5.C Grassland, Mineral soils	CO_2	Tier 2	CS, D	No
5.C Grassland, Organic soils	CO_2	Tier 2	CS, D	No
5.D Wetlands, Living biomass	CO_2	Tier 2	CS, D	No
5.D Wetlands, Dead organic matter	CO_2	Tier 2	CS, D	No
5.D Wetlands, Soils	CO_2	Tier 2	CS, D	Yes
5(II) Wetlands	N_2O	Tier 2	CS, D	No
5.E Settlements, Living biomass	CO_2	Tier 2	CS, D	No
5(IV) Cropland Limestone	CO_2	Tier 2	CS, D	Yes
5(V) Biomass Burning	CH_4	Tier 2, Tier 1	CS, D	No
5(V) Biomass Burning	N_2O	Tier 2, Tier 1	CS, D	No

7.1.3 Key categories

Key Category Analysis (KCA) tier 1 and 2 for year 1990, 2012 and trend for Denmark has been carried out in accordance with the IPCC Good Practice Guidance / IPCC Guidelines (2006). Table 7.2 shows which of the LULUCF categories are identified as 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.

[1] Key category according to the KCA tier 1 or tier 2 for Denmark (excluding Greenland and Faroe Islands), including LULUCF, level 1990/ level 2012/ trend.

The CO_2 emissions from forests are key for forest remaining forest both on the level and the trend. For Cropland both mineral and organic soils are key sources as well as lime stone.

Table 7.2 Key categories, LULUCF.

			Tier 1			Tier 2		
			1990	2012	1990-2012	1990	2012	1990-2012
LULUCF	5.A.1 Forest	CO_2		Level	Trend		Level	Trend
LULUCF	5.B Cropland, Living biomass	CO_2		Level	Trend		Level	Trend
LULUCF	5.B Cropland, Mineral soils	CO_2	Level	Level		Level	Level	
LULUCF	5.B Cropland, Organic soils	CO_2	Level	Level		Level	Level	
LULUCF	5.C Grassland, Living biomass	CO_2		Level	Trend		Level	Trend
LULUCF	5.D Wetlands, Soils	CO_2						Trend
LULUCF	5(IV) Cropland Limestone	CO_2	Level		Trend	Level		Trend

7.1.4 Methods

Approximately 2/3 of the total Danish land area is cultivated and 14.7 per cent forested. Together with high number of cattle and pigs there is a high (environmental) pressure on the landscape. To reduce the impact an active policy has been adopted to protect the environment. The adopted policy aims at doubling the forested area within the next 80-100 years, restoration of former wetlands and establishment of protected national parks. In Denmark almost all natural habitats and all forests are protected. Therefore only limited conversions from forest or wetlands into cropland or grassland are occurring.

Estimation of carbon stock changes in the Danish forests is based on a combination of surveys and the National Forest Inventory (NFI). Changes in carbon stock in mineral cropland soils are estimated with a nationally developed Tier 3 model, whereas the emission calculation from organic soils is based on nationally developed emission factors.

Since the last submission has a minor revision of the land use matrix for the whole period taken place. Primarily because of a misclassification of some urban parks as forest. The revision has only minor impact on the emission estimate.

No permanent snow cover exists in Denmark and only a very small insignificant area with rocks and cliffs. OL is restricted to beaches and sand dunes. The official land area is 43 098 km^2. The new land use matrix has estimated the total area to 43 056 km^2. This area includes rivers and lakes. The small discrepancy is due to differences in the definition of the 7000 km long coastline. The land use matrix uses the latest official vector maps from Danish Geodata Agency.

The emission data are reported in the CRF format under IPCC categories 5A (Forestry), 5B (Cropland), 5C (Grassland), 5D (Wetlands) and 5E (Settlements) and 5F (Other Land). Denmark is free from ice and rocks and Other Land therefore represents beaches and sand dunes. Fertilisation of Forests and Other Land is negligible and all fertiliser consumption is therefore reported in the agricultural sector. All liming is reported under Cropland because only very limited amounts are used in forestry and on permanent grassland. Field burning of biomass is prohibited in Denmark. Wildfires in forest are reported. This is normally around 0-10 hectares per year. Controlled burning of heathland is taking place of approximately 300-700 hectares to maintain the heath.

Savannas and rice cultivation do not occur in Denmark.

The Cropland and Grassland area are based on agricultural EU subsidiary systems and very detailed. A drawback is, however, that one field in one year can be classified as CL and the next year as GL and then again converted back to CL. This creates large conversion rates between cropland and grassland but mainly towards grassland as an extensification currently takes place in Denmark (Table 7.3). The switching between CL and GL will, however, have no effect on the emission estimates except for an estimated release of N_2O from mineralisation of organic matter. This issue is also recognized in the IPCC 2006 Guidelines. Table 7.3 shows the overall development from 1990 to 2012. Afforestation is mainly taking place on CL and GL not previous classified as forest. Areas, which are deforestated are mainly converted to WE as a consequence of clearing of some areas in the State forests towards more open areas, to CL due to conversion of christmas trees agricultural cropland. Since 1990 more than 31 100 hectares have been changed into SE and other infrastructures. No land is converted into OL.

In the new land use matrix has a linear approach for all land use changes been adopted for the period 1990 to 2005 and from 2005 to 2011. From 2011 and onwards is used annually updated data from the different data suppliers. Some of these data are not updated annually and thus a time lag in the implementation of the land use changes may occur in some areas. Conversion to annual updates may create more fluctuating area changes than in the previous years.

Table 7.3 Land Use Change from 1990 to 2012 based on GIS vector layers and Earth Observations. The figures are given in hectares.

1990\ 2012	Forest	Cropland	Grassland	Wetlands	Lakes	Settlements	Other	Sum
Forest	538 189	1 270	1 713	2 145	346	310	0	543 973
Cropland	48 355	2 590 240	49 600	12 074	2 691	15 403	0	2 718 362
Grassland	45 985	74 740	260 279	3 294	2 691	15 384	0	402 374
Wetlands	18	560	0	69 853	6	71	0	70 509
Lakes	0	0	0	0	58 357	1	0	58 358
Settlements	0	0	0	0	0	485 543	0	485 543
Other	0	0	0	0	0	0	26 433	26 433
Sum	632 547	2 666 811	311 592	87 367	64 092	516 712	26 433	4 305 552
Percentage	14.7%	61.9%	7.2%	2.0%	1.5%	12.0%	0.6%	100.0%

Table 7.4 gives an overview of the emission from the LULUCF sector in Denmark. Forests have been sinks in Denmark for the last decade but due to the age distribution of the forests - containing a majority of mature forests - a slight decrease of the carbon stock is observed, as the old forests are regenerated with young trees and a net source were observed. The changes occur before the 2008-2012 period and the results can also partly be attributed to the recalculations - as described later. Currently the NFI indicates that forests are a sink. Cropland is ranging from being a net source from up to 4,642 Gg in 1990 to be a net source of 3,185 Gg in 2010. High fluctuations in the emission from CL between years are related to the actual crop yield that year and the climatic conditions. Low crop yields combined with high temperatures reduce the total amount of carbon in agricultural soils whereas a year with a high yield and low temperatures increase the carbon stock in soil.

From 1990 and onwards a general decrease in the emission from Cropland is estimated due to a higher incorporation of straw (ban of field burning), demands of growing of catch crops in the autumn, a change from low yielding spring barley to high yielding winter wheat, an increased carbon stock in hedgerows, a reduced consumption of lime and that organic agricultural soils are disappearing. The area with restored wetlands has increased and consequently the accumulation of organic matter has also increased here leading to a lower net source.

Table 7.4 Overall emission (Gg CO_2) from the LULUCF sector in Denmark, 1990- 2012.

Greenhouse gas source and sink categories	1990	1995	2000	2005	2008	2009	2010	2011	2012
5. Land Use, Land-Use Change and Forestry, CO_2	5,265.22	3,655.80	3,219.87	4,461.90	-1,611.35	3,032.18	-337.70	-2,756.28	-851.70
A. Forest Land	126.2	-954.7	-764.1	615.4	-5716.4	31.1	-4046.5	-6311.3	-4453.54
B. Cropland	4855.0	4389.2	3760.5	3473.5	3730.7	2625.3	3349.4	3156.2	2955.24
C. Grassland	183.6	152.2	158.9	234.6	269.3	256.5	246.4	277.4	553.52
D. Wetlands	87.5	51.3	41.8	99.5	59.7	71.9	63.5	69.6	2.27
E. Settlements	12.9	17.8	22.7	39.0	45.3	47.4	49.5	51.7	90.81
F. Other Land	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO
5. Land Use, Land-Use Change and Forestry, N_2O (CO_2 eq)	16.5	15.2	14.2	13.2	12.7	12.5	12.5	12.4	13.1
A. Forest Land	16.1	14.7	13.8	12.9	12.3	12.1	12.1	12.1	12.1
B. Cropland	0.3	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0.9
C. Grassland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D. Wetlands	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
E. Settlements	NO	NO	NO	NO	NO	NO	NO	NO	NO
F. Other Land	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO
5. Land Use, Land-Use Change and Forestry, total CO_2 eq	5282.2	3671.0	3234.1	4475.2	-1598.7	3044.7	-325.2	-2743.8	-838.5

7.2 Forest remaining forest (5.A.1)

7.2.1 Forest census

From 1881 to 2000, a National Forest Census has been carried out roughly every 10 years based on questionnaires sent to forest owners (Larsen and Johannsen, 2002). Since the data was 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 height of the trees. Open woodlands and open areas within the forest were generally not included. All values for growing stock, biomass or carbon pools based on data from the National Forest Census were estimated from the reported data on forest area and its distribution to main species, age class and site productivity classes. The two last censuses were carried out in 1990 and 2000.

The 1990 National Forest Census was based on reported forest statistics from 22,300 respondents, resulting in information on area, main species, age class distribution and productive indicators. The estimated forest area was 445 000 ha or 10.3 % of the land. Of the total forest area 64 % was coniferous forest and 34 % was deciduous forest (the remainder was temporarily unstocked). The total volume was estimated at 55.2 million cubic metres of which 57 % was coniferous.

The number of respondents in the 2000 National Forest Census was 32,300, which is considerably higher than in the 1990 survey. The change in the number of respondents probably contributed to the observed increase in forest area and growing stock between the 1990 and 2000 census. The estimated forest area was 486 000 ha or 11.3 % of the land. Of the total forest area 60 % was coniferous forest and 36 % was deciduous forest (the remainder was temporarily unstocked). The total volume was estimated at 77.9 million cubic metres of which 63 % was coniferous.

7.2.2 National forest inventory

In 2002, a new sample-based National Forest Inventory (NFI) was initiated (Nord-Larsen et al., 2008). This type of forest inventory is very similar to inventories used in other countries, e.g. Sweden or Norway. The NFI has replaced the National Forest Census.

The 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. At each grid intersection, a cluster of four circular plots (primary sampling unit, PSU) for measuring forest factors (e.g. wood volume) are placed in a 200 x 200 m grid. 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 and is re-measured in subsequent inventories every five years. Two thirds are temporary and are moved randomly within the particular 2x2 km grid cell in subsequent inventories. The sample of permanent and temporary field plots has been systematically divided into five non-overlapping, interpenetrating panels that are each measured in one year and constitute a systematic sample of the entire country. Hence all the plots are measured in a 5-year cycle.

Based on analysis of aerial photos, each sample plot (SSU) is allocated to one of three basic categories, reflecting the likelihood of forest or other wooded land (OWL) cover in the plot: (0) Unlikely to contain forest or other wooded land cover, (1) Likely to contain forest, and (2) Likely to contain other wooded land. All plots in the last two categories are inventoried in the field.

In the most recent five-year rotation of the NFI (2008-2012) the number of clusters (PSU) and sample plots (SSU) were 4.138 and 9.425, respectively. On average 1,885 yr^{-1} plots (SSU) were identified as having forest or other wooded land cover based on the aerial photos and were thus selected for inventory. Only 3 sample plots were missing in the 2008-2012 inventories, due to difficulties of access.

Table 7.5 Number of measured clusters and sample plots in the five year rotation 2008-2012. Forest covered sample plots not inventoried in the field are denoted "Missing".

Year	Clusters			Sample plots		
	Total	Forest	Missing	Total	Forest	Missing
2008	2 212	804	2	8 644	1 896	3
2009	2 195	783	0	8 604	1 800	0
2010	2 196	793	0	8 614	1 855	0
2011	2 173	850	0	8 520	1 896	0
2012	2 200	908	0	8 617	1 978	0
Total	10 976	4 138	2	42 999	9425	3

Each plot is divided into three concentric circles with radius 3.5, 10 and 15 m. A single caliper measurement of diameter is made at breast height for all trees in the 3.5 m circle. Trees with diameter larger than 10 cm are measured in the 10 m circle and only trees larger than 40 cm are measured in the 15 m circle. On a random sample of 2-6 trees further measurements of total height, crown height, age and diameter at stump height are made and the presence of defoliation, discoloration, mast, mosses and lichens are recorded. The presence of regeneration on the plots is registered and the species, age and height of the regeneration are recorded. Stumps from trees harvested within a year from the measurement are measured for diameter.

Deadwood is measured on the sample plots. Standing deadwood with a diameter at breast height diameter larger than 4 cm is measured according to the same principles as live trees. Lying deadwood with a diameter of more than 10 cm is measured within the 15 m radius sample plot. Length of the lying deadwood is measured as the length of the tree that exceeds 10 cm in diameter and is within the sample plot. The diameter is measured at the middle of the lying deadwood measured for length. In addition to the size measurements of deadwood the degree of decay is recorded on an ordinal scale.

On each plot the presence and state of ditches and drainage conditions are recorded. Further, the presence of peatland is recorded and the depth of the peat is measured. Finally, the depth of the humus layer is measured on all plots.

7.2.3 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 2006 National Forest Inventory). With the objective to obtain time consistent and precise estimates of forest areas to report to UNFCC and under the Kyoto protocol, two projects have aimed at mapping the forest area in Denmark based on satellite images. Forest area and forest area change have been estimated 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 EO data (23 August 1990) and other data collected from 1992-2005 and for 2005 using NFI in situ data. Forest maps are developed using Landsat imagery mainly Landsat 5 (TM) and 7 (ETM+) data to classify and estimate the area of 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 (Huber & Tøttrup 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 of Bornholm, none of the scenes was cloud-free. To still 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 (MMU) of 0.5 ha, a geometric accuracy of < 15 m RMS and a thematic accuracy of 90 % +/- 5 % for the land use class Forest.

7.2.4 Forest definition

The forest definition adopted in the NFI is identical to the FAO definition (TBFRA, 2000). It includes "wooded areas larger than 0.5 ha, that 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, fire breaks and other small open areas, that are an integrated part of the forest, are also included.

7.2.5 Estimation of forest carbon pools

In the following, procedures for estimating forest carbon pools are described. For the specific formulas used in the calculations, readers are referred to Annex 3F.

Estimation of forest area

Based on analysis of aerial photos, each sample plot (SSU) is allocated to one of three forest status categories (Z), reflecting the likelihood of forest or other wooded land (OWL) 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.

On individual sample plots (j) the forest cover percentage (X) is calculated as the proportion of the forest area (A) to the total plot area of the 15 m radius circle (A15). The average forest percentage (X) on plots with forest status Z=1 (and 2) is calculated as the sum of the forest percentages times an indicator variable (R) that is 1 if Z equals 1 (or 2) and 0 otherwise, divided by the number of plots with forest status Z=1 (or 2).

The overall average forest percentage ($\overline{X}$) is calculated as the sum of: (1) observed forest cover percentages of the individual sample plots, (2) the number of unobserved sample plots with forest status Z=1 times the average forest cover percentage of sample plots with forest status 1, and (3) the number of unobserved sample plots with forest status 2 times the average forest cover percentage of observed sample plots with forest status Z=2 divided by the number of observed and unobserved sample plots. In this context sample plots with forest status 0 are regarded as observed and assumed to have a forest cover percentage of 0. Finally, the overall forest area (A_{Forest}) is calculated as the overall average forest percentage times the total land area (A_{total}).

When estimating the forest area with a specific characteristic (*k*), such as forest established before or after 1990, the proportion of the plot area with the particular characteristic is found by summing the forested plot areas times an indicator variable (*R*) that is 1 if the plot has the *k*th characteristic and 0 otherwise. Subsequently the plot area with the *k*th characteristic is divided by the total forested plot area.

The total forest area with a particular characteristic (A_k) is found as the forest area percentage with the particular characteristic *k* times the total forest area.

Estimation of volume, biomass and carbon pools

For estimation of volume of individual trees, we use the volume functions developed for the most common Danish forest tree species (Madsen, 1985, Madsen 1987 and Madsen and Heusèrr 1993). The functions use individual tree diameter and height as well as quadratic mean diameter of the forest stand as independent variables.

Based on the trees measured for both height and diameter, diameter-height regressions are developed for each species and growth region. The functions use the observed mean height and mean diameter on each sample plot for creating localized regressions using the regression form suggested by Sloboda et al. (1993). For plots where no height measurements are available, generalized regressions are developed based on the Näslund-equation modified by Johannsen (1992).

The next step is to estimate the quadratic mean diameter of the trees on the sample plot. As the trees are measured in different concentric circles depending on their diameter, the basal area on each sample plot is estimated by scaling the basal area of each tree (standing or felled) according to the circular area in which the tree has been measured. A similar calculation has been made for the number of stems. Finally, mean squared diameter is calculated from the basal area and stem numbers.

Based on the diameter, estimated or measured height of individual trees and the squared mean diameter before thinning, the volume of individual trees is estimated using the species specific volume functions by Madsen (1987) and Madsen & Heusèrr (1993). The volume of trees less than 3 meters tall is estimated using an alternative function. The calculated volumes are total stem volume over bark for conifers and total above ground volume over bark for deciduous species.

Based on the estimated individual tree volumes, above ground biomass of the individual tree (stem biomass for conifers and total above ground biomass for broadleaves) is subsequently calculated as the total volume times the basic density. Species specific basic densities are based on Moltesen (1988), Skovsgaard et al. (2011) and Skovsgaard & Nord-Larsen (2012). Finally, total biomass (below and above ground) is estimated using expansion factors. For coniferous species an expansion factor model developed for Norway spruce (Skovsgaard et al. 2011) is applied whereas for deciduous species an expansion factor model developed for beech (Skovsgaard & Nord-Larsen, 2012) is used.

Total or regional volume, biomass and pools of carbon are estimated based on the estimates of individual tree volumes, biomass and carbon. First, volume, biomass or carbon per hectare is estimated for each of the concentric circles (c=3.5, 10 or 15 m radius) on each plot as the plot area depends on the diameter of the tree. Using the estimates from individual plots, the area weighted mean volume, biomass or carbon per hectare for the three concentric circles is estimated. The overall mean volume, biomass or carbon is estimated as the sum of the average volumes for the three circles. Finally, the total or regional volume, biomass or carbon is estimated as the forest area times the overall mean volume.

The total volume, biomass or carbon pools with a given characteristic are estimated in a similar way as the total figures. First, volume, biomass or carbon per hectare with the given characteristic is estimated for each of the concentric circles (c=3.5, 10 or 15 m radius) on each plot. Using the estimates from individual plots, the area weighted mean volume, biomass or carbon per hectare with the given characteristic for the three concentric circles is estimated. The overall mean volume, biomass or carbon is estimated as the sum of the average volumes for the three circles. Finally, the total or regional volume, biomass or carbon with the given characteristic is estimated as the forest area times the overall mean volume.

Dead wood volume, biomass and carbon content

The volume of standing dead trees is calculated similarly to the calculations for live trees. The volume of lying dead trees within the sample plot is calculated as the length of the dead wood times the cross sectional area at the middle of the dead wood. Biomass of the dead wood is calculated as the volume times the species specific basic density and a reduction factor according to the structural decay of the wood. Finally, carbon content for each standing or lying dead tree is calculated by multiplying the dead wood biomass by 0.5.

Total or regional volume, biomass and carbon pools of deadwood are estimated based on the estimates of volumes, biomass and carbon for individual dead trees or pieces of dead wood. First, deadwood volume, biomass or carbon per hectare is estimated for each of the concentric circles (c=3.5, 10 or 15 m radius). Estimates for lying dead wood are made using the 15 m circle. Using the estimates from individual plots, the area weighted mean volume, biomass or carbon per hectare of deadwood for the three concentric circles is estimated. The overall mean deadwood volume, biomass or carbon is estimated as the sum of the average volumes for the three circles. Finally, the total or regional deadwood volume, biomass or carbon is estimated as the forest area times the overall mean volume.

Forest floor

On each NFI plot (SSU) the depth of the forest floor is measured. As peatlands are reported specifically, a maximum depth of 15 cm is used in the calculations. Forest floor carbon for individual species is estimated by multiplication of the forest floor depth with the plot area, a species specific density (Vesterdal & Raulund-Rasmussen, 1998) and the fraction of the individual species. The fractions are based on the proportion of basal area of the individual species and total forest floor carbon is estimated by summation of forest floor carbon of the different species.

Average forest floor carbon is estimated by summation of forest floor carbon on the individual plots and dividing the total by the total plot area. Total forest floor carbon is subsequently estimated by multiplication of the average forest floor carbon by the total forest area.

Forest floor carbon stocks were assessed in the Forest Soil Inventory described below. However, there was no good basis to estimate change over time for this C pool as historic data were very scarce (see below). Hence changes in this C pool were based on depth measurements performed on all NFI plots.

Forest mineral soil

The NFI monitoring was supplemented by an additional forest soil inventory in order to document that forest soils is not an overlooked source for CO_2 emissions. The monitoring of soil C-stocks concerns two of the five carbon pools identified by IPCC (2003), litter (forest floor) and mineral soil to a depth of minimum 30 cm.

There is relatively good information from various soil profile databases on mineral soil carbon stocks to 1 m depth for well-drained Danish forest soils (Vejre et al., 2003; Krogh et al., 2003). However, there has been no spatially systematic study performed on temporal change in forest soil carbon. This has limited the possibility to explore the development in forest soil carbon stocks over time. This need is most pronounced for the quickly changing litter carbon pool and previous C stock estimations (Vejre et al., 2003) did not include moist and wet forest soils.

According to decision 16/CMP ”A Party may choose not to account for a given pool in a commitment period if transparent and verifiable information is provided that the pool is not a source.” The forest soil inventory aims to document that forest soils are not a major source for emissions of CO2, i.e. that there is no detectable depletion in soil carbon. This may be called the “no source principle“(Somogyi & Horvath, 2007). According to IPCC (2003) the necessary documentation may come from various sources such as:

- Representative and verifiable sampling and 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 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. For well-drained soils there may be temporal changes in soil carbon stocks at fine spatial resolution (ha-level) due to clearcutting and replanting, but for the entire forest area with the whole range of age classes, the assumption is that soil carbon stocks are unchanged over time. In fact, the conversion toward close-to-nature forestry with continuous crown cover and abandonment of clearcutting suggests a future increase in soil carbon stocks rather than depletion (Brunner et al., 2005; Yanai et al., 2000). Areas with wet forest soils have probably been sources for increased CO_2 emissions in a period after ditching and drainage activities took place from the late 19th century. These activities led to increased mineralization of peaty soils. However, during the last 20 years, drainage activities have diminished strongly and has almost ceased in state forests as a direct effect of the Strategy for the State forests to convert to more Close to Nature Forest Management, including restoration of more natural hydrology (see more on http://www.naturstyrelsen.dk/). Here, the natural hydrological conditions are actively restored by filling up ditches in some areas. It is expected that this change in management will lead to sequestration of carbon as these forest soils gradually get wetter and the rate of decomposition decreases more than rates of organic matter inputs from litterfall. Exact information on the extent of restored natural hydrology is not available, but is being assessed based on expert judgement and information from forest managers.

Since the reporting in 2009 for 1990-2007, quantitative information has gradually become available; a project (SINKS) initiated in 2007 has delivered data on soil C change based on repeated sampling of soil C pools in forests remaining forests, and more data on soil C pools are being made available. The preliminary data suggest that forest soil C pools are not sources for CO_2

and thus support that more accurate estimates of litter and soil C pool removals/emissions do not need to be included in the reporting.

New data

The only existing systematic sampling of Danish forest soils has been conducted within the so-called Kvadratnet ("Agricultural Network", http://www.landbrugsinfo.dk/Planteavl/Goedskning/Naeringsstoffer/Kvadratnet-for-nitratundersoegelser/Sider/Startside.aspx). It was established in the 1980's in order to optimize the applied amounts of fertilizer in agriculture by monitoring nitrate leaching to groundwater resources in the most common land uses. Soil samples from the years around 1990 exist in soil storages. Given the time constraints of the commitment period and reporting deadlines, changes in soil carbon stocks could only be assessed by repeated sampling of soils within this monitoring grid.

The Agricultural monitoring grid is 7x7 km and by 1990 it included 108 plots with forest cover (Østergaard & Mamsen, 1990). Soil sampling and analysis was conducted in 1986-90 in all 108 forest plots of Agricultural Network, and a subset of 25 plots was resampled in 1994 (Breuning-Madsen & Olsson, 1995) as a part of the Pan-European forest monitoring programme, which uses these 25 plots for assessment of the forest condition. The 25 plots resampled in 1994 have been resampled again in 2007 as a part of the demonstration project BioSoil (http://forest.jrc.ec.europa.eu/contracts/-biosoil), under the Pan-European forest monitoring programme Forest Focus and in 2008/2009 the other 83 plots were resampled, except for one plot for which the land owner did not grant access to re-sampling.

Mineral soil samples from 1990 are thus available from 108 forest plots. The sampling was complete for the period 2007-2010, while soil-archive samples from 1990 were missing for six plots. Soil samples from 1986-1987 were used for one of these plots while it was not possible to retrieve archived soil samples for the last five plots. The sampling of O-horizons was also complete for the 108 plots for the period 2007-2009, while O-horizon samples from 1990 were of a very poor quality and only available from 32 plots. Consequently, forest floor samples from 1994 were used to represent forest floors in 1990, while results based on soil samples 0-100 cm from 1994 were only used to check other data.

The plots were in all cases (with a few exceptions due to practical circumstances) designed as a 50 x 50 m square. In 2007-09 ten forest floor and mineral soil cores were collected along a transect determined as the diagonal from the south-west to north-east corner of the square. In the 1990 16 soil cores were taken randomly across the square plot, while forest floor samples were only collected occasionally in an unspecified manner.

The O-horizon samples from 2007-2009 were area-based samples (Vesterdal & Raulund-Rasmussen, 1998) removed from a 25 x 25 cm area, that were brought to the laboratory in separate bags.

The mineral soil samples from 2007-2009 were taken in the ten sampling points where O-horizons had been removed. A 2-3 cm thick soil corer was used. The mineral soil samples from around 1990 were taken in a similar manner for the 16 sampling points. Samples from 4-5 different horizons were pooled in the field. Only one joint sample pr. plot per depth were analysed for carbon content. Hence, information on within-plot variation in soil carbon contents is not available. The division into horizons differed slightly between the three sampling campaigns: 1986-1990, 2007 and 2008/2009. In 1986-1990 the division was 0-25, 25-50, 50-75 and 75-100 cm; in 2007 (the 25 BioSoil plots) it was 0-10, 10-20, 20-40, 40-80 and 80-100 cm; and in 2008/2009 0-10, 10-25m 25-50, 50-75 and 75-100 cm.

In the lab, all samples were dried at 40°C until constant weight. Before sieving through a 2 mm sieve, more clay-rich mineral soil samples were crushed in a mortar, while sandy soil samples were gently crushed or sieved directly. The stones (>2 mm) left after sieving were weighed (DW_{stone}), while the fine soil (<2 mm) was dried at 40°C for at least 48 h, and then weighed (DW_{soil}). A sub-sample of the fine soil, about 20 g, was removed after thorough mixing for finer grinding in an agate mortar.

The ten O-horizon samples from each plot were weighed separately, and then ground in Retsch grinder through a 2 mm net. From each of the ten samples, 10 % of the material was removed after thorough mixing to get a pooled sample for the plot. About 100 ml of the pooled sample was removed after thorough mixing and then ground more finely in a Tecator mill.

Mineral soil samples were analysed by dry combustion (Elementar Analyzer) for total organic carbon (TOC) and O-horizon samples for total carbon by a laboratory certified according to ISO 10694. Analyses were done by Agrolab/ Institut Koldingen, Sarstedt, Germany.

For each of the plots, the mineral soil carbon stocks in 2007-2009, $C_{m\text{-}2009}$ (tonne C ha^{-1}), was calculated as

$$C_{m-2009} = \sum_{i=1}^{4(or5)} d_{m-2009} \cdot 10000 \cdot (1 - RV_{stone-2009}) \cdot \rho_{soil} \cdot c_{soil-2009}$$

where d_m is the depth of a given horizon (m), and ρ_{soil} is the bulk density of soils (g cm^{-3}) assessed by use of published pedotransfer functions (Vejre et al., 2003). $c_{soil\text{-}2009}$ is the C concentration (mg g^{-1}). RV_{stone} is the relative volume of the stone (versus that of the fine soil):

$$RV_{stone-2009} = \frac{DW_{stone-2009} / \rho_{stone}}{DW_{stone-2009} / \rho_{stone} + DW_{soil-2009} / \rho_{soil}}$$

where ρ_{stone}=2.65 g cm^{-3}, $DW_{soil\text{-}2009}$ (g)is the dry weight of the fine soil (<2 mm) in the soil samples from 2007-2009 and $DW_{stone\text{-}2009}$ (g) is correspondingly the weight of stones in the soil sample (>2 mm).

For each of the plots, the forest floor carbon stocks in 2007-2009, $C_{ff\text{-}2009}$ (t C ha^{-1}), was calculated as

$$C_{ff-2009} = \sum_{i=1}^{10} DW_{ff-2009,i} \cdot 0.0016 \cdot c_{ff-2009}$$

where $DW_{ff\text{-}2009,i}$ (g dry weight) is the dry weight of sample number i, i=1-10 and $c_{ff\text{-}2009}$ is the C concentration of the pooled sample per plot (mg g^{-1})

The mineral soil dry weight in 1990 was calculated in the same manner as for 2007-2009, assuming that the relative stone volume was identical to that of 2007-2009. The forest floor depth was, however, not measured in 1990, nor was an area-based forest floor weight recorded. Forest floor depth (d_{ff}, m) measured for profiles on 25 plots in 1994, was used instead, while forest floor densities for the individual plots were obtained from the new measurements performed in 2007. For these 25 plots, forest floor C-stocks in 1990, $C_{ff-1990}$ (tonne C ha-1) were calculated as

$$C_{ff-1990} = d_{ff} \cdot 10000 \cdot \rho_{ff-2007} \cdot c_{ff-1990}$$

where $c_{ff-1990}$ (mg g^{-1}) is the carbon concentration of the forest floor samples from 1994 (measured in 2007), and $\rho_{ff-2007}$ (g m^{-3}) is the average bulk density of the forest floor for the individual plot as measured in 2007:

$$\rho_{ff-2009} = \frac{\sum_{i=1}^{10} DW_{ff,i}}{0.25 \cdot 0.25}$$

Considering the forest structure in Denmark with many small forests (about 70 % of the forest estates are of less than 5 ha) the “Kvadranet” is a very coarse grid. Even if the grid was fully sampled, it is therefore unlikely that the 108 plots represent the Danish forest area of approximately 500 000 ha. We thus evaluated based on power analyses that further sampling was necessary for future monitoring and chose to include a randomly selected subset of the permanent plots of the National Forest Inventory (NFI) for this purpose. A total of 277 plots were sampled.

It will not be possible, as with the Agricultural Network, to resample soils of the NFI plots for changes in soil C within the short time frame before Kyoto Protocol reporting. From 2012 and onward the NFI plots can be resampled to better support the work to demonstrate that soil carbon stocks are not a source for CO_2 emissions. As the Danish reporting of the three forest carbon pools aboveground biomass, belowground biomass and dead wood is based on the NFI, this will also ensure the consistency of monitoring of all five forest carbon pools defined by IPCC (2003). In the first reporting efforts, however, information on C-stocks and site properties from the NFI will enable better upscaling of results from Agricultural Network to the Danish forest area.

Changes in forest soil carbon stocks in forests planted before 1990

The preliminary results from the Agricultural Network showed that there is a large variation in soil C pools among sites for both forest floors (only 32 plots) and mineral soils. The mean C pool of forest floors was about 22 and 28 tonnes C ha^{-1} in 1990 and 2007-09, respectively. The corresponding C pools for mineral soils were 156 in 1990 and 157 tonnes C ha^{-1} in 2007-09 (Table 7.6). A simple t-test of the mean changes in forest floor and mineral soils pools between 1990 and 2007-2009 (5.6 and 1.5 tonnes C ha^{-1} yr^{-1} respectively) indicate that changes were not significant (Table 7.7, Figure 7.1a-b).

Table 7.6 Basic statistics on soil C pools measured in the Agricultural Network.

	Mean Pool	Standard deviation	Minimum	Maximum
	tonne C ha^{-1}			
Forest floor 1990	22.12	19.12	0.76	80.34
Forest floor 2007-2009	27.68	30.05	3.94	164.48
Mineral soil 1990	155.78	115.91	29.31	848.14
Mineral soil 2007-2009	157.26	100.34	18.66	853.08

Table 7.7 Basic statistics on the differences in C soil pools between 1990 and 2007-2009 and statistics from a simple t-test (H_0: change in soil C-stock = 0).

	Total number of sites	Number of sites in t-test	Mean change	Std	Minimum	Maximum	P-value
			(tonne C ha^{-1})				
Forest floor	108	31	5.56	24.78	-61.44	84.13	0.22
Mineral soil	108	104	1.48	47.56	-182.62	131.51	0.75

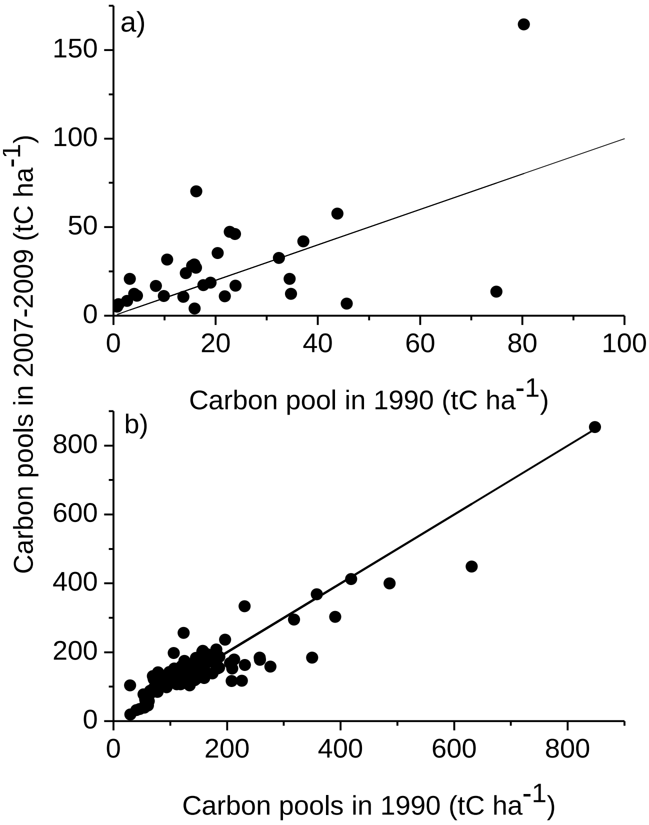

Figure 7.1 C pools in forest soils for forest before 1990. a) Forest floor C in 2007-2009 versus 1990, b) Mineral soil C in 2007-2009 versus 1990. Lines: y=x.

Some mineral soils had one or several horizons of organic origin and these soils had very high soil C-stocks to 1 m depth (>300 tonne C ha^{-1}), and these will probably be handled separately in further work with the data. Determination of true changes in organic soils requires that the total depth of the organic layer is known, while soils were only sampled until 1 m in SINKS.

Carbon pools 2008-2012

Carbon pools in live and dead biomass estimated for the most recent rotation of the NFI (2008-2012) is 41,0 million tonnes C. The live above ground biomass carbon makes up about 82 % of the total carbon in biomass and dead wood makes up only 1.7 % of the total. Carbon in biomass in forests established after 1990 make up 3.0 % of the total.

Table 7.8 Carbon in forest biomass for NFI rotations with reference years 2008-2012.

			2008	2009	2010	2011	2012
Forests established before 1990	Area		540.124	539.600	539.076	538.553	538.189
	Live biomass	Above ground	31.109	31.011	31.395	32.563	33.347
		Below ground	6.086	6.087	6.160	6.403	6.580
	Dead wood		545	566	628	653	673
	Forest soil	Litter	6.042	6.059	6.577	6.837	7.091
		Soil					
Forests established after 1990	Area		79.787	84.033	88.279	92.525	94.358
	Live biomass	Above ground	735	782	840	886	885
		Below ground	162	169	178	184	179
	Dead wood		23	24	23	20	16
	Forest soil	Litter	342	359	381	378	380
		Soil					

The amount of carbon in biomass in forests established before 1990 has been slowly increasing since 2006. Based on preliminary results of an evaluation of the subsequent measurement cycles 2002-2006 and 2007-2011, the increase is at least partly caused by an increased average biomass per hectare. However, part of the increase is also due to an increase in forest area, which is caused by improved detection of forest caused by improvements of aerial photos used for this.

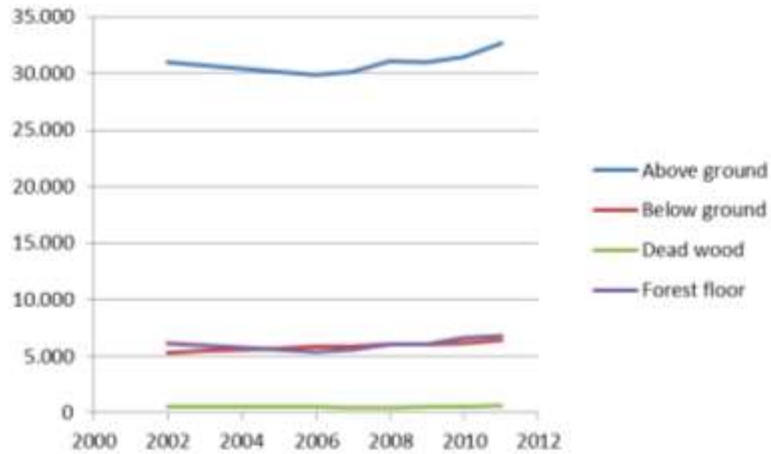

Figure 7.2 Forest carbon in forests established before 1990 estimated from NFI data from 2002-2011. Note that estimates for 2002-2005 are based on only 1-4 years of measurements. Only from 2006 the estimates are based on a full five-year rotation of the NFI.

The amount of carbon in biomass in forests established after 1990 has been increasing rapidly during the time of NFI measurements. The very low estimates of forest carbon at the beginning of the NFI measurements may in part be due to a large number of plots not measured in the field as a result of start up problems which may have biased the results. Also, in the early measurements aerial photographs were of a poorer quality and recent afforestations may have been difficult to detect.

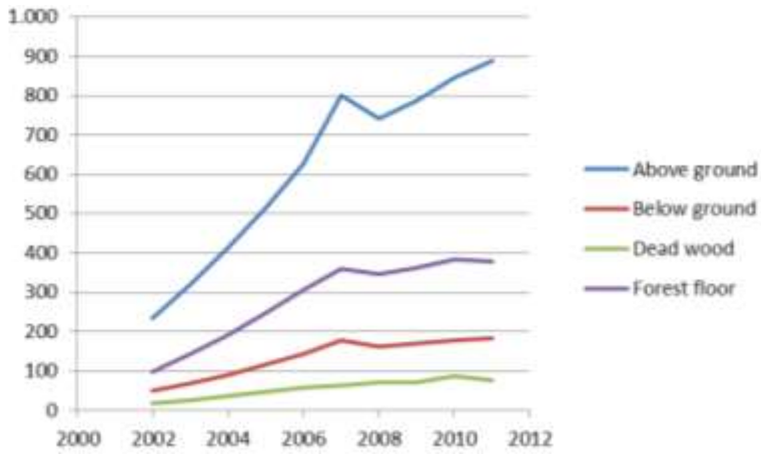

Figure 7.3 Forest carbon in forests established after 1990 estimated from NFI data from 2002-2011. Note that estimates for 2002-2005 are based on only 1-4 years of measurements. Only from 2006 the estimates are based on a full five-year rotation of the NFI.

7.2.6 Uncertainties and time series consistency

Danish national forest inventories have developed over the years from the earliest inventories more than a century ago. 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 the number of respondents increased to 32,300. Not unexpectedly 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. Also, it is not possible to single out the effect of the increased number of questionnaires on estimates of species distribution, carbon pools etc.

In 2002, the sample based forest inventory released the previous forest census for the first time enabling annual forest statistics. The NFI includes areas and forest owners that have not previously been included in the forest census. Firstly because not every forest owner was included in the previous surveys and secondly because not all forest areas according to the FAO definitions would be perceived as forest by the respondents. Consequently, the change from questionnaire based forest census to sample based forest inventory has led to an increase in forest area estimates that is not possible to separate from the actual increase in forest area that occurred during that period of time.

Specifically, in relation to the reporting of carbon pools in forest, the change from questionnaire based forest census to sample based forest inventory has changed the calculation of forest volume, biomass and carbon. In the forest census, forest carbon is estimated from the reported forest area within different species, age and site classes and a number of forest growth models. In the forest inventory, forest volume (and subsequently carbon) is measured on the plots. The observed forest area and carbon is subsequently expanded to regions or the entire country using statistical models. This has lead to a substantial increase in forest volume, biomass and carbon estimates, mainly due to methodological differences.

In the estimation of carbon emissions from existing forests, the information collected in relation to different forest census and inventories is combined with the satellite based land use/land cover map for the base year 1990 and for the year 2005. Hereby, consistent estimates of emissions from existing forests are obtained utilising as much information from the data sources as possible and hereby providing best possible time series. For the period from 2006 and onwards - there is full consistency of the data.

The uncertainty of the estimates of the carbon pools have been analysed by the use of bootstrap analysis. For the total carbon pool of the living biomass standard error is estimated to be 0.6 tonne C pr. ha or equalling 0.9 per cent. Applying the stock change method the emission/sink estimates of the different parts of the carbon pools depend on the certainty of each pool at two consecutive times.

The uncertainty of the estimates for subsets of the full forest area is related to the sampling intensity. With more subdivisions the uncertainty increases as the sampling size is reduced. An initial bootstrap analysis of this has been performed.

Table 7.9 Tier 1 estimate of the uncertainty in the forest.

		1990	2012					
		Emission/ sink, Gg CO_2 eqv.	Emission/- sink, Gg CO_2 eqv	Activity data, %	Emission factor, %	Combined uncertainty	Total uncertainty, %	Uncertainty, 95 %, Gg CO_2 eqv.
5. LULUCF		5282.55	-838.44				24.7	207.4
5.A Forests		141.9	-4441.5				15.0	664.8
Forest remaining forest	CO_2	49.6	-4491.4	15	2.00	15.1	15.1	679.7
Land converted to forest	CO_2	76.6	37.8	15	8.74	17.4	17.4	6.6
Drainage of forest soils	N_2O	15.6	12.1	30	10	31.6	31.6	3.8

7.2.7 QA/QC and verification

A continuous focus on the measurements of carbon pools in forest will contribute to QA/QC and verification in the following submissions. As we gain more data through resampling of permanent plots in the NFI this will further support the verification of the data reported. These will be available for the reporting performed in 2013.

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.

Integration with multi-phase and multi scale inventory - through e.g. other in-situ data like LiDAR scanning or remote sensing like satellite imagery will through research contribute to the continued QA/QC process of the NFI and the carbon stock estimates for forests.

7.2.8 Recalculations and changes made in response to the review process

The estimation methods are similar to the last reporting. There are sampling errors, but basically the continuous sampling, with partial replacement, provide stable estimates of the carbon pools in forests.

7.2.9 Planned improvements

Below is a list of planned improvements.

- A further QA/QC of the Land Use matrix will be performed.
- Further analysis of the changes in forest area - including afforestation and deforestation - and if possible more detailed information on these will be collected and analysed.
- Documentation for carbon pools in soil and litter is expected to be further improved in the next submission.
- Documentation for extent of restored natural hydrology will be included if available and will mainly refer to the period of the NFI since 2002, as no systematic information is available prior to this time and changes are first detectable based on the full analysis of the re-measurements performed in 2011. This is expected to confirm the reduced drainage of forest areas.
- Further analysis of uncertainty estimates for all the carbon pools in the forest areas based on the remeasurements and bootstrap analyses.

7.3 Land converted to forests

7.3.1 Forest area

See section 7.2.1 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

7.3.2 Forest definition

See section 7.2.1 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories (e.g. land use and land-use change matrix)

7.3.3 Methodological issues for land converted to forest

See also section 7.2.1

Living biomass

With respect to the option for distinguishing forest with and without harvesting, it is not possible with the available data. Data from the NFI is utilised based on the land use mapping to identify sample plots on afforested/reforested (AR) areas. It is - however not possible to determine the amount of harvesting. Furthermore, Denmark applies an approach utilising total carbon stock change, both growth and harvesting is included in the overall estimation.

When converting land to forest land the standing living above- and below ground biomass are removed from the land. In Table 7.10 the default values for the amount of living biomass is shown.

For land converted from cropland a standard default loss 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 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. For conversion from DM to carbon a default fraction of 0.5 kg C per kg DM is used.

Table 7.10 Default values for the amount of DM (dry matter, kg per hectare) used for estimating carbon stock changes where land use conversions take place.

		Dry matter, kg DM pr hectare	
		Above ground biomass	Below ground biomass
Cropland		9 577	2 298
Grassland	Improved Grassland	2 400	6 720
	Unmanaged Grassland	2 200	6 160
Wetlands	Peat extraction	0	0
	Other Wetland	3 600	10 080
Settlements		2 200	2 200
Other land		0	0

Soils

The included soil carbon pool changes concerned only carbon sequestration due to development of forest floors, i.e. the organic layer on top of the mineral soil. Carbon sequestration was included in this layer since national scientific projects had indicated that this was the soil compartment mainly prone to changes following land-use change. The previous NIR reports did not account for possible changes in carbon pools of the mineral soil; based on chronosequence studies of afforested stands, no consistent changes had been detected in mineral soil organic matter during the first 30 years following afforestation (Vesterdal et al., 2002a; Vesterdal et al., 2007). This is also supported by the finding that there was no significant difference in mineral soil carbon stocks in paired forest-cropland sites at 28 different sites in Denmark (Vesterdal et al., 2002b). These conclusions are supported by data from the new national forest soil inventory.

New data

New information on carbon pools in forest soils is available from the national project, SINKS. In this project forest soils are sampled in two grids, Agricultural Network and the National Forest Inventory (NFI), see Section 7.2.1 for a description.

Apart from 108 plots in forests planted before 1990, the Agricultural Network included 15 plots in afforestation since 1990. The sampling took place together with the sampling in forests planted before 1990, and was thus complete for the period 2007-2009. Archived soil samples from 1990, when the plots were arable land, were missing for 1 plot.

The sampling, the sample preparation, chemical analyses and calculations were similar to that performed from forests planted before 1990, see 7.2.1

A few of the 277 plots sampled in the NFI grid are probably also located in forests planted since 1990. The data calculations are currently being performed, and these data will be reported in the next NIR.

7.3.4 Changes in forest soil carbon stocks in forests planted on arable land since 1990

The average carbon sequestration rates for forest floors for broadleaves and conifers were estimated from the information from scientific projects in afforestation chronosequences; the average annual sequestration of carbon in forests floors was 0.09 and 0.31 tonne C ha^{-1} yr^{-1} under broadleaves and conifers, respectively (Table 7.11.). These rates of change have been used for calculation of forest floor carbon sequestration in afforested land, however, the accumulation of conifer forest floors is assumed to start only after eight years based on observations from chronosequence and other field data.

Table 7.11 Forest floor carbon sequestration rates in afforestation areas for different species in national chronosequential studies.

Tree species category	Tree species	Study type	Age (yr)	Forest floor C sequestration (tonne C ha^{-1} yr^{-1})	Source*
Broadleaves	Oak	Chronosequence	29	0.08	1
	Oak	Stand	30	0.02	2
	Oak	Stand	30	0.05	2
	Oak	Stand	30	0.04	2
	Oak	Stand	30	0.02	2
	Oak	Stand	30	0.13	3
	Oak	Stand	40	0.09	3
	Beech	Stand	30	0.09	2
	Beech	Stand	30	0.10	2
	Beech	Stand	30	0.12	2
	Beech	Stand	30	0.13	2
	Beech	Stand	30	0.18	3
	Beech	Stand	40	0.14	3
	Average (SEM)			*0.09 (0.01)*	
Conifers	Norway	Chronosequence	30	0.35	1
	Spruce	Chronosequence	41	0.43	1
		Stand	30	0.21	2
		Stand	30	0.15	2
		Stand	30	0.20	2
		Stand	30	0.30	2
		Stand	30	0.30	3
		Stand	40	0.65	3
	Sitka spruce	Stand	30	0.43	2
		Stand	30	0.24	2
		Stand	30	0.22	2
		Stand	30	0.25	2
	Average (SEM)			*0.31 (0.04)*	

* 1) Vesterdal et al. (2007), 2) Vesterdal & Raulund-Rasmussen (1998), 3) Vesterdal et al. (2008).

The results from scientific projects have lately been checked by analysis of preliminary results from the Agricultural Network. The afforested plots in the monitoring grid also revealed large variation in soil carbon pools among for both forest floors and mineral soils (Table 7.12). The mean carbon pool of the forest floor among the afforested sites was about 2.5 t C ha^{-1} in 2007-2009 (and supposedly 0 t C ha^{-1} at the time of the afforestation) while the mean carbon pools for mineral soils were 114 and 108 t C ha^{-1} in 1990 and 2007-2009 respectively (Table 7.18). A simple t-test on the mean change in mineral soils pools between 1990 and 2007-2009 (-1.87 t C ha^{-1} yr^{-1}) showed that the change was not significant (Table 7.12 and Figure 7.2) while there, as expected, was a significant sequestration of carbon in the forest floor due to litterfall inputs and subsequent buildup of the organic layer (Table 7.13, Figure 7.3). The age of the afforested stands ranged from 8-19 years, so only the establishment phase was covered.

Table 7.12 Basic statistics on soil carbon pools measured in the "Agricultural Network".

	Mean C pool	Std	Min	Max
	(tonne C ha^{-1})			
Forest floor at the time of the afforestation	-	-	-	-
Forest floor 2007-2009	2.53	1.79	0.25	5.56
Mineral soil 1990	113.63	35.37	68.00	186.06
Mineral soil 2007-2009	107.83	41.25	52.82	220.06

Table 7.13 Statistics from a simple t-test on the change in soil carbon between ca. 1990 and 2009 for forests after 1990.

	Total number of sites	Number of sites in t-test	Mean change	Std	Min	Max	P-value
			(tonne C ha^{-1})				
O-horizon	15	15	2.53	1.79	0.25	5.56	<.0001
Mineral soil	15	14	-1.87	17.59	-35.32	34.00	0.70

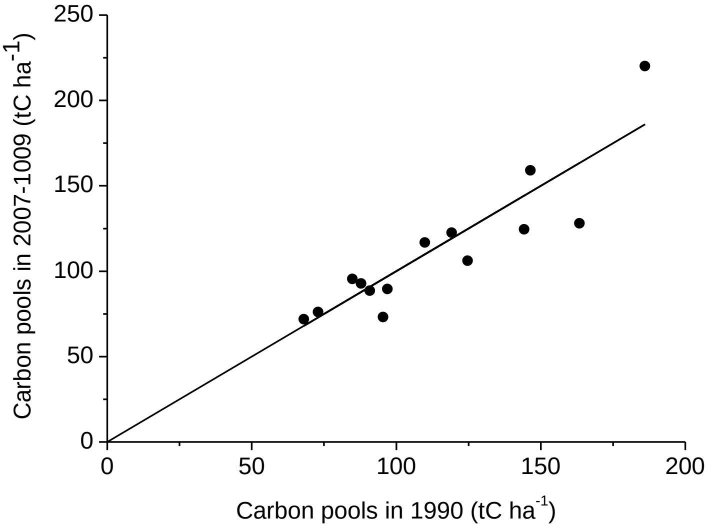

Figure 7.4 Carbon pools in mineral soils in 2009 versus 1990. Forests established on arable land since 1990. Line: y=x.

The amount of carbon in the forest floors increased with the age of the afforested stand (Figure 7.4), while this was not the case for the mineral soil (Figure 7.5).

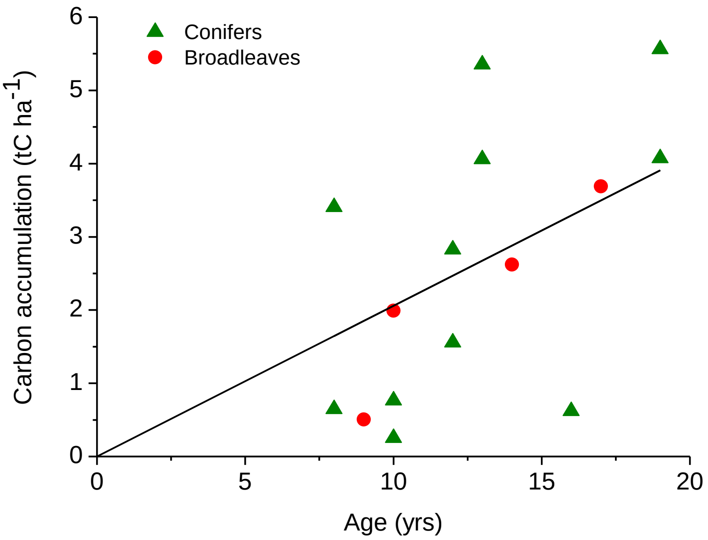

Figure 7.5 Forest floor carbon pools in forests afforested since 1990 in the Agricultural Network. The regression was forced through (0,0) (C acc. = 0.2057 x age, R^2=0.3124, p<0.0001).

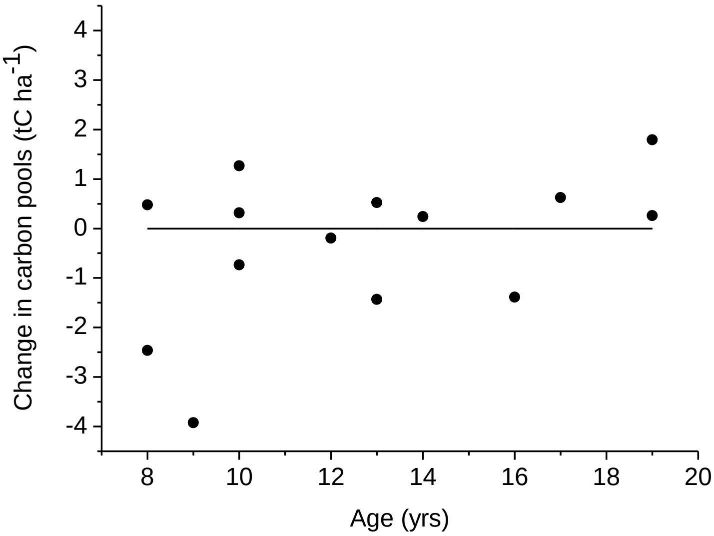

Figure 7.6 Change in mineral soil carbon stocks for forests since 1990. Line: y=0 (Regression line (not shown): R^r=0.0005, p=0.9356).

Average carbon sequestration rates for forest floors for broadleaves and conifers were also estimated from "Agricultural Network" in order to check the forest floor carbon sequestration rates used in reporting; in this case the average annual sequestration of carbon in forests floors was 0.16 and 0.20 t C ha^{-1} yr^{-1} under broadleaves and conifers, respectively (Table 7.14). These values are lower compared to the values obtained from 30-40 yr-old stands. (Table 7.11).

Table 7.14 Forest floor carbon sequestration rates in afforestation areas for different species. Data from the "Agricultural Network".

Tree species category	Tree species	Study type	Age (year)	Forest floor C sequestration (tonne C ha^{-1} yr^{-1})	Site
Broadleaves	Oak	Monitoring plots	14	0,19	837
	Oak	Monitoring plots	17	0,22	301
	Maple	Monitoring plots	9	0,06	485
	Lime	Monitoring plots	10	0,20	571
	Average (SEM)			*0.16 (0.07)*	
Conifers	Norway spruce	Monitoring plots	19	0,21	479
	Sitka spruce	Monitoring plots	13	0,41	335
	Sitka spruce	Monitoring plots	10	0,03	340
	Normann fir	Monitoring plots	13	0,31	31
	Normann fir	Monitoring plots	16	0,04	171
	Normann fir	Monitoring plots	12	0,13	235
	Normann fir	Monitoring plots	8	0,08	292
	Normann fir	Monitoring plots	12	0,24	689
	Silver fir	Monitoring plots	19	0,29	66
	Larch	Monitoring plots	8	0,43	334
	Mixed conifers	Monitoring plots	10	0,08	509
	Average (SEM)			*0.20 (0.14)*	

Lastly we combined all data to explore the trends in forest floor carbon stocks among broadleaves and conifers (Figure 7.7). The rates used seem reasonable, even if the inclusion of new data indicate that it might be too high for conifers in the stand establishment phase. Thus, accumulation of conifer forest floors is assumed to start after 8 years of chronosequences. This is reasonable since observations in chronosequences indicate that there is little litterfall in conifer stands to build up forest floors during the first 10 years.

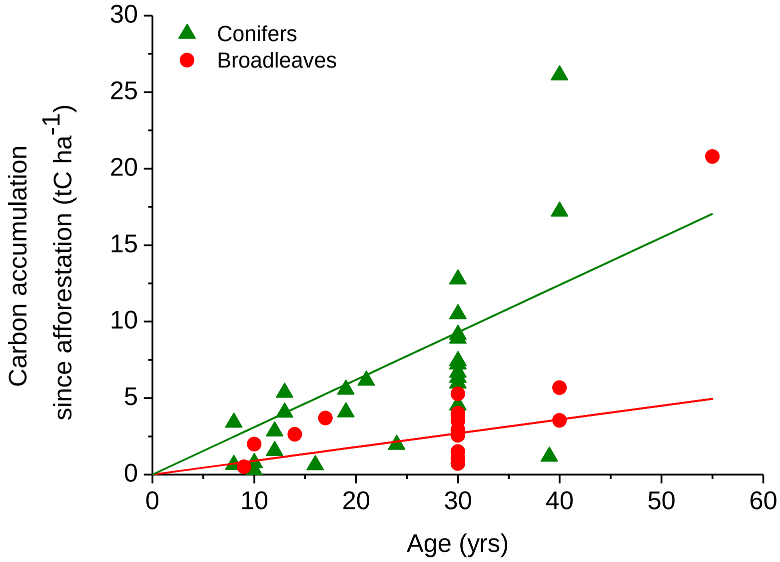

Figure 7.7 Forest floor carbon pools in afforested plots. All available data from chronosequential studies and the "Agricultural Network" are included. Lines show the carbon sequestration rates used in the reporting: 0.31 tonne carbon ha^{-1} yr^{-1} for conifers and 0.09 tonne carbon ha^{-1} yr^{-1} for broadleaves.

Several previous national field studies mentioned above (Vesterdal et al. 2002a, 2002b, 2007) did not suggest measurable decadal changes in mineral soil carbon following afforestation. In the Forest Soil Inventory (SINKS project), soil carbon content to 100 cm in forest land remaining forest land was compared with soil carbon in the same depth found in a parallel project for cropland soils (Table 7.15). These data also support that mineral soils are neither sinks nor sources for CO_2 following afforestation of former cropland. Using a transition time of 50 years, these soil carbon contents were used to calculate the small rates of soil carbon stock change for cropland to forest conversion.

Table 7.15 Mineral soil carbon content (Mg ha^{-1}) in cropland and forest land based on the Agricultural Network. N: number of plots, mean and standard deviation (std).

Land use	Sandy soils			Loamy soils		
	N	mean	std	N	mean	std
Cropland		137			158	
Forest land	261	154	79	116	164	103
Grassland and Other land	19	150	84		150a	84a
Settlements		120 b			120 b	

[a] Same data as for sandy soils.
[b] Agreed with the UFCCC-ERT during the 2011 review.

In conclusion, preliminary results from the Forest Soil Inventory project show no evidence that mineral soil carbon pools for forests on former arable land are neither sinks nor sources for CO_2. The data from the SINKS project support the conclusions drawn from Vesterdal et al. (2002, 2007), Vesterdal and Raulund-Rasmussen (1998), and Vesterdal et al. (2008) for forest floors. The comparison between Danish land-uses (Table 7.15) suggests that particularly sandy soils would sequester carbon following afforestation of cropland, whereas carbon stocks in loamy soils are quite similar between land uses. Thus, a no-source principle would be justified in case of land-use conversions to forest.

Until final results from the Forest Soil Inventory are available we continue to use the previously used average carbon sequestration rates: 0.09 tonne carbon ha^{-1} yr^{-1} for broadleaves and 0.31 for conifers.

The sequestration of CO_2 in forest floors in forests established since 1990 has gradually increased and the annual CO_2 sequestration will increase much more over the next decades when cohorts of afforestation areas enter the stage of maximum current increment.

The reporting of the forest floor in the afforestation in the 2008-2012 period is based on the NFI monitoring of forest floor depth as described above.

7.3.5 Uncertainties and time series consistency

See Section 7.2.1 and 7.2.2 for recalculation since 1990.

7.3.6 QA/QC and verification

A continuous focus on the measurements of carbon pools in land converted to forest will contribute to QA/QC and verification in the following submissions. See also Chapter 7.2.1

7.3.7 Recalculations, including changes made in response to the review process

In the updated land use matrix that now includes mapping of three years: 1990, 2005 and 2011, significant changes have been noted related to land use and land use changes. This includes increased afforestation in areas without support from public funds. This includes 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). In the previous reporting, mainly afforestation based on subsidies were expected and included in the reporting.

7.3.8 Planned improvements

A QA/QC of the Land Use matrix is a continuous process.

The basic information utilised to give the data for the emission estimates for units of land subjected to afforestation/reforestation is based on National Forest Inventory (NFI) observations of stock change, specific related to the afforestated areas. This will include all changes in carbon pools - also if affected by harvest - including thinnings of young stands. Based on the NFI it will be possible - for the next reporting to provide some indications of the frequency of harvesting/thinning occurring on the afforestated areas. Given the fact that the afforestated area is still a relatively small part of the full forest area, there will be more uncertainty on the estimate related to afforestated areas compared to the area of forest remaining forest.

Documentation for carbon pools in soil and litter is expected to be further improved in the next submission.

7.4 Cropland (5B)

7.4.1 Cropland and cropland management (5B1)

The total Danish cropped agricultural area of approximately 2.7 million hectare can relate to approximately 620 000 individual fields, which again is located at 200 000 land parcels. This gives an average field size of less than four ha. The actual crop grown in each land parcel (LPIS) is known from 1998 and onwards. Since 1990 the agricultural area recorded by Statistics Denmark has decreased from 2.78 million hectare to 2.64 million hectare (Table 7.16). The total crop yield given as kernel, root fruits and grass as measured in dry matter (million kg dry matter per year) is, however, at the same level and increasing due to improved cropping techniques, Figure 7.8

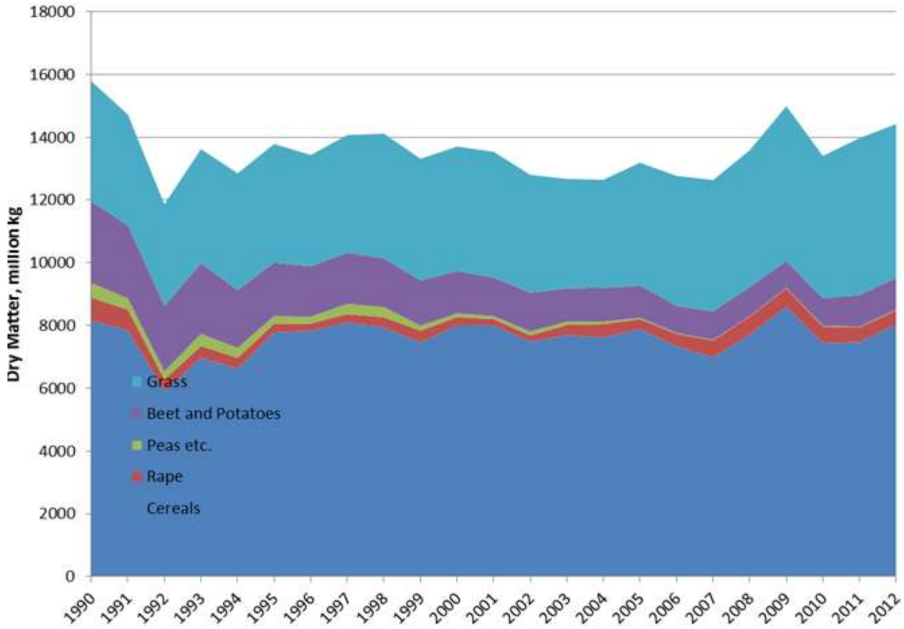

Figure 7.8 Total crop yield given as kernel, root fruits and grass as measured in dry matter (Million kg dry matter per year)

The main reason for the loss of land for agricultural purposes is urbanisation and afforestation. The major 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 (>63 kg N per ha per year) is reported under Grassland. All fertilisation with nitrogen is reported under Agriculture 4D2.

Table 7.16 shows the development in the agricultural area from 1990 to 2012 (Statistics Denmark). A general trend is a continuous decrease of 6 000 - 7 000 ha per year in the agricultural area.

Table 7.16 Cropland area in Denmark 1990- 2012 according to Statistics Denmark and the Land Use Matrix, hectares.

	1990	1995	2000	2005	2010	2011	2012
Annual crops (CL) 1	2 236 535	1 969 275	1 938 633	1 953 306	2 049 304	2 050 108	2 053 093
Grass in rotation (CL)	306 325	310 568	330 834	342 417	327 319	336 061	331 512
Permanent grass (CL and GL)	217 235	207 122	166 261	192 968	199 859	186 652	200 413
Horticulture – vegetables (CL)	16 428	12 915	10 803	9 557	10 812	11 215	10 305
Perennial fruit trees – perennial wooden crops (CL)	10 267	10 669	9 892	9 464	8 181	7 477	7 570
Set-a-side and other land (CL)	3 861	217 801	192 441	200 751	51 309	48 273	41 800
Total agricultural land area reported by Statistics Denmark	2 788 276	2 726 048	2 646 982	2 707 236	2 646 400	2 639 905	2 644 631
Willow and other crops for energy purposes (CL)	588	588	695	1 320	4 049	4 795	5 410
Hedgerows (CL)	61 326	61 019	60 554	60 170	59 791	59 732	59 659
"Other agricultural land"	80 783	107 253	119 847	61 115	105 720	94 385	86 433

[1]CL refers to that the area is treated under Cropland. GL refers to Grassland.

Cropland area

The Cropland area is defined as the agricultural area as given by Statistics Denmark, Perennial wooden crops (fruit trees, orchards and willow), hedgerows (perennial trees/bushes not meeting the forest definition) in the agricultural landscape and “Other agricultural land”. The latter is defined as the difference in the area between the total Cropland area as defined by land use matrix (see Table 7.3) minus agricultural crops in rotation as given by statistics Denmark minus the area with fruit trees and the area with hedgerows. “Other agricultural land” is thus comparable small areas and probably without agricultural and wooden crops, which cannot be allocated to other land use categories. In the inventory carbon in living biomass for “Other agricultural land” is given the same value as for annual crops so than interannual changes in the cropland area from Statistics Denmark are eliminated.

The area with Perennial wooden crops are the area given by Statistics Denmark and for some categories it is split further down with data from the EU crop subsidiary system, which gives information on which crops are grown where on species level.

The main data for land use in Cropland (5.B.1) is the agricultural area given by Statistics Denmark. Both annual agricultural and wooden perennial crops are allocated into grids (climatic, soil type and municipality) with the help of the EU Land Parcel Information System (LPIS). LPIS contains information of the exact position of the field. The survey data from Statistics Denmark differs a little from the LPIS system (<±2% for the major crops). Area and yield data from each region is used for the calculations as reported by Statistics Denmark.

The area with hedgerows is based on analysis of aerial photos from 1990 and 2005 combined with planting and removal statistics of hedges from the Ministry of Food, Agriculture and Fisheries. The major part of the hedge erection is subsidies in Denmark and therefore monitored.

Cropland definition

The land area under "CL" consists of: Cropland with annual crops, cropland with wooden perennial crops, area with hedgerows and “Other agricultural area”. The latter consists of small undefined areas lying inside the area, which is allocated as cropland in the cropland area.

For purposes of the calculations for annual crops a division as follows is used: Winter and spring wheat, rye, triticale, winter and spring barley, oat, winter and spring rape, grass for grass seed production, grassland in rotation, potatoes, sugar beets, peas, maize for silage, cereals for silage, vegetables and miscanthus.

For purposes of perennial wooden crops a division as follows is used: Apple, Pears, Cherries, Plumes, Rosehips, Elderberries, Hazel and Walnuts, Grapes, Other fruit trees, Black current, Other fruit bushes, Hedgerows and Willows.

Biomass from Christmas trees in the agricultural area is reported under forests.

Cropland - Methodological issues

The following data sources are used for determination of cropland area, for determination of any land-use changes, for allocation of natural and administrative parameters, for development of emission factors for soils and biomass and for calculation of carbon stocks in soils and biomass at various times.

- Agricultural area data from Statistics Denmark, 1980 to 2012
- Area and harvest surveys from Statistics Denmark, 1980 to 2012.
- Area with willow from the agricultural subsidiary system.
- EUs Land Parcel Information System, 1998 and onwards (grown crops on field and soil level).
- Digital soil map, 1:25.000.
- Arial photos of hedgerows in 1990 and 2005.
- Hedgerow planting data 1977 to 2012.
- Lime consumption data 1990 to 2012.

The model for carbon stock changes in hedges is based on a growth model from the National Forest Inventory (NFI) classified into plant and soil type and height.

Emissions from living biomass

For annual agricultural crops on cropland remaining cropland (5B1) it is assumed that no changes in above-ground, below-ground, dead biomass and litter are occurring cf. IPPC 2003 (3.3.1.1.1). The variations in the actual agricultural area collected by Statistics Denmark may be up to 100,000 hectares per year. When estimating the carbon stock in living biomass such changes may create large variations between years, which may be artefacts. 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 from Statistics Denmark create large fluctuations in the carbon stock in living biomass compared to other sources. 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 is equivalent to an average spring barley crop with aboveground biomass of 9 577 kg DM (dry matter) pr hectare and a below ground DM of 2 298 kg pr hectare. Default dry matter values for the different crop categories used in the inventory was given in Table 7.10.

Fruit trees and other perennial wooden plants

Fruit trees, other perennial commercial wooden plants and durable horticultural plantations are reported separately under Cropland (Table 5.B). These are only of minor importance in Denmark. The total area for different main classes and the used carbon stock in above-ground and below-ground biomass are given in Table 7.17. Due to the limited area and small changes between years the CO_2 removal/emission is calculated without a growth model for the different tree categories. Instead the average stock figures are used in Table 7.17 multiplied with changes in the area to estimate the annual emissions/removals. Perennial horticultural crops account for approximately 0.07 % of the standing carbon stock. Christmas trees are reported under forest (5.A).

The carbon fraction of dry matter (DM) is assumed to be 0.5 for all species. For parameter estimation of living biomass, see Gyldenkærne et al. 2005 for fruit trees, for willow and Miscanthus:

http://www.nordicbiomass.dk/dansk/nye_afgroeder.asp

Table 7.17 Mg living biomass per hectare and area, ha, with perennial wooden trees and – bushes, 1990- 2012.

	Living biomass, Mg DM per ha	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
Black currant	5,20	1 269	1 828	1 492	2 001	1 856	2 071	1 848	1 935	2 041	1 855
Other berries	5,20	663	547	611	698	708	589	578	533	608	734
Rosehip	13,99	0	0	0	0	0	120	159	197	197	34
Cherries	25,45	1 787	2 653	2 804	2 131	2 169	1 951	1 864	1 743	1 466	1 401
Plumes	25,45	0	0	0	0	0	60	63	68	65	73
Hazelnut and Walnuts	25,45	0	0	0	15	13	45	14	14	23	28
Aples	33,76	2 726	1 658	1 678	1 751	1 812	1 797	1 730	1 684	1 550	1 703
Pears	13,99	351	546	441	413	466	442	372	357	336	344
Elderberry	25,45	0	0	0	9	15	10	12	9	16	14
Grapes	5,20	0	0	0	18	22	31	37	45	50	57
Other fruit trees	13,99	0	0	0	110	125	21	48	60	74	67
Rowan-berries	33,76	0	0	0	0	0	14	16	16	10	12
Willow	17,43	588	588	695	1 320	1 736	1 832	2 736	4 049	4 795	5 410
Miscanthus	17,43	1	1	6	33	88	80	80	156	774	70
Total		7 385	7 821	7 727	8 499	9 010	9 062	9 556	10 865	12 005	11 804

Hedgerows

Since the beginning of the early 1970s governmental subsidiaries have been given to increase the area with hedgerows to reduce soil erosion. Annually financial support is given to approximately 600-800 km of hedgerow. There are no figures on how many hedgerows have been removed in the same period as these to a large extend are not protected. Therefore 144 aerial photos on a 2x2 km^2 square for 1990 and 2005 have been analysed to monitor and detect changes in the landscape. The squares are distributed throughout Denmark in a stratified way according to primarily soil and wind conditions (Figure 7.9). A very large dynamic in the location of the hedges between 1990 and 2005 was observed (Figure 7.9). Only areas not meeting the definition of forests and areas not classified under Perennial Wooden crops (fruit trees, willows etc.) were included in the analysis. The hedges were further allocated into eight different regions, mainly according to soil type (e.g. growth pattern).

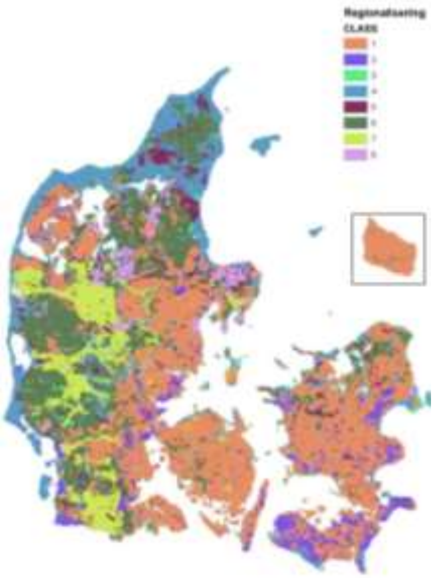

Figure 7.7 Designated areas with different types/classes of hedges.

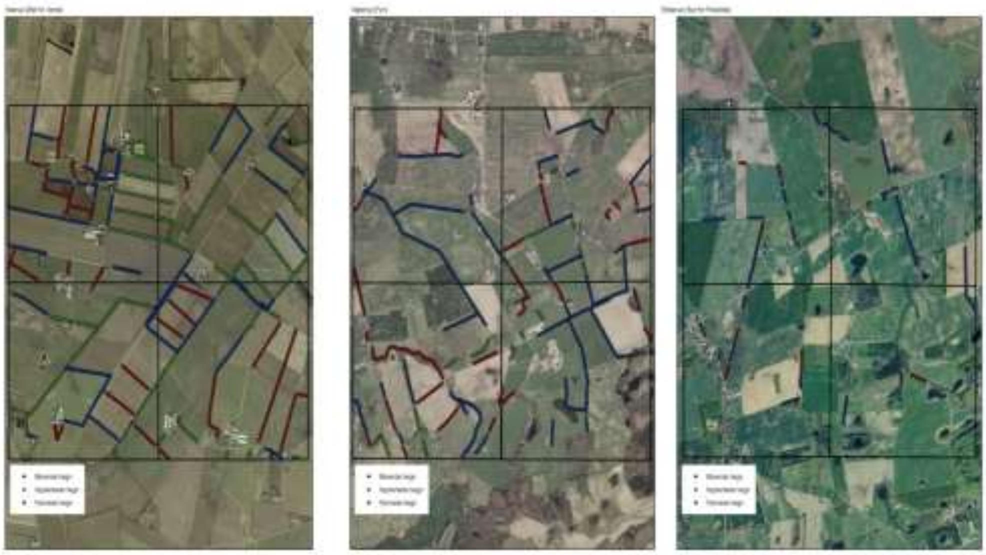

Figure 7.9 The dynamics of hedgerows in the Danish Landscape 1990 to 2005. Blue colour indicates no changes, red colours are removed hedges and green colours are new hedges (Source: M. Fuglsang, DCE).

The overall results from the analysis of hedges are shown in Table 7.18. The total area with hedges has decreased with 2 % but the total volume and the carbon stock has increased due to changed sizes and composition.

Table 7.18 Hedges in the cropland 1990 and 2005.

	1990	2005	Change in percent 1990-2005
Area, ha	61 326	60 093	-2.0
Volume, million. m3	4 139	4 402	6.4
Carbon stock, Gg	939	1 072	14.2

In Table 7.19 the actual planting and removal rates for hedgerows is shown. The 1970s and 1980s have a high concern to protect and maintain the hedgerows and a substantial replacement took place. Currently is the governmental subsidiary targeted to broadleaved hedgerow replacing old single-rowed conifers (mainly white spruce *(Picea glauca)*). In 1990 75 % of the replaced conifers hedgerows were replaced with 3- to 6-rowed broad-leaved hedges. In 2005 only 20 % are replacements and the remaining is new hedges cf. Table 7.19. Over the years a decrease in the number of subsidized hedgerows has taken place. The Ministry of Food, Agriculture and Fisheries is responsible for all administration, registration and mapping of all subsidised hedgerow planting in Denmark.

Table 7.19 Hedges planted and removed under the governmental subsidiary system 1985 to 2012.

	1985	1990	1995	2000	2005	2008	2009	2010	2011	2012
Planted 3-rowed, km	1 082	928	560	852	390	141	128	109	96	107
Planted 6-rowed, km	0	0	252	250	115	41	38	29	37	33
Planted small biotopes, ha							96	64	52	33
Percentage removed, %	75	75	36	27	20	20	20	20	20	20
Percentage new, %	25	25	64	74	80	80	80	80	80	80
Hedges remowed, ha	608	522	218	219	76	83	25	21	20	21

The biomass estimation of the hedges is based on measurements made in the Danish NFI where plots with similar height and plant species are used as transfer functions (Figure 7.10).

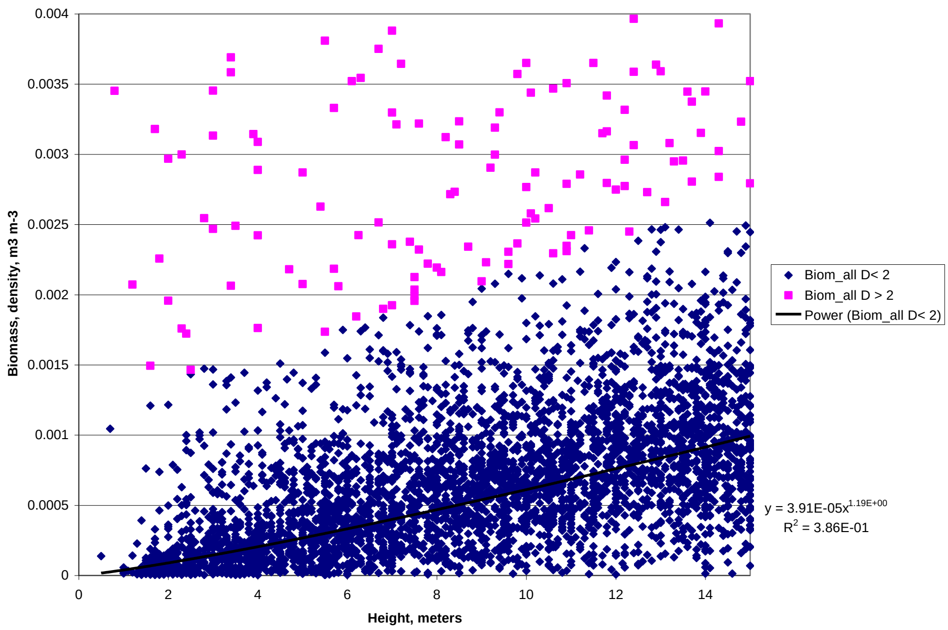

Figure 7.10 Biomass function estimated as m^3 biomass per m^3 versus tree height in NFI plots less than 15 meter (Courtesy Thomas Nord-Larsen, SL, LIFE, KU).

Emission from soils

Based on a GIS analysis of the data in the LPIS and a newly produced soil map of the organic soil the agricultural area is distributed between mineral soils and organic soils and subdivided into cropland and permanent grassland.

Mineral soils – 5B1

For carbon changes in for agricultural crops a 3-pooled dynamic soil model is used (Petersen, 2003; Petersen et al. 2002, 2005, 2010, Gyldenkærne et al. 2005) to calculate the soil carbon dynamics in relation to the Danish commitments to UNFCCC. C-TOOL is only used in CL. No change in the carbon stock in soils under perennial wooden plants, hedgerows and "Other agricultural cropland" is expected and reported as NA. These areas are also only a very minor part of the cropland area. For agricultural crops C-TOOL is run on a regional level.

C-TOOL

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. A simple diagram of C-TOOL is shown in Figure 7.11.

C-TOOL is parameterised and validated against long-term field experiments (100-150 years) conducted in Denmark, UK (Rothamsted) and Sweden and is "State-of-the-art". A detailed description of C-TOOL can be found at www.agrsci.dk/c-tool/index.htmls. More recent investigations have shown that C-TOOL is not properly parameterised on soils having more than 6 % organic carbon. Soils having 6-12 % organic carbon is therefore treated as organic soils with an emission factor of 50 % of organic soils > 12 % organic carbon.

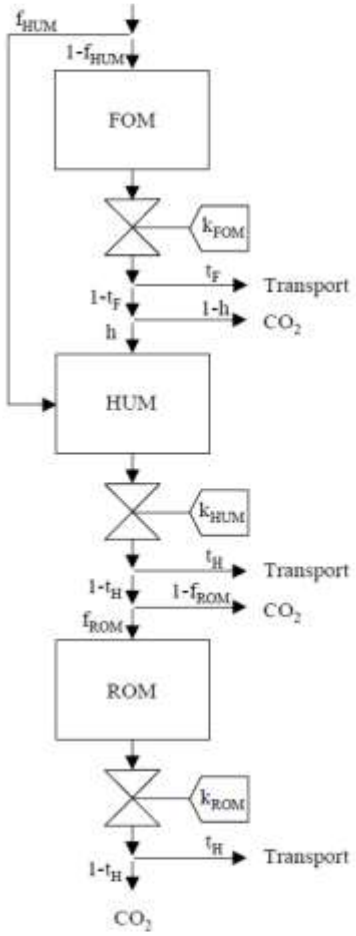

Figure 7.11 A simple diagram of C-TOOL. Please refer to www.agrsci.dk/c-tool for more information.

Input data to C-TOOL and out put

As carbon input to each region for each year is taken the actual crop area and crop yield from Statistics Denmark for that particular region and crop species as given by 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 %.

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 cereals it is 16 %.

More detailed figures on the distribution as an example of the crop yield and areas are given in Annex 3F, Table 3.F10-12 for a specific region (Eastern Jutland) in year 2010.

The overall input to C-TOOL varies between years (Figure 7.8) due to the actual growing conditions in that year. 2012 was a fairly good year in terms of harvested crops. The cereal yield was the third highest since 1990 and on a general decreasing area. 2010 and 2011 were medium years, whereas 2009 were the best cereal year ever. The variation in the input to C-TOOL gives a large inter-annual variation in the carbon input to the soil for all years of the time series. Combined with large inter-annual differences in the temperature this creates large 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, whereas in years with a high yield and low temperatures the carbon stock in soils is increased.

The amount of animal manure produced 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. This also includes data whether the manure has been biogassed or not. The manure data are used as input to C-TOOL.

In Figure 7.12 is shown the overall input of C to the agricultural soils. Due to a ban of field burning in 1990, increased management and demand on catch crops an increase in the C input to soils can be seen.

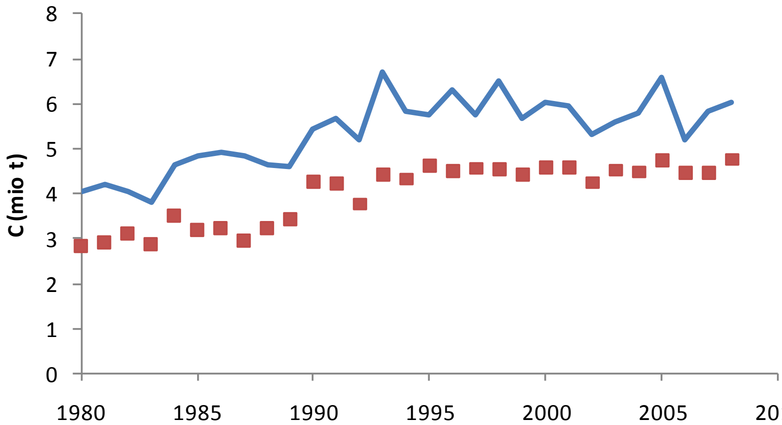

Figure 7.12 Calculated C input to the soil (red squares) and modelled (blue curve) development of the FOM pools, million tonnes C.

Since 1997 there has been a demand for growing N catch crops in Denmark in order to reduce N leaching. Besides reducing the N leaching these crops increase the carbon stock in the soil. Between 120 000 and 200 000 hectares of the agricultural area has this additional crop every year. The demand for catch crops has altered the way of farming in two main ways. For farmers with cattle the farmers are sowing grass seed in their normal cereal fields. This grass sword must not be ploughed into the soil before winter/next spring. For farmers growing grass seed, which is common in Denmark, old grass seed fields are not ploughed before next spring in contradiction to the current situation where it would be ploughed early autumn. It has been estimated that the obligatory catch crops are increasing the amount of C returned to soil with 0.36 to 2.14 tonnes carbon per hectare per year (Olesen et al. 2004). The area with catch crops in each region is estimated from each farms obligatory N accounting, in which the area of catch crops area given on farm level (www.pdir.dk).

C-TOOL is initiated with data from 1980 and run multipliable times until stability, before the emissions from 1980 and onwards was calculated. Actual 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 contradiction 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, yield high emissions from the soil compared to more cold years, which will yield low emissions.

In recent years (1999- 2012) Denmark has experienced very warm winters although 2010 was very cold and below the average from 1961 to 1990. In 18 out of the last 20 years the annual average temperature has been above the average temperature from 1961 to 1990. Year 2012 had an average temperature of 8.3 °C or 0.6 °C above the average from 1961 to 1990.

Year 2006 resulted in a high loss due to the warmest year up to now combined with a harvest yield 5 % below the average for 1997 to 2009 (measured as kernel yield from cereals) (Figure 7.13). In this year the organic matter input from crop residues and animal manure were not able to compensate for the loss (Figure 7.13). 2007 was not as warm, which led to an increase in the carbon stock. 2009 was cooler than 2008 but 2009 gave the highest cereal yield ever monitored in Denmark despite the fact that the agricultural area has decreased since 1980. This led to a very high input of organic matter into the soil, which again increased the soil carbon stock.

2010 were very cold with low harvest yields and 2011 were moderate too due to draught. An overall decreasing C stock in mineral soils is therefore estimated.

The combination of a higher yield in 2012 than in 2011 combined with a lower temperature in 2012 than in 2011 has resulted in a lower C loss from soils in 2012 than in 2011.

The FOM-pool (Fresh Organic Matter), which has a very fast turnover rate, consists of approx. 1.0 % of the total carbon content in the agricultural soil. Because of its large fluctuation between individual years and its small impact on the overall trend in the long-term development of the carbon stock in the soil, it has been agreed with the previous ERT during the in-country review in 2010, that all input sources are included in the modelling but in the reporting on the development an instant turnover of the FOM pool is used. The reported development is thus the two pools, HUM (Humified Organic Matter) and ROM (Resilient Organic Matter) which account for 99 % of the total amount of carbon in the soil. Figure 7.13 shows the development in the two pools. As can be seen there is a small increase in the total modelled carbon stock from 2008 to 2010 but a decrease in HUM and ROM. A new warm year with normal harvest yields will speed up the degradation of the FOM pool and as a consequence the two lines will get closer again.

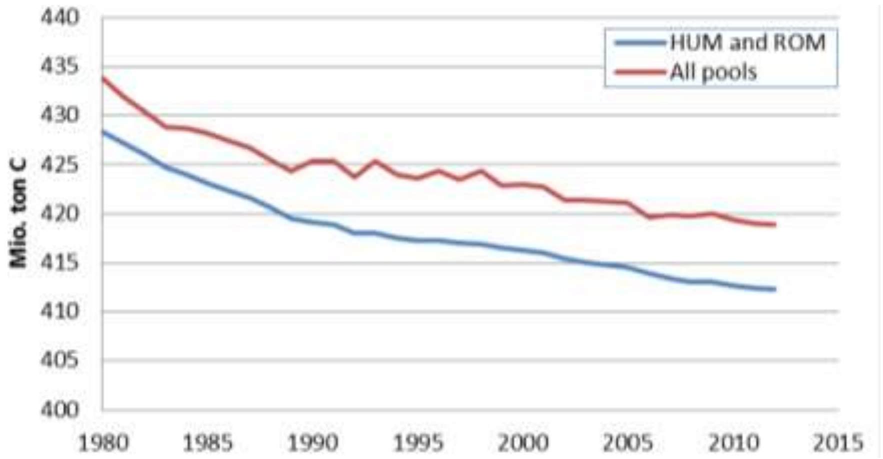

Figure 7.13 The development in the C-stock in agricultural soils, Tg C (million tonne C).

As a whole the modelled emissions are found to be the most realistic emissions estimates for Denmark. As described in the agricultural sector the Danish farmers have faced increased demands for lower environmental impact since the mid-1980s. The general effect on the carbon stock in soil is that the 1980s showed a decrease in the carbon stock. In the 1990s the carbon stock seemed to stabilise due to the higher input of organic matter. Due to the increased global warming a declining carbon stock was modelled between 2000 and 2011. Since 1990 C-TOOL has estimated a loss of 1.5 % of the total carbon stock in the mineral agricultural soils. No precise uncertainty calculation has been made. However, it must be assumed that uncertainty in the estimate in the annual loss/gain is around 25 %. As Denmark has very good data on harvest yields and area data the uncertainty in the trend is very low. The estimated annual amounts of carbon in the agricultural soils are given in Table 7.20.

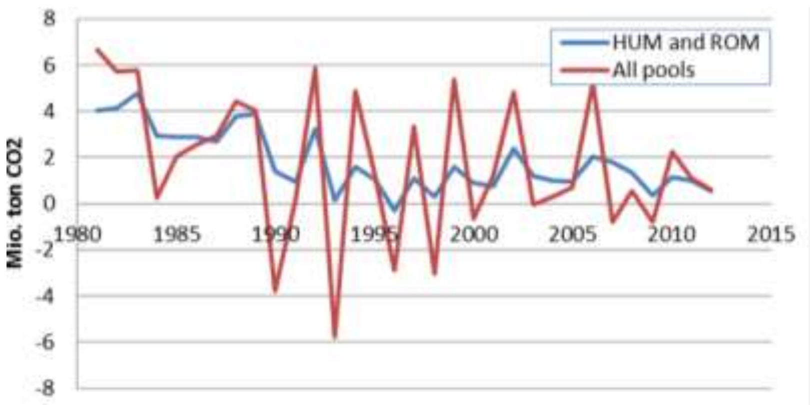

Figure 7.14 Estimated annual emissions from mineral soils 1990 to 2012 (million tonne CO_2 yr^{-1}).

Table 7.20 Modelled carbon stock (0-100 cm) in mineral soils from 1980 to 2011, Tg C.

Year	All pools	Fast FOM model
1980	433,795	428,295
1981	431,976	427,201
1982	430,412	426,068
1983	428,834	424,763
1984	428,764	423,954
1985	428,208	423,168
1986	427,508	422,382
1987	426,710	421,654
1988	425,496	420,625
1989	424,394	419,568
1990	425,419	419,182
1991	425,356	418,920
1992	423,752	418,029
1993	425,330	417,983
1994	423,994	417,545
1995	423,646	417,254
1996	424,436	417,329
1997	423,524	417,032
1998	424,346	416,949
1999	422,883	416,516
2000	423,050	416,266
2001	422,716	416,055
2002	421,398	415,406
2003	421,410	415,075
2004	421,323	414,798
2005	421,127	414,534
2006	419,695	413,975
2007	419,908	413,481
2008	419,755	413,113
2009	419,969	413,014
2010	419,354	412,700
2011	419,058	412,432
2012	418.897	412.274

Independent verification of C-TOOL

An independent validation of C-TOOL has been performed by soil sampling in the Danish Agricultural grid. The grid was established in 1987 and in a 7 x 7 km^2 grid square. In 1987 > 600 agricultural plots were sampled and analysed for carbon. Half of them were resampled in 1998 and a full resampling of 464 plots was made in 2008/2009. Figure 7.15 shows the development in the carbon stock in 0-100 cm depth in the paired plots. It can be seen that there has been an increase in the soil C stock in the sandy soils (Coarse Sand, Fine Sand and Loamy Sand). This is mainly due to that the Danish cattle herd is located on these soils combined with large areas with grass in rotation. This favour the soil C stock. Contrary to this is observed a loss in the C stock on the loamy soils (Sandy Loam and Loam). On these soils are annual crops the most common cultivars combined with a limited number of cattle and pigs. On these soils it seems difficult to maintain the soil C stock. Although there is some variability the overall conclusion is that there is a small loss from the Danish agricultural soils.

C-TOOL has estimated an overall loss from 1987 to 2009 of 7-10 million tonnes C and in the soil sampling grind is found an average loss of approx. 5 tonnes C per ha. With approx. 2 million hectares in rotation this gives a total loss of 10 million tonnes C from 1987 to 2009. The conclusion is therefore that the modelled outcome from C-TOOL represents a proper value for the development of the carbon stock in the Danish agricultural soils.

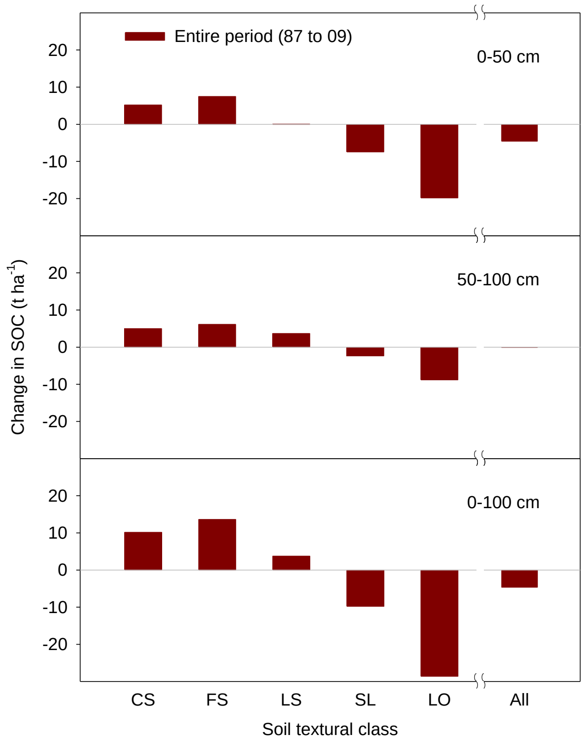

Figure 7.15   The change in carbon stock in soil (0 - 100 cm) in >460 paired agricultural plots from 1987 to 2009 (Olesen et al. in prep.)

Organic soils - 5B1

A complete new soil map of the organic soils was made in 2010 for the inventory (Figure 7.16). The new soil map is a statistical map based on >10 000 soil samples down to the mineral soil in 30 cm intervals combined with a very detailed digital elevation map (DEM) for each 1.6 x 1.6 m^2 covering the entire Denmark, water table maps and old maps with organic soils. The definition of an organic soil in the new map is 20 % organic matter with a depth of minimum 30 cm (Greve et al., 2013, submitted). The total area with organic soils has been estimated to approx. 106 642 ha.

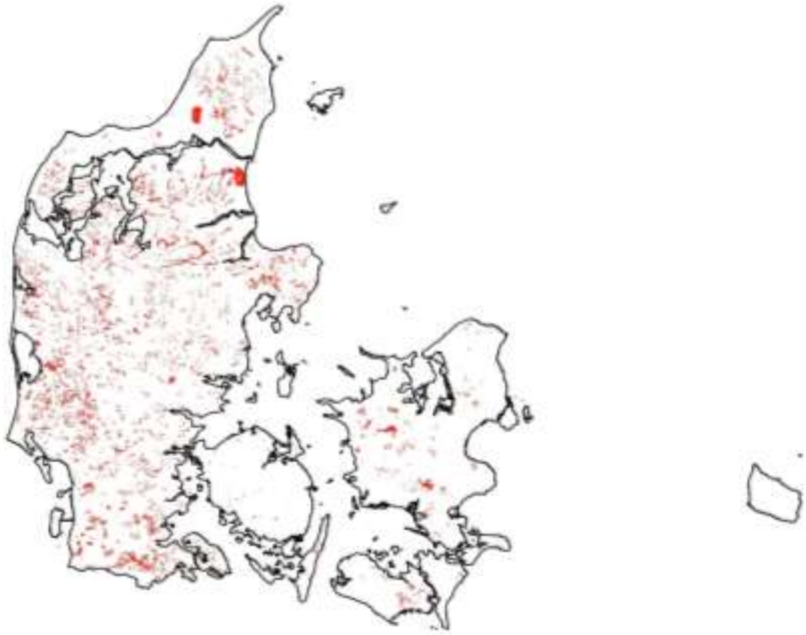

Figure 7.16 The new organic soil map for Denmark for year 2010, > 12 % OC (Greve et al. 2012, submitted).

On top of the organic soil map digital maps has been laid a map where 99 % of all Danish farmed fields (>636 000 fields) from the EU subsidiary system are precisely mapped with an uncertainty down to < ± 0.5 meter. The actual grown crop is known for each field. In total more than 270 different crop types or combination of crop and crop management are recorded. In 2012 40 706 hectares with annual crops were located to be grown on the organic soil area and 10 180 hectares with grass in rotation.

The previous Danish soil classification was carried out in 1975. In 1975 it was estimated that there were 178 000 hectares of organic soils (>12 % C). Of this were 118 000 ha in the Cropland and the Grassland area and the remaining 60 000 ha were located in the Forests, Wetlands, Settlements and Other land. Overlay between the field map and the soil map has shown that only around 51 000 hectare in 2012 is farmed in the Cropland area and 17 200 hectare in Grassland and that the depth of the organic layer has become very shallow. The major reason for the drastic reduction is that Denmark is quite flat with shallow organic layers, which combined with intensive agricultural utilisation with high drainage rates has oxidized a major part of the organic matter.

The outcome is that during recent years more and more previously organic soils do not qualify to be organic by definition and that the area will decrease rapidly in future.

Emission factors for organic soils

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, in prep). The overall result is shown in Table 7.21 compared with the IPCC default values. Maljanen et al. (2010) recently 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 m^{-2} yr^{-1} (mean +/- standard deviation, n = 4). The available studies (n = 4) represented three Finnish and one Norwegian site (Lohila et al., 2004; Maljanen et al., 2001, 2004; Grønlund et al., 2008). The upscaled 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 temperate cold zone covers the major part of Europe the measured Danish values also seems to be in line with the IPCC guidelines. Emissions from organic soils on permanent grassland are reported under Grassland (CRF Table 5.C.1).

The dominating use of the organic soils 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 % organic carbon fixed emission factor have been used for this area. No data has been found in the literature as they in the scientific world do not qualify as organic and hence little attention has been paid to these soils. Normally mineral soils in equilibrium will have an organic matter of 1-4 % organic carbon. Soils having higher contents are most likely developed under humid conditions with low degradation rates. Drained and managed soils having > 6 % organic carbon can therefore not be seen as being in their equilibrium state and will evidently lose carbon. We have therefore decided to allocate an emission of 50 % of what we have measured for soils > 12 % organic carbon in an attempt to account for these losses. These emissions are reported under 5B organic soils.

Table 7.21 Emission factors from organic soils, tonne C per ha per year.

	Cropland		Grassland	Uncertainty
	Annual crops and grass in rotation	Fertilised permanent grass	Permanent grass	Percent
Soils > 12 % OC	8.7	5.17	1.25	90
Soils 6-12 % OC	4.36	2.59	-	90
IPCC, Cold temperate	5.0		1.25[a]	90
IPCC, Warm temperate	10.0		2.5	90

[a] There seems to be an error in the guidelines on the emission from grassland. It is assumed that the figure should be one fourth of the emission from annual crops (5 t C per ha).

As emission factor for N_2O the IPCC 2003 default value of 8 kg N_2O-N per ha per year is used for the area with > 12 % organic carbon. This emission is reported in the agricultural sector, 4D2.

To estimate the emission from the organic soils a linear decrease in the area with organic soils between 1975 and 2010 has been assumed. All CO_2 emissions from organic soils converted from other Land Use categories to Cropland are reported under 5.B.1 and not under the respective land use conversion classes 5.B.2.1 to 5.B.2.5. The related N_2O emission is reported in the agricultural sector in CRF Table 4.Ds1.

The total emissions from the organic soils are given in Table 7.22.

Table 7.22 Emissions from cropland organic soils 1990 to 2012.

	1990	1995	2000	2005	2008	2009	2010	2011	2012
Cropland, 6-12 % OC, ha	46 270	43 045	39 820	36 595	34 660	34 015	33 370	32 734	32734
Cropland, > 12 % OC, ha	74 473	69 282	64 092	58 901	55 786	54 748	53 710	52 687	50886
Cropland, total, ha	120 743	112 327	103 912	95 496	90 446	88 763	87 080	85 420	83620
Emission, total, Gg C	-787	-733	-678	-623	-590	-579	-568	-558	-540
Emission, total, Gg CO2	-2 887	-2 686	-2 485	-2 284	-2 163	-2 123	-2 082	-2 045	-1981

Uncertainties and time series consistency

A Tier 1 uncertainty analysis has been made for part of the LULUCF sector cf. Table 7.21. The uncertainty in the activity data for the agricultural sector is very low. The highest uncertainty is associated with the emission factors. Especially the emission/sink from mineral soils and organic soils has a high influence on the overall uncertainty.

The LULUCF sector contributes to a large extend to the total estimated uncertainty. In recognition of the difficulties in analyses of uncertainty, the estimated uptake of CO_2 in the forestry sector must be treated with caution.

Table 7.21 Tier 1 uncertainty analysis for Cropland for 2012.

		1990 Emission/sink, Gg CO_2 eqv.	2012 Emission/sink, Gg CO_2 eqv.	Activity data, %	Emission factor, %	Combined uncertainty	Total uncertainty, %	Uncertainty 95 %, Gg CO_2 eqv.
5.B Cropland		4232.3	2763.9				67.2	1856.8
Living biomass	CO_2	-73.5	193.0	10	50	51.0	51.0	98.4
Dead organic matter	CO_2	2.9	12.2	10	50	51.0	51.0	6.2
Mineral soils	CO_2	1415.3	577.1	10	75	75.7	75.7	436.6
Organic soils	CO_2	2887.3	1980.7	10	90	90.6	90.6	1793.6

The time series are complete.

QA/QC and verification

A general QA/QC plan is developed for cropland. The following Points of Measures (PM) are taken into account.

- Collection and error check on in-data.
- Control of sums.
- Comparison with other data.

The area estimates for cropland and grassland in 2012 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 includes both Statistics Denmark and DCE. The total uncertainty in the major crop data is estimated by Statistics Denmark to be <2 %. Together with detailed soil maps this gives a unique possibility to estimate 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 QA of crop data is made by Statistics Denmark.

Data on newly planted and removed hedgerows are based on subsidised hedgerows and QA is carried out by the Ministry of Food, Agriculture and Fisheries, 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 to be very low because of the subsidy system.

There is an unknown uncertainty in the number of un-registered removal 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 to be very low due to the subsidised system.

As shown in Figure 7.12 and 7.13 the loss estimated by C-TOOL seems very 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.

Recalculations, including changes made in response to the review process

Recalculations have been made for emission estimates which are affected of the land use matrix due to the small changes. This has only a small influence on the emission estimate as the major sources are the mineral and the organic soils in cropland remaining cropland.

N_2O emissions from Grassland and Wetlands converted to Cropland have been included. These emissions account for 0.034 % of the total emission from cropland.

All recalculations have reduced the overall emission level from cropland with 190 Gg CO_2 in 1990 and with 180 Gg CO_2 in 2011 equivalent to app. 0.3 % of the total emission from cropland

All changes have been implemented for all years.

Planned improvements

A new version of C-TOOL has been developed. It is expected that the new version will be used in the next submission. Verification and investigation of the hedgerows will take place in 2016. A new soil sampling in the agricultural network is planned in 2018/2019.

7.4.2 Land converted to cropland (5B2)

Agriculture covers more than 63 % of the total area giving a large impact on the environment. As a consequence there are many initiatives to transfer agricultural land into natural habitats and forest, and the continuous development of infrastructure demands more land. Land converted to cropland is therefore not an issue. The largest challenge is that the farmers in one year may report that a certain field is cropland and the next year is permanent grassland where it could stay for several years before it again is ploughed and turned into annual cropland for one year. Despite or rather because of the detailed information which is available, is it impossible to have a conservative land use transition between these two land use categories. The new land use matrix showed that 49 600 hectares were converted from GL to CL from 1990 to 2012 and that 74 740 hectares were in a transition stage from CL to GL The difference between these two figures also indicate a conversion to less intensive agriculture. No conversion from the other land use categories to CL has been found.

Approaches used for representing land

The area converted from other land use to Cropland is based on remote sensing of the Danish area in 1990, 2005, 2011 and 2012 combined with data in LPIS on which crops are grown in each field.

Methodological issues

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 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. 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 but recorded as a loss of carbon in the respective category (5A2, 5C2, 5D2 and 5E2).

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 deforestated areas the average carbon stock per hectare for all deforestated areas 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 will have an instant oxidation. The actual amount depends on which type of forest is converted. Based on the measured Danish data on the nitrogen content in the litter and by using an emission factor of 1.25 % is the N_2O emission from the litter layer 4.5 kg N_2O-N per ha from broadleaves and 9.1 kg N_2O-N from conifers. This emission is reported under Cropland 5(III) for all land use conversions cases despite the land use conversion are to other land uses, see Section 7.11.

Conversion from other categories is assumed as NO as no dead organic matter is reported for these categories.

Change in carbon stock in soils

The actual amount depends on which type of land it is converted from, see Table 7.22. To reach the new equilibrium state is used a default transition period of 50 years. The default IPCC-value of 20 years seems according to Danish investigations not to be applicable for Danish conditions.

N_2O emissions for land converted to Cropland is based on the Tier 2 methodology with the default C stock as given in Table 7.15 and using a C:N value of 15 and an emission factor of 0.0125 kg N_2O-N kg N^{-1} released.

Uncertainties and time series consistency

The time series are complete.

See uncertainties and time series consistency in Section 7.4.1.

QA/QC and verification

See QA/QC and verification in Section 7.4.

Recalculation

See recalculation in Section 7.4.

Planned improvements

See planned improvements in Section 7.4.

7.5 Grassland (5C)

7.5.1 Grassland remaining grassland (5C1)

Denmark is an intensive agricultural country with many small holders and small fields where CL and GL are mixed together making it difficult to distinguish between dedicated CL and dedicated GL. According to the Danish Land Parcel Information System (LPIS) there are approx. 100 000 fields of total 200 000 ha with permanent GL in 2012 giving an average size of two ha. Some of them cannot be regarded as permanent GL and are therefore included in CL.

Grassland area

The total area with grassland has been estimated in the Land Use matrix. In 1990 the grazing grassland were 217 235 hectares and Other grassland were 183 611 hectares. In 2012 the reported area with grazing grassland were 200 413 hectares and 111 179 hectare with other grassland. The main reason for the decrease in grassland is afforestation and conversion to SE but a better classification of the area which has allowed classifying some of the areas as cropland is also important. The fluctuation is mainly due to difficulties to estimate the land use change between CL and GL. Especially from 2011 to 2012 a large reclassification from GL to CL combined with an increase in the area with grazed grassland from Statistics Denmark is observed.

Grassland definition

Grassland is 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.

Other grassland includes heath land and other areas, e.g. scrub land, which may be grazed by cattle and sheep or land which is kept open for recreational purposes. "Other Grassland" may contain bushes and other wooden plants, which do not meet the thresholds for forest. This is land where the crown cover is below 10 % and where the height at maturity do not reach 5 meter. It includes also nature protection sites, military training sites, electricity network lines etc.

Methodological issues for grassland

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 new organic soil map with an overlay of the fields were the farmers are reporting agricultural crops. Permanent grass fields receiving >63 kg N per ha per year is reported under Grassland. If the farmers are reporting permanent grassland but are using >63 kg N per ha per year it is assumed that this field is grass in rotation because of the fertilization level.

Change in carbon stock in living biomass

No changes in living biomass are assumed for GL remaining GL except for a minor conversion between "Grazing land" and "Other grassland". Because of an increased area reported as grazed grassland in 2012 compared to previous years a quite large emission from GL has been estimated in 2012 compared to previous years.

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 the default IPCC 2003 EF of 1 250 kg C per ha per year is used (there is a likely error in the guidelines as the value is given as 0.25 kg C per ha per year).

Uncertainties and time series consistency

Table 7.22 Tier 1 uncertainty analysis for Grassland for 2012.

		1990 Emission/-sink, Gg CO_2 eqv.	2012 Emission/-sink, Gg CO_2 eqv.	Activity data, %	Emission factor, %	Combined uncertainty	Total uncertainty, %	Uncertainty 95 %, Gg CO_2 eqv.
5.C.Grassland		183.6	553.5				44.6	246.8
Living biomass	CO_2	75.3	463.2	10	50	51.0	51.0	236.2
Dead organic matter	CO_2	1.6	7.0	10	50	51.0	51.0	3.6
Mineral soils	CO_2	0.2	4.5	10	75	75.7	75.7	3.4
Organic soils	CO_2	106.6	78.7	10	90	90.6	90.6	71.3

The time series are complete.

QA/QC and verification
See QA/QC and verification in Section 7.3.1.

Recalculations
The area has been recalculates because of the updated land use matrix.

Planned improvements
None.

7.5.2 Land converted to grassland (5C2)

As agriculture covers more than 63 % of the land area and in order to reduce the environmental impact there is a strategy for turning CL into GL or FL and where deforestation takes place it is often turned into GL or WE.

Approaches used for representing land
The area converted from other land use to GL is based on use of Land Parcel Information data, Natura 2000 vector layers, other vector maps and remote sensing of the Danish area in 1990, 2005, 2011 and 2012. Areas used for gravel digging are normally converted to GL because the normal procedure is removal of the topsoil, and then gravel digging. After having finished the gravel digging the topsoil is reversed to the land and the area turned into marginal grassland/recreational area. To avoid too many land conversions are gravel digging converted directly from CL to GL instead of CL-SE-GL. For an example with an open gravel pit and a restored area please see: Hedeland resort

Methodological issues

Change in carbon stock in living biomass

For land converted to "grazing land" a standard default gain value of 2 400 kg DM (dry matter) per hectare in above-ground biomass (IPCC 2006, Table 6.4) and 6 720 kg DM per hectare in below-ground biomass (IPCC 2006, Table 6.1) is used. For "Other grassland" not purely free of wooden trees/bushes it is assumed that there is a living biomass of 2 200 kg DM per ha in above ground biomass and 6 160 kg DM per ha in below ground biomass (R:S-factor of 2.8, IPCC 2003 default guideline). For conversion from DM to C a default fraction of fraction of 0.5 kg C per kg DM is used (Table 7.10).

For conversion from GL to other land use categories the same value is used, but recorded as a loss of carbon in the respective category (5A2, 5B2, 5D2 and 5E2).

Change in carbon stock in dead organic matter

When forest land is converted to GL it is assumed that all dead organic matter will be cleared and instant oxidation is taking place.

Conversion from other categories is assumed as NA as no dead organic matter is reported for this category.

Change in carbon stock in soils

The actual amount depends on which type of land it is converted from, see Table 7.15. To reach the new equilibrium state a default transition period of 50 years is used. The default IPCC-value of 20 years seems according to Danish investigations not to be applicable for Danish conditions.

Uncertainties and time series consistency

See Section 7.5.1.

7.6 Wetlands (5D)

Wetland includes:

- unmanaged fully water covered wetlands (lakes and rivers)
- unmanaged partly water covered wetlands (fens and bogs)
- managed water reservoirs (currently not occurring in Denmark)
- managed drained land for peat extraction
- managed partly water covered wetlands (re-established wetlands on primarily former cropland and grassland).

In the beginning of 1990 the total area with wetland has been estimated to 128 867 hectares. By end of 2012 this area has increased to 151 458 hectares. Of this was 58 538 ha lakes and rivers in 1990 increasing to 64 092 ha by end of 2012 inside the > 7000 km long coastline.

7.6.1 Wetlands remaining wetlands – peat extraction (5D1)

The new land use matrix has provided updated figures on the area with partly water covered and fully water covered wetland areas. Partly water covered areas are moors and other areas with raised water table. Fully water covered areas are lakes and rivers.

Wetland area

In the beginning of 1990 the total area with partly covered WE remaining WE has been estimated to 70 509 hectares and the area with lakes to 58 358 hectares. By end of 2012 the area with partly water covered WE remaining WE has decreased slightly to 69 853 hectares. The estimated area with lakes has been reduced with one hectar The total area with peat extraction is about 300 hectares open surface (Lykke Larsen, Pindstrup Mosebrug, personal comm.). Based on aerial photos it is estimated that 1 596 hectares are land connected to the peat extraction areas.

Approaches used for representing land areas

The area for wetlands remaining wetlands is primarily based on data from 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 four excavation sites (Figure 7.17). The actual three locations are Fuglsø mose on Djursland, Lille Vildmose and Store Vildmose – both in Northern Jutland. All locations are nutrient poor raised bogs.

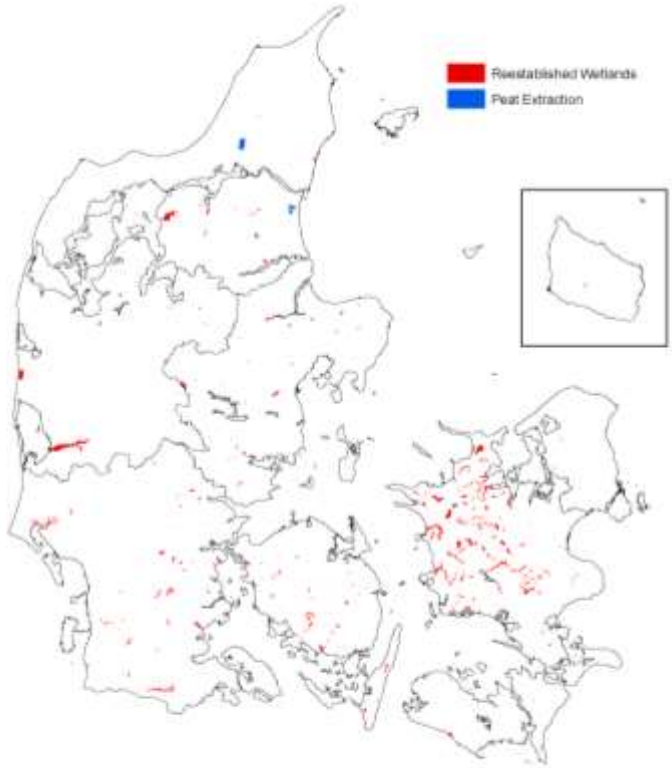

Figure 7.17 Areas with established wetlands, increased water tables and peat extraction in 2008.

Methodological issues for partly water covered wetlands

No changes in the carbon stocks and emissions are reported.

Methodological issues for peat extraction areas

Change in carbon stock in living biomass

No changes in living biomass occurring on the area are reported.

Change in carbon stock in dead organic matter

Dead organic matter is not occurring.

Change in carbon stock in soils

The surface emission from the open peat extraction area is calculated according to Tier 1 (IPCC, 2003) for nutrient poor areas with an emission factor of 0.5 tonnes C per hectare land with peat extraction per year.

The amount of excavated peat (m^3 per year) is for each individual extraction site reported to and published by Statistics Denmark (www.dst.dk, Table RST). The total amount of peat excavated has since 1990 been reduced from 399 000 m^3 to 152 000 m^3 in 2012. This is a >50 % reduction compared to the 10 years ago. For conversion to carbon a density factor of 200 kg per m^3 is used (personal comm. with Pindstrup Mosebrug, www.pindstrup.dk who is responsible for the majority of the extraction sites). Furthermore, a DM content of 0.5, an ash content of 0.02 (www.pdir.dk) and a carbon content of 0.58 kg C per kg OM are applied.

For other areas in WE remaining WE is no changes reported.

Nitrous oxide emission

The nitrous oxide emission from peat land extraction areas is estimated from the total N-turnover multiplied with the default IPCC emission factor of 1.25 %. The C:N-ration in the peat is estimated to 36 in an analysis from the Danish Plant Directorate (www.pdir.dk). Hence the N_2O emission is estimated to 0.546 kg N_2O per tonnes C. Only nitrogen in the degradation of the surface is accounted for in the inventory. N_2O from N in the excavated peat is not estimated.

Uncertainties and time series consistency

Table 7.23 Tier 1 uncertainty analysis for WE remaining WEs and re-established WE for 2012.

		1990 Emission/-sink, Gg CO_2 eqv.	2012 Emission/-sink, Gg CO_2 eqv.	Activity data, %	Emission factor, %	Combined uncertainty	Total uncertainty, %	Uncertainty 95 % Gg CO_2 eqv.
5.D Wetlands		87.9	2.4				88.1	2.1
Living biomass	CO_2	2.6	-0.2	10	50	51.0	51.0	0.1
Dead organic matter	CO_2	0.5	0.0	10	100	100.5	0	0
Soils	CO_2	84.7	2.5	10	100	100.5	100.5	2.5
Land for peat extraction	N_2O	0.1	0.1	10	100	100.5	100.5	0.1

The time series are complete.

QA/QC and verification

The peat excavation area has been verified with aerial photos and the amount of excavated peat is made by Statistics Denmark.

Recalculation

None.

Category-specific planned improvements

No improvements are planned.

7.6.2 Land converted to wetland (5D2)

In order to restore nature and reduce the environmental impact Denmark has actively re-established WE (Figure 7.17). The size of each restoration project range from less than 1 ha up to 2 500 ha. The benefit of the restoration programme is more nature but also a reduction in leaching of nitrogen into lakes, rivers and coastal water. The establishment of WE takes place either as large areas turned into lakes or low laying fens.

Since 1990 23 248 ha have been established. These are primarily on CL and GL. Of this is 5 734 hectares converted into new lakes. A major part is restored as a part of the Danish Action Plan for the Aquatic Environment part two (VMP II, running from 1997 to 2006) where land was bought for this purpose but also 2 145 hectares of forest has been converted to partly water covered wetlands. This has primarily taken place in the state owned forest. It is accounted for that 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 therefore currently reported as NO.

Approaches used for representing land areas

Geographical vector layers are available for almost all established WE.

Methodological issues

Change in carbon stock in living biomass

For land converted to partly covered wetland a standard default gain value of 4 000 kg DM (dry matter) per hectare in above-ground biomass and 1 200 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.

For conversion from wetland to other land use categories the same value but recorded as a loss of carbon in the respective category (5A2, 5B2, 5C2 and 5E2) are used.

Change in carbon stock in dead organic matter

When forest land is converted to wetland it is assumed that all dead organic matter will be cleared with instant oxidation.

Conversion from other categories is assumed as NA as no dead organic matter is reported for these categories.

Change in carbon stock in soils

A default carbon sequestration of 0.5 tonnes C per hectare is assumed for land converted to partly water covered WE.

Nitrous oxide emission

No estimates for the N_2O emission from re-established wetlands have been made.

Methane emission

CH_4 emissions are not estimated due to lack of methodology.

Uncertainties and time series consistency

The time series are complete.

QA/QC and verification

No verification has been made yet.

Recalculation
A recalculation has been made due to new area data on the established WE has been obtained.

Planned improvements
None.

7.7 Settlements (5E)

The annual changes in carbon stock in settlements are assumed to be negligible, and because no estimates have been made, most changes are reported as NA in the CRF Table 5.E. For reporting purposes for land use conversions a default biomass in low buildings, grave yards is established.

The total area with SE has been estimated to 485 543 hectares in 1990 increasing to 516 712 hectares by end of 2012 or to approx. 11 % of the total Danish area.

7.7.1 Settlements remaining settlement (5E1)

Settlement area
The total area with SE has been estimated to 465 779 hectares in 1990 increasing to 491 286 hectares in 2012 or approx. 12 % of the total Danish area. The area is estimated from the cadastral maps and the date where the land parcel was included in the cadastral map, e.g. a change from agriculture to a permanent residence or a road.

Settlement definition
Settlements are defined as all areas with infrastructures, roads, grave yards, sport facilities etc.

Methodological issues
Change in carbon stock in living biomass
No changes in carbon stocks are reported for SE remaining SE.

Change in carbon stock in dead organic matter
No changes in carbon stocks are reported for SE remaining SE.

Change in carbon stock in soils
No changes in carbon stock in soils are assumed.

Uncertainties and time series consistency

Table 7.24 Tier 1 uncertainty analysis for Settlements for 2012.

		1990 Emission/-sink, Gg CO_2 eqv.	2012 Emission/-sink, Gg CO_2 eqv.	Activity data, %	Emission factor, %	Combined uncertainty	Total uncertainty, %	Uncertainty 95 %, Gg CO_2 eqv.
5.E Settlements		12.9	90.8				37.0	33.6
Living biomass	CO_2	11.4	56.0	10	50	51.0	51.0	28.5
Dead organic matter	CO_2	0.6	0.0	10	50	51.0	51.0	0.0
Soils	CO_2	1.0	34.8	10	50	51.0	51.0	17.7

The time series are complete.

QA/QC and verification

No QA/QC has been performed.

Recalculations

A recalculation of the area has been made due to new land use matrix, which slightly has increased the SE area.

Planned improvements

No improvements are planned.

7.7.2 Land converted to settlement (5E2)

Land converted to SE is mostly taking place around the big cities and primarily on cropland and grassland.

Settlement area

The area converted to SE is based on cadastral maps and other digital maps. For simplicity for the years 1990 to 2012 is only used three occasions 1990, 2005 and 2012 with a linear increase in the area in the years between. In future will annual updates take place so that the increase from 2012 to 2013 will be all new houses and roads included in the cadastral map from 31.12. 2012 to 31.12.2013

Methodological issues

Change in carbon stock in living biomass

For land converted to single-family houses a standard default gain value of 2 200 kg DM (dry matter) per hectare in above-ground biomass and 2 200 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.

For conversion from settlements to other land use categories the same value is used, but recorded as a loss of carbon in the respective category (5A2, 5B2, 5C2 and 5D2).

Change in carbon stock in dead organic matter

When forest land is converted to settlements it is assumed that all dead organic matter will be cleared. Conversion from other categories is assumed as NA as no dead organic matter is reported for these categories.

The N_2O emission is estimated from an instant oxidation of the litter layer.

Change in carbon stock in soils

A default value of 120 tonnes carbon per ha is assumed to be areas Settlements (Table 7.15). For all areas converted from other land use to Settlement is assumed that equilibrium state will be reached after 100 years from the carbon stock in the previous land use category. This is agreed with the UNFCCCs review team during the review in 2012.

Uncertainties and time series consistency

See uncertainties and time series consistency in Section 7.7.1

The time series are complete.

QA/QC and verification

No QA/QC has been performed.

Category-specific recalculations

The review team in 2011 argued that carbon losses due to deforestation into settlements should be included in the inventory despite there is no IPCC guidelines for this. During the review it was agreed on that an appropriate equilibrium carbon stock in Settlements could be 120 tonnes of carbon per ha (0-100 cm) which is approximately 20-25 % lower than found in FL, CL and GL.

Planned improvements

No improvements are planned.

7.8 Other Land

No permanent snow cover exists in Denmark and only a very small insignificant area with rocks and cliffs. OL is restricted to beaches and sand dunes and estimated to 26 433 hectares.

No land use changes from 5A, 5B, 5C, 5D and 5E is reported.

7.9 Direct N_2O emissions from N fertilization of Forest Land and Other land use – 5(I)

Only a very small amount of nitrogen fertilisers are used in the Danish forests and primarily to Christmas trees. All emissions are reported under Agriculture CRF Table 4.Ds1 since there is only one common national statistics for N fertilization in agriculture and forestry.

7.10 Non-CO_2 emissions from drainage of forest soils and wetlands – 5(II)

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 (http://www.skovognatur.dk/Ud/Beskrivelser/Hovedstaden/Gribskov/VandetTilbage.htm). During the recent years, there has been an effort to restore wetland habitat 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.

Very few data exist for N_2O emissions in Danish forests. A national project and EU projects have provided data for hydrological gradients in mini-catchments in an old-growth forest and an afforestation area (Christiansen et al., in prep.) and data for one intensively studied beech forest plot (Skiba et al., 2009). For general application at the national level, tier 1 methods will be applied based on default emission factors (IPCC GPG). Emission factors will be compared with the few examples of emission factors data from national projects.

7.10.1 Methodological issues

Equation 3a.2.1 of IPCC GPG was used for estimation of direct N_2O emissions from drained forest soils (tier 1).

Default emission factors (IPCC GPG, Table 3a.2.1) were used for calculation of N_2O emissions. Danish organic soils were considered to be "Nutrient Rich" based on the general presence of fens (minerotrophic peat) and the relatively high N deposition to Danish forests. Rewetted forest soils were assumed to have an N_2O emission corresponding to the natural level and emissions were therefore by default set to zero in accordance with IPCC GPG.

7.10.2 Areas of drained forest soils

Based on expert judgment, the area of drained forest soils were 65 % of mineral forest soils and 75 % of organic forest soils in 1990. It is further judged that the amount of drained forest soils have decreased in the period until 2008 resulting in an area of drained forest soils with 55 % of mineral forest soils and 50 % of organic forest soils. Organic soils constituted 5 % of the forest area based on information on presence of peat from the NFI. A more detailed analysis of forest soils including a mapping is under preparation. A detailed analysis of the re-measurements of the NFI since 2002 will give some indications of the changes in that period, but no data exists prior to 2002. The combined analysis will be included in the next reporting.

7.10.3 Emissions of N_2O from drained forest soils

Estimates of N_2O emissions (Gg N_2O per year) from drained forest soils are based on the IPCC 2003 values. This means that for mineral soils is 0.06 kg N_2O-N per ha per year and for organic soils 0.6 kg N_2O-N per ha per year.

Emission factors are generally in reasonable accordance with those obtained in national projects. In mini-catchments Christiansen et al. (in prep.) found average annual emissions of 0.56±1.1 kg N_2O-N per ha per year for an afforested stand (30 years) and of 0.78±4.2 kg N_2O-N per ha per year for an old-growth forest. Both sites included hydrological gradients from wet/moist to well-drained conditions. For a well-drained Danish beech forest site, Skiba et al. (2009) reported average annual emissions of 0.45±0.48 kg N_2O-N per ha per year.

7.11 N_2O emissions from disturbance associated with land-use conversion to cropland – 5(III)

The main land-use conversion involving deforestation is the conversion from forest to cropland and grassland and a minor deforestation to SE. A major part of the deforestation in 2012 is conversion of christmas trees plantations to cropland and grassland.

This land-use change is expected to be a source for N_2O emissions due to the decomposition of forest floors and corresponding increased mineralization of N. It is assumed that forest floors are completely decomposed during the conversion. Emissions of N_2O are based on default emission factors (IPCC, 2003).

7.11.1 Methodological issues

For all deforestated areas it is assumed that the forest floor disappears regardless if the land use conversion is into CL, GL, WE or SE. This is in contradiction to the guidelines and CRF Table 5(III), which is only related to disturbance associated with land-use conversion to CL.

The average nitrogen content of forest floors based on the repeated soil inventory was used to estimate the N mineralized for conifers and broadleaves, respectively. A proportion of 1.25 % of the N stock mineralized is assumed to be emitted as N_2O-N.

7.11.2 Emissions of N_2O from deforestation and land-use conversion

The average N content of broadleaf and conifer forest floors for Danish forest plots are given in Table 7.25 together with the estimated N fraction emitted as N_2O. According to IPCC (2003), a default fraction of 1.25 % is assumed emitted as N_2O-N during mineralization of the total N content following conversion.

Table 7.25 Total N content of forest floors in Denmark from the systematic grid "Agricultural Network". The total N content is used for estimation of the amount of N (1.25%) emitted as N_2O during mineralization of the total forest floor N content following land-use change from forest to grassland.

Tree species	Number of plots	Mean N content (kg ha^{-1})	Standard dev. (kg ha^{-1})	Min N content (kg ha^{-1})	Max N content (kg ha^{-1})	N_2O-N, (kg ha^{-1})
Broadleaves	48	359	310	42	1472	4.5
Conifers	60	728	637	20	3447	9.1

In 1990, emissions of N_2O from deforestation were estimated at 0.0098 Gg N_2O for mineral soils and 0.0005 Gg N_2O for organic soils. In 2012 the figures were 0.0019 and 0.0001 Gg N_2O for mineral and organic soils, respectively.

For land use conversion from GL and WE to CL is used the default methodology from IPCC (IPCC 2003) (Eq. 3.3.13 – 3.3.15). The used average carbon stocks are given in Table 7.15. The default methodology assume that an N_2O emission only occur if there is a decrease in the carbon stock the methodology will only estimate a N_2O emission if the land converted from has a higher carbon stock than the land converted to. As the carbon stock in Danish GL soil has been estimated to a lower value than in cropland soils the default methodology will not estimate a N_2O emission for these occasions but estimate a N_2O emission when converted from CL to GL.

7.12 CO_2 emissions from agricultural lime application – 5(IV)

Liming of agricultural soils has taken place for many years. Only a very little amount of lime is applied in forests (<0.5 %) and on permanent grassland. Therefore all liming is included in the inventory under cropland (CRF Table 5(IV)).

The Danish Agricultural Advisory Centre (DAAC) has published the lime consumption for agricultural purposes annually since 1960 (Table 7.26). DAAC are collecting data from all producers and importers. By legislation all producers and importers are obligated to have their products analysed for acid neutralisation content. The analysis is carried out by the Danish AgriFish Agency and published annually (PDIR 2004). The published data from DAAC are corrected for acid neutralisation contents for each product and thus given in pure $CaCO_3$. For that reason there is no need to correct for inert materials and differ between lime and dolomite as made in the guidelines, as this has already been included in the background data. The data from DAAC includes all different products used in agriculture, including e.g. $CaCO_3$ from the sugar refineries.

The amount of lime used in private gardens has been estimated from the main supplier to private gardens. According to the company (Kongerslev Havekalk A/S, pers. comm.) they are responsible for 80 % of the sale to private gardens. Their sales figures have been used to estimate the total consumption in private gardens. Furthermore, the figures are corrected for acid neutralisation capacity according to the data from the Danish AgriFish Agency. This gives an approximate amount of 2 300 tonnes $CaCO_3$ per year in private gardens. This figure has been used for all years.

A very small consumption of CAN (Calcium Ammonium Nitrate) and Urea is taking place in Denmark. The amount of CO_2 included in these two fertilisers is included in the lime consumption. Data is taken from the annual fertiliser statistics published by Statistics Denmark.

The amount of lime used for agricultural purposes has declined with 70 % since 1990. From 2000 to 2012 the consumption has been very stable around 400-500 Gg $CaCO_3$. The sold amount in 2012 was 426 Gg $CaCO_3$. 500 Gg is expected to be the lowest consumption needed to maintain appropriate pH values in the Danish agricultural soils at the moment. The main reason for the reduced lime consumption is a decreased need for acid neutralisation due to less SO_X deposition in Denmark (which also can be seen in the Norwegian inventory) and a reduced consumption of fertilisers containing ammonium. The inter-annual variation is primarily due to weather conditions (if it is possible to drive in the fields) and the economy in agriculture.

The amount of carbon is calculated according to the guidelines where the carbon content is 12/100 of the $CaCO_3$. It is assumed that all carbon disappear as CO_2 the same year as the lime is applied.

Table 7.26 Lime and CAN application to cropland and grassland and in forests, 1990-2012.

Greenhouse gas source and sink categories	1990	1995	2000	2005	2008	2009	2010	2011	2012
Agriculture, Gg $_{CaCO3}$	1283	1125	590	497	518	410	345	365	426
Private gardens, Gg $CaCO_3$	2,3	2,3	2,3	2,3	2,3	2,3	2,3	2,3	2.3
CAN and Urea	131,4	149,9	89,9	4,3	2,9	8,3	9,0	9,0	9.0
Total, Gg $_{CaCO3}$	1417	1277	682	504	523	421	356	376	437
Total, Gg C pr yr	623	562	300	221	230	185	157	165	192

Table 7.27 Tier 1 uncertainty analysis for Liming for 2012.

		1990 Emission/sink, Gg CO_2 eqv.	2012 Emission/sink, Gg CO_2 eqv.	Activity data, %	Emission factor, %	Combined uncertainty	Total uncertainty, %	Uncertainty 95 %, Gg CO_2 eqv.
5(IV) Liming	CO_2	622.9	192.3	5	50	50.2	50.2	96.6

The time series is complete.

The collected data is assumed to be very reliable. It is assumed that the uncertainty is in the range of 5 %. The emission factor may be overestimated due to expected leaching of CO_3^{--}, however no data is available on this issue.

7.13 Biomass burning – 5(V)

Burning of forest is prohibited as well as burning of wooden debris from hedgerows are very seldom. Only controlled burning of heathland of approximately 300 hectares per year is taking place. However in 2012 the area with controlled burning of heathland increased to 709 hectares. Due to the humid climate wildfires in the forest are very seldom and normally 0-10 hectares per year.

Data on wild and controlled fires has been collected by the Danish Nature Agency from the forest departments for the period 1990 to 2012. The emission factors are taken from the IPCC 2006 guidelines. As the burned forest is located on poor sandy soils are the default standing carbon stock assumed to be 150 Cubic meter per hectare, which is slightly lower than the average standing carbon stock in the Danish forests. The fraction burned for forest is taken from the guidelines whereas for heat land a factor of 0.33 is used. It is based on expert judgment made by the Danish Nature Agency who is responsible from for the controlled burning.

Table 7.27 Burned areas 1990 –2012, ha per year.

	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012
Forestland area burned	150	1	0	0	6	0	0	0	0	0	0
Heathland area burned	47	53	122	638	202	270	282	296	359	377	709
Total burned area	197	54	122	638	208	270	282	296	359	377	709

Table 7.28 Tier 1 uncertainty analysis for Biomass burning for 2012.

		1990 Emission/sink, Gg CO_2 eqv.	2012 Emission/sink, Gg CO_2 eqv.	Activity data, %	Emission factor, %	Combined uncertainty	Total uncertainty, %	Uncertainty 95 %, Gg CO_2 eqv.
5(V) Biomass Burning	CH_4	0.5	0.0	50	30	58.3	58.3	0.014
5(V) Biomass Burning	N_2O	0.4	0.0	50	30	58.3	58.3	0.020

7.14 Uncertainty, Tier 2 analysis

A first approach has been done to run a Tier 2 Monte Carlo uncertainty simulation for the LULUCF sector. The results are given in Table 7.29 and Table 7.30.

Table 7.29 shows the estimated median emission for the major sources in the LULUCF sector. The organic agricultural soil shows the highest uncertainty in 2012 and Forest remaining Forest the 2nd highest.

In the overall uncertainty estimates for Denmark is only included Tier 1 uncertainty estimates. The Tier 2 uncertainty estimates shown below are only for the LULUCF sector in 2012.

Table 7.29 Detailed uncertainty tier 2 estimates for the LULUCF sector in 2012, Gg CO_2-eqv.

Category	Emissions, Median	Below 2.5%	Above 97.5%	Plus 95%	Minus 95%
5.	-739.30	-2227.59	2002.49	-371%	201%
5.B.1 Cropland, Organic soils	1973.7	848.6	4643.3	-361%	152%
5.A.1 Forest remaining forest	-4489.2	-5216.1	-3867.5	-84%	98%
5.B.1 Cropland, Mineral soils	578.8	283.8	1186.7	-82%	40%
5.C.1 Grassland, Living biomass	346.8	211.0	563.2	-29%	18%
5.B.1 Cropland, Living biomass	271.7	167.8	443.8	-23%	14%
5(IV) Cropland Limestone	192.3	119.4	314.1	-16%	10%
5.C.2 Land converted to grassland	127.4	77.8	207.4	-11%	7%
5.C.1 Grassland, Organic soils	78.8	38.5	160.8	-11%	5%
5.D.1 Wetlands, Soils	34.4	13.6	88.9	-7%	3%
5.B.2 Land converted to cropland	-70.8	-115.4	-42.6	-4%	6%
5.D.2 Land converted to Wetlands	-32.6	-81.5	-12.8	-3%	7%
5.E.2 Settlements, Living biomass	55.8	34.2	91.6	-5%	3%
5.E.2 Settlements, Soils	34.8	21.6	56.5	-3%	2%
5.A.2 Land converted to forest	37.9	31.9	44.9	-1%	1%
5(II) Forest Land.	12.0	8.9	16.3	-1%	0%
5(III) Disturbance, Land converted to cropland	1.0	0.5	2.1	0%	0%
5(II) Wetlands	0.1	0.1	0.3	0%	0%
5.E.2 Settlements, Dead organic matter	0.0	0.0	0.1	0%	0%
5(V) Biomass Burning	0.1	0.0	0.1	0%	0%

The estimated trend uncertainty is shown in Table 7.30.

Table 7.30 Danish uncertainty estimates for the LULUCF sector, tier 2 approach, 2012.

	Uncertainty of total emission, %		Trend 1990-2012, %	Uncertainty of trend, %-age points	
CO_2	201.3%	-370.9%	114.2%	28.5%	-20.8%

In the next submission an update will take place of the uncertainty factors and the Tier 2 uncertainty estimates in the LULUCF sector will be included in the overall Danish inventory.

7.15 References

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8 Waste (CRF sector 6)

8.1 Overview of the sector

The waste sector consists of the CRF source categories: 6.A Solid Waste Disposal on Land, 6.B. Wastewater Handling, 6.C. Waste Incineration and 6.D. Waste Other. The data presented in Chapter 8 relate to Denmark only, whereas information for Greenland is included in Chapter 16 and for the Faroe Islands in Annex 8.

For the CRF category 6.A. Solid Waste Disposal on Land, the CH_4 emissions reported in this chapter are a result of calculations in continuation of previously used and reported methodology. Changes in the time trend for this year´s submission are due to re-allocation and verification of reported waste types according to the harmonised European waste codes (Statutory Order no. 1309, 18/12/2012). The new harmonised European waste code data collection system and the old ISAG system result in 18 new waste types and associated model input parameters as described in Chapter 8.2 and Thomsen & Hjelgaard (2014).

For the CRF category 6.B. Wastewater Handling, the emissions reported in this chapter are a result of calculations in continuation of previously used and reported methodology. Changes in the time trend for this year's submission are below 1% and due to updated activity data on the biological oxygen demand and a change in the methane correction factor, MCF, from 1 to 0.8 according to the 2006 IPCC guidelines (IPCC, 2009) and in agreement with available plant level data on methane production, flaring and venting as presented in Chapter 8.5.5. It has not been possible to obtain completeness in plant specific data regarding the methane production, flaring and venting. Status of such review are presented in Chapter 8.3 and in Thomsen & Hoffmann, 2014 (see Chapter 8.9).

For the CRF source category 6.C. Waste Incineration, the main emissions are included in the energy sector since all incineration of municipal, industrial, medical and hazardous waste in Denmark is done with energy recovery. The Waste Incineration category includes CH_4 and N_2O emissions from the minor sources of cremation of corpses and carcasses.

The source sector 6.D. Waste Other covers emissions from combustion of biogas in biogas production plants (mentioned as Gasification of biogas in the CRF tables) for the years 1994-2005 where these emissions existed. This activity is not occurring in 2006 - 2012. The Waste Other category also includes CO_2, CH_4 and N_2O emissions from the sources: accidental building fires, accidental vehicle fires and compost production.

Chapter 8.7 and 8.8 presents improved QA/QC procedures and recalculations reflecting the recommended improvements of the 2011 centralised review.

In Table 8.1.1, 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 3G, Table 3G-1.1.

Table 8.1.1 Emissions for the waste sector, Gg CO_2 equivalents.

			1990	1995	2000	2005	2010	2011	2012
6 A.	Solid Waste Disposal on Land	CH_4	1366	1209	1047	862	720	731	698
6 B.	Wastewater Handling	CH_4	65	68	73	72	74	75	74
6 B.	Wastewater Handling	N_2O	105	108	90	84	76	79	73
6 C.	Waste Incineration	CH_4	0.01	0.01	0.01	0.01	0.02	0.01	0.01
6 C.	Waste Incineration	N_2O	0.20	0.21	0.22	0.24	0.29	0.27	0.27
6 D.	Waste Other	CO_2	18	20	18	18	18	18	16
6 D.	Waste Other	CH_4	31	41	70	73	88	90	92
6 D.	Waste Other	N_2O	13	23	160	62	110	118	127
6.	Waste	Total	1598	1469	1459	1173	1087	1113	1080

6.A. Solid Waste Disposal on Land is the dominant source in the waste sector with contributions in the time series varying from 85 % (1990) to 65 % (2012) of the total emission, given in CO_2 equivalents. Throughout the time series, the emissions are decreasing due to a reduction in the amount of waste deposited. Comparing 2012 with 1990, the emissions from Solid Waste Disposal Sites have decreased with 49%.

6.B. Wastewater Handling. For this source, N_2O contributes the most to the sectorial total, varying between contributions of 5 % (2003) and 8 % (2008). In 2012 the contribution is 7 %. CH_4 from this source contributes with between 4 % (1990) and 7 % (2012) of the sectorial total. The CH_4 emissions increase steadily over the time series. Comparing 2012 with 1990, the emissions from Wastewater Handling have decreased with 14 %.

6.C. Waste Incineration. This source contributes with CH_4 and N_2O emissions from human and animal cremations. The contribution to CO_2 equivalent emissions from the sum of CH_4 and N_2O is for the time series 1990-2012 between 0.01 % (1991) and 0.03 % (2010). The trend for the total emissions 1990 - 2012 from this source is increasing; compared to 1990 the 2012 and 2010 emissions have increased with 38 % and 49 % respectively. This increase is almost entirely caused by the increase in animal cremation as this activity has risen with 825 % from 1990 to 2012.

6.D. Waste Other. This source contributes with CO_2, CH_4 and N_2O emissions from accidental fires and compost production. The contribution to the total emissions from the waste sector varies from 4 % (1990) to 22 % (2002). Throughout the time series, emissions from Waste Other are increasing; from 1990 to 2012 this category increases with 285 %. The great increase in emissions from 6.D is almost entirely caused by the increasing use of composting at municipal treatment sites.

As a result for the entire waste sector, the sectorial total emission in units of CO_2 equivalents (provided in Table 8.1.1) is decreasing throughout the time series; the emission in 2012 has decreased with 32 % compared to 1990.

Table 8.1.2 specifies the origin and type of the methods and emission factors applied in the Danish inventory.

Table 8.1.2 Reported emissions, calculated methods and type of emissions factors for the subcategory waste handling in the Danish inventory. (CS=country specific, D=default, OTH=other).

CRF	Source	Emissions reported	Method	Emission factor
6 A.	Solid Waste Disposal on land	CH_4	Tier 2,CS	CS,D
6 B.	Wastewater Handling	CH_4	CS	CS
		N_2O	CS	CS
6 C.	Waste Incineration	CH_4	Tier 1	Tier 1/CS
		N_2O	Tier 1	Tier 1/CS
6 D.	Waste Other	CO_2	Tier 1, CS	CS, OTH
		CH_4	Tier 1, CS	CS, OTH
		N_2O	Tier 1, CS	CS, OTH

8.1.1 Key category identification

In the key category analysis (KCA) the waste emissions are divided into fourteen categories. In the Tier 1 and Tier 2 KCA, three of the fourteen source categories are identified as key categories in 2012 (Table 8.1.3). The Tier 1 key source identification is based on ranking of absolute quantitative emission, while the Tier 2 KCA takes into account the uncertainties in the calculated emissions, cf. Chapter 1.5).

Off the fourteen categories, Solid Waste Disposal on Land and Composting are the only categories identified as key sources for level. According to the level assessment for both Tier 1 and Tier 2 KCAs Solid Waste Disposal on Land is a key source for level for both year 1990 and 2012. Solid Waste Disposal on Land and Composting are also key category contributions to the trend of the national total of greenhouse gases, calculated in CO_2 equivalents, from 1990 to 2012 for both Tier 1 and Tier 2 KCAs.

Identified key categories within the waste sector are presented in Table 8.1.3. For further information on the KCA level and trend assessments please refer to Chapter 1.5 and Annex 1.

Table 8.1.3 Key category identification Tier1 and Tier 2 from the waste sector 1990 and 2012.

		Tier 1			Tier 2		
		1990	2012	1990-2012	1990	2012	1990-2012
6 A. Solid Waste Disposal on Land	CH_4	Level	Level	Trend	Level	Level	Trend
6 B. Wastewater Handling, direct	CH_4	-	-	-	-	-	-
	N_2O	-	-	-	-	-	-
6 B. Wastewater Handling, indirect	N_2O	-	-	-	-	-	-
6 C. Incineration of corpses	CH_4	-	-	-	-	-	-
	N_2O	-	-	-	-	-	-
6 C. Incineration of carcasses	CH_4	-	-	-	-	-	-
	N_2O	-	-	-	-	-	-
6 D. Accidental fires, buildings	CO_2	-	-	-	-	-	-
	CH_4	-	-	-	-	-	-
6 D. Accidental fires, vehicles	CO_2	-	-	-	-	-	-
	CH_4	-	-	-	-	-	-
6 D. Compost production	CH_4	-	-	-	-	Level	Trend
	N_2O	-	-	Trend	-	Level	Trend

As may be observed from Table 8.1.3 category 6B. and 6C. are divided into two sub-categories, whereas category 6D is divided into three sub-categories. Sub-categories are defined according to inventory reporting and emission models used and the outcome of the KCA influenced by the level of disaggregation into sub-categories.

8.2 Solid waste disposal on land (CRF source category 6A)

For many years, only managed waste disposal sites have existed in Denmark. Unmanaged and illegal disposal of waste is considered to play a negligible role in the context of this category. The amount of deposited waste has decreased markedly throughout the time series.

In 2010, the Danish EPA implemented to the new Waste Data System to collect waste statistics. The design of the Waste Data System is considerably different from the ISAG Waste Information System it succeeds. Unlike the previous ISAG system, all waste operators, and not only the plants receiving waste, must now report to the Waste Data System. The fact that waste operators must report to the system makes it possible to collect more accurate data about what industry from which the waste originates. However, the 2010 and 2011 datasets are characterised by the fact that waste operators and waste reception facilities have had to get used to reporting to the system, and even though the Danish EPA has conducted quality assurance of the figures, there is still some uncertainty in the data (The Danish Government, 2013).

The general development for solid waste at disposal sites is a result of action plans by the Danish government called the "Action plan for Waste and Recycling 1993-1997" and "Waste 21 1998-2004" (The 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. Further, in 1996 a municipal obligation to assign combustible waste to incineration was introduced. In 2003, the Danish Government set up targets for the year 2008 for waste handling in a "Waste Strategy 2005-2008" report (The Danish Government, 2003). According to this strategy, the target for 2008 is a maximum of 9 % of the total waste to be deposited. In the waste statistics report for the year 2004, data shows that this target was met, since 7.7 % of total waste was deposited in 2004 (DEPA, 2006a). Waste Strategy 2009-12, part I (The Danish Government, 2009) was the sixth waste management plan or strategy adopted by the successive governments dating back to 1986. Waste Strategy 2009-12 set up targets for 2012 according to which a maximum of 6 % of the total waste produced is to be deposited (The Danish Government, 2009). In 2009, it appears that this target has already been met as only 5.6 % of all produced waste was deposited. Data on this level of information from the ISAG database/waste statistics (1994-2009) is presented in Annex 3G, Table 3G-2.1.

Waste Strategy 2009-2012, Part II includes goals of continued decrease in the amount of waste being deposited in Denmark and an increase in reuse, recycling and recovery (Danish Ministry of Environment, 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 (DEPA, 2010c). The same waste classes are defined in the new Statutory Order for Landfill (Statutory Order no. 719, 24/06/2011), which refers to the Statutory Order for Waste (Statutory Order no. 1309, 18/12/2012) regarding characterisation of the waste according to the European waste code system; the EWC-code list included in Annex 2 of the statutory Order no. 1319. The New Danish Waste Reporting System (www.mst.dk) is based on the EWC-code system, which forms the basis for the estimation of yearly deposited 18 waste types presented in this year´s NIR; details are further described in this chapter, in Annex 3G and in Thomsen and Hjelgaard, 2014).

8.2.1 Source category description

From 1994 to 2005, the number of registered solid waste disposal sites (SWDSs) landfill sites in Denmark has decreased from 176 to 134 (DEPA, 2006b, 2013). Of the closed and still active solid waste disposal sites (SWDS) existing today, 81 of the 134 was closed in 2003, leaving 53 still active SWDS reported to the new waste data system in 2012. Methane collections from 26 of these SWDS are reported to be used at energy-producing installations and 29 are included in the Energy statistics (DEPA, 2003a; Interministerial report, 2007; DEA, 2013a and b) (cf. chapter 8.9).

A quantitative overview of the source category are provided in Table 8.2.1 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 estimate has decreased with 49 % from 1990 to 2012.

A full time series (1990-2012) of these data are shown in Annex 3G, Table 3G-2.2. The amount of waste and the resulting CH_4 emission can also be found in the CRF tables submitted (http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/6598.php).

Table 8.2.1 Annual amounts of deposited waste, generated methane, recovered methane collected for biogas production, oxidised methane in the top layer and resulting net emission for the Danish SWDS.

Year	Landfilled waste	Gross methane emission	Recovered methane	Methane oxidised in the top layers	Net methane emission	
	Gg	Gg CH_4	Gg CH_4	Gg CH_4	Gg CH_4	Gg CO_2 eq
1990	3190	72.8	0.5	7.2	65.0	1366
1995	1969	71.6	7.6	5.8	57.6	1209
2000	1489	66.7	11.3	5.5	49.9	1047
2005	983	55.6	9.9	4.6	41.1	862
2006	1786	44.5	6.4	3.8	34.3	720
2007	2439	42.7	4.0	3.9	34.8	731
2008	1107	41.2	4.3	3.7	33.2	698
2009	3190	72.8	0.5	7.2	65.0	1366
2010	1969	71.6	7.6	5.8	57.6	1209
2011	1489	66.7	11.3	5.5	49.9	1047
2012	983	55.6	9.9	4.6	41.1	862

The decrease in the emission throughout the time series is not quite as steep as the general decrease in the amount of waste deposited. This is partly due to the lag time involved in the exponential degradation processes generating the CH_4 (cf. eq. 8.2.4) and partly due to a significant decrease in the amount of degradable organic waste deposited at landfills in Denmark (cf. Annex 3G, Table 3G-2.3).

Methodological issues

The estimation of CH_4 emission from Danish SWDSs is based on a First Order Decay (FOD) model equivalent to the IPCC Tier 2 methodology (IPCC 1997, 2000 and 2006). The model calculations are performed using national statistics on landfill waste categories reported in the national waste statistics.

This year's submission is based on allocation of the old ISAG and the new waste data for which amount are reported according to the European waste codes into 18 defined waste types with individual content of degradable organic matter and half-life´s as provided in table 8.2.2.

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

$$\frac{dN}{dt} = -k \cdot N \qquad \text{Eq. 8.2.1}$$

where k is the decay constant. Equation 8.2.1 can be solved for the simple case of a momentarily single deposition at time t (W_t) yielding:

$$N(t) = W_t \cdot e^{-k\,t} \qquad \text{Eq. 8.2.2}$$

where k relates to the half-life time for the content of degradable organic carbon (DOC) in the bulk waste, as:

$$t_{1/2} = \frac{ln2}{k} \Rightarrow k = \frac{ln2}{t_{1/2}} \qquad \text{Eq. 8.2.3}$$

The content of degradable organic carbon (DOC_i), half-life times ($t_{½}$) and the corresponding methane generation constants (k) are presented in Table 8.2.2.

Table 8.2.2 Half-life times ($t_{½}$), degradation rates constants (k) and content of degradable organic matter (DOC_i) according to 18 waste type, of which 11 are characterised as inert*.

Waste type[1]	DOC_i, [%, ww][2]	$t_{½}$, [yr, ww][3]	k, [yr^{-1}, ww]
Food	15	4	0.173
Paper and cardboard	40	12	0.058
Wood	43	23	0.0
Plastic*	0		
Textile, fur and leather	24	12	0.058
Biodegradable garden waste	20	7	0.099
Chemicals, inert*	0		
Electric & Hazardous*	0		
Glass*	0		
Metal*	0		
Scrap vehicles*	0		
Demolition	4	23	0.030
Soil & Stone*	0		
Particulate matter and dust*	0		
Sludge, inert*	0		
Sludge, degradable	57	12	0.058
Ash & Slag*	0		
Other not combustible waste*	0		

[1]Waste types marked "*"are characterised as being inert, meaning that these fraction do not decompose, i.e. $DOC_f = 0$.
[2]Default IPCC, 2006, Vol. 5, Chapter 2, Table 2.4.
[3]Default IPCC, 2006, Vol. 5, Chapter 3, Table 3.4.
[4]For demolition waste, the degradable fraction is assumed to be wood and the half-life for wood is therefore used.

The amount of generated methane decreases exponentially over time according to first order degradation 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 year 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. 8.2.4).

$$DDOCm(t) = W_i \cdot DOC_i \cdot DOC_f \cdot MCF + DDOCm(t-1) \cdot e^{-k} \qquad \text{Eq. 8.2.4}$$

where the methane conversion factor, MCF, is set to the default value of 1 for managed SWDS corresponding to the situation in Denmark (page 3.14, IPCC 2006). DOC_i is the mass fraction of degradable organic carbon in the deposited waste types (Table 8.2.2), and DOC_f represents the fraction of the degradable organic carbon that decompose as function of e.g. pH, temperature and waste composition at the SDWS. For Denmark the default DOC_f value is set to 0.5 (IPCC 2006, page 3.13).

Eq. 8.2.4 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. 8.2.4 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)):

$$DDOCm\ decomp_T = DDOCm(t-1) \cdot (1 - e^{-k}) \qquad \text{Eq. 8.2.5}$$

Based on Equation 8.2.4 and 8.2.5 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

$$CH_4\ generated_T = DDOCm\ decomp_T \cdot F \cdot 16/12 \qquad \text{Eq. 8.2.6}$$

where *F*, which is the fraction of methane in the gas from landfills, is set equal to 0.41 (DGC, 2009) and 16/12 is the 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 SWDS top layers needs to be subtracted from the generated methane:

$$CH_4\ Emissions = \left(\sum_x CH_4\ generated_{x,T} - R_T \right) \cdot (1 - OX_T) \qquad \text{Eq. 8.2.7}$$

where CH_4 *Emissions* is the methane emitted in year *T*, in units of Gg. *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. Energy producing installations at 16 sites are registered. The Danish Energy Agency registers the biogas amounts recovered at disposal sites in energy units (TJ) (DEA, 2012). The amount of gas in energy unit is converted to volume of gas using the net calorific value of 15.19 MJ per Nm^3 (DGC, 2009; Vattenfall, 2010; Verdo, 2011). As for the FOD model, the content of CH_4 in the gas recovered is estimated to 41 % and the density of CH_4 is 0.678 kg per m^3.

OX_T is the assumed oxidation of CH_4 in the top layer. The amount oxidised is uncertain and varies according to SWDS characteristics and management practices. For the Danish model an oxidation factor (OX) of 0.1 used; i.e. the default value for industrialised countries with well-managed disposal sites (IPCC, 2000 and 2006).

The amount of CH_4 recovered, *R(t)*, is calculated as:

$$R_T = \frac{B \cdot 0.41 \cdot 0.678\text{kg/m}^3}{15.19\text{MJ/m}^3} \qquad \text{Eq. 8.2.8}$$

where B is the collected amount of biogas as reported by the DEA in units of MJ. The CH_4 recovered is reported in Table 8.2.1 and 8.2.9 in units of Gg.

Model results and activity data

The amounts of waste deposited are registered and published in the national ISAG and new waste system (www.mst.dk) databases and have been allocated into 18 waste types as presented in Table 8.2.3 and in Annex 3G-2-3

Table 8.2.3 Waste amounts divided between eighteen waste types of which eleven* have been identified as inert waste fractions (cf. Table 8.2.2), Gg.

Waste types	1990	1995	2000	2005	2010	2011	2012
Food	111.7	52.0	26.5	4.6	1.0	0.7	0.9
Paper and cardboard	180.2	84.1	43.0	7.5	1.9	2.6	1.9
Wood	201.5	260.9	254.8	2.6	70.7	96.6	54.7
Plastic	27.0	14.2	8.8	4.6	5.5	7.8	4.3
Textile, fur and leather	5.0	3.1	2.3	0.8	2.2	3.1	2.4
Biodegradable garden waste	136.0	65.2	35.2	7.0	0.0	22.9	5.2
Chemicals, inert	7.7	4.7	3.6	1.4	1.0	0.6	0.1
Electric & Hazardous*	0.5	0.3	0.7	83.7	0.0	0.1	1.4
Glass*	37.3	18.5	10.6	4.8	5.4	5.3	2.9
Metal*	184.3	127.8	107.4	77.9	134.9	156.0	132.6
Scrap vehicles	104.5	64.5	48.8	48.7	16.0	17.2	1.5
Demolition, inert*	282.8	174.5	132.0	87.1	94.8	176.7	155.4
Soil & Stone*	466.1	308.6	271.3	174.0	1321.0	1774.0	624.1
Particulate matter and dust*	32.1	0.0	0.3	0.1	2.5	5.4	25.0
Sludge, inert	90.7	44.5	25.0	10.7	2.2	9.8	11.1
Sludge, degradable	210.7	135.7	107.1	37.7	18.5	22.8	13.4
Ash & Slag	465.8	145.0	8.5	33.8	48.4	54.2	23.3
Other not combustible waste	645.9	464.8	402.9	395.9	59.9	82.8	46.6
Total inert, [Gg]	2062.0	1193.0	887.9	835.6	1596.8	2113.2	872.9
Total, [Gg]	3189.8	1968.5	1488.8	983.0	1786.0	2438.6	1106.8

Data on the amounts of municipal solid waste deposited at managed solid waste disposal sites are reported by the Danish Environmental Protection Agency (DEPA) in old database ISAG database for the years 1994-2009 and the new waste data system (2010-2012). The ISAG data system provides landfill data for the years 1994-2009 (DEPA, 1996a, 1998a, 1999a, 2001a, 2001b, 2002a, 2004a, 2004b, 2005a, 2006a, 2006b, 2008, 2010a, 2011a) and the new waste data system provides data for 2011 (DEPA, 2013). Data for 2010 and 2012 have not yet been published by the Danish EPA and was obtained by direct contact in the DEPA (cf. chapter 8.7). The reporting year´s 2010 (and to a lesser extent 2011-2012) are associated with increased uncertainty (DEPA, 2013).

For the years 2010-2012 allocations has been performed according to the reported European waste codes (Statutory Order no. 1309, 18/12/2012) in the new waste data system (cf. Annex 3G, Table 3G-2.4).

For the old ISAG database, 1994-2009, have been analysed in depth and specific waste fractions have been allocated according to the 18 defined waste types as provided in Table 8.2.2.

Waste characterization data for the year 1985 and information on the total amount of waste deposited at SWDSs in 1970 reported by the Danish EPA in 1993 (DEPA, 1993) was used in the back calculation of the time series from 1994-1985.

Data for 1971-1984 have been determined by assuming a linear development between 1970 and 1985. 1960-1969 data are assumed constant at the 1970 level.

Waste amounts for the whole time series, i.e. 1960- 2012, categorised, allocated and divided into 18 waste types as described above, are provided in Annex 3G, Table 3G-2.3. Corresponding annual fractional distributions of the total amount of deposited waste according to type, respecting mass conservation, is presented in units of mass fractions in Table 8.2.4 (for the whole time series the reader is referred to Annex 3G, Table 3G-2.5).

Table 8.2.4. Fractional distribution of reported waste, according to the old ISAG and the new waste data system (EWC), allocated according to the 18 waste types.

Waste types	1990	1995	2000	2005	2010	2011	2012
Food	3.50	2.64	1.78	0.46	0.06	0.03	0.09
Paper and cardboard	5.65	4.27	2.89	0.76	0.11	0.11	0.17
Wood	6.32	13.26	17.11	0.27	3.96	3.96	4.94
Plastic*	0.85	0.72	0.59	0.47	0.31	0.32	0.38
Textile, fur and leather	0.16	0.16	0.16	0.08	0.12	0.13	0.22
Biodegradable garden waste	4.26	3.31	2.37	0.72	0.00	0.94	0.47
Chemicals, inert*	0.24	0.24	0.24	0.14	0.05	0.02	0.01
Electric & Hazardous*	0.02	0.02	0.05	8.51	0.00	0.00	0.13
Glass*	1.17	0.94	0.71	0.49	0.30	0.22	0.26
Metal*	5.78	6.49	7.21	7.93	7.55	6.40	11.98
Scrap vehicles*	3.28	3.28	3.28	4.96	0.90	0.71	0.14
Demolition	8.87	8.87	8.87	8.87	5.31	7.25	14.04
- of which are concrete, bricks, tiles and ceramics	0.00	0.00	0.00	0.00	0.28	0.21	0.29
- of which are insulation & asbestos-containing materials	0.00	0.37	0.59	2.24	2.60	3.37	7.17
- of which are other demolition	0.00	0.00	0.00	0.00	2.43	3.67	6.58
Soil & Stone*	14.61	15.68	18.22	17.70	73.96	72.75	56.39
Particulate matter and dust*	1.01	0.00	0.02	0.01	0.14	0.22	2.26
Sludge, inert*	2.84	2.26	1.68	1.09	0.12	0.40	1.00
- of which originates from desanding and screenings at WWTPs*	0.00	0.00	0.00	0.00	0.12	0.22	0.75
- of which originates from physico-chemical treatments of water(*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- of which originates from anaerobic treatment of waste*	0.00	0.00	0.00	0.00	0.00	0.04	0.06
- of which are sludge and filter cakes primarily from gas treatment*	0.00	0.00	0.00	0.00	0.00	0.05	0.08
- of which originates from primary filtration & clarification of water*	0.00	0.00	0.00	0.00	0.00	0.09	0.10
Sludge, degradable	6.60	6.90	7.19	3.83	1.04	0.93	1.21
- of which originates from treatment of urban WW	0.00	0.00	0.00	0.00	0.41	0.44	0.65
- of which originates from biological treatment of industrial WW	0.00	2.77	3.35	3.07	0.01	0.02	0.02
- of which originates from other treatment of industrial WW	0.00	0.00	0.00	0.00	0.02	0.02	0.03
- of which originates from physico-chemical treatments of water	0.00	0.07	0.04	0.06	0.00	0.17	0.01
- of which originates from oil/water separators and oil regeneration	0.00	0.00	0.00	0.00	0.00	0.01	0.02
- of which is originates from sewage cleaning	0.00	0.00	0.00	0.00	0.23	0.04	0.12
- of which is categorised as manure	0.00	0.00	0.00	0.00	0.02	0.00	0.01
- of which is categorised as organic chemicals	0.00	0.00	0.00	0.03	0.35	0.24	0.34
- of which is categorised as other	0.00	0.87	0.74	0.47	NR	NR	NR
- of which 10-30% is dry matter	0.00	2.80	3.43	0.78	NR	NR	NR
- of which >30% dry is matter	0.00	2.65	1.31	0.52	NR	NR	NR
Ash & Slag*	14.60	7.36	0.57	3.44	2.71	2.22	2.10
- of which is categorised as bottom ash, slag and boiler dust*	0.00	7.36	0.57	3.24	1.93	1.92	1.47
- of is categorised as which fly ash*	0.00	0.01	0.00	0.20	0.30	0.18	0.45
- of is categorised as which other*	0.00	0.00	0.00	0.00	0.48	0.12	0.19
Other waste, inert*	20.25	23.61	27.06	40.27	3.35	3.39	4.21
- of which is categorised not combustible municipal waste	0.00	11.44	14.11	30.59	3.35	3.39	4.21
- of which is not combustible garden waste	0.00	0.75	0.23	0.05	0.00	0.00	0.00
- of which is not combustible industrial waste	0.00	8.08	6.32	0.63	0.00	0.00	0.00
- of which is not combustible building & construction waste	0.00	3.35	6.40	8.99	0.00	0.00	0.00

While Table 8.2.4 presents the fractional distribution of 18 identified waste types of known DOC_i values, corresponding methane generation potentials are presented in Table 8.2.5.

Table 8.2.5 Methane generation potential for each of the 18 waste types, Gg CH_4 per Gg waste

Waste types	$L_{o,i}/W_i$
Food	0.041
Paper and cardboard	0.109
Wood	0.118
Plastic*	0
Textile, fur and leather	0.066
Biodegradable garden waste	0.055
Chemicals, inert*	0
Electric & Hazardous*	0
Glass*	0
Metal*	0
Scrap vehicles*	0
Demolition	0.011
Soil & Stone*	0
Particulate matter and dust*	0
Sludge, inert*	0
Sludge, degradable	0.156
Ash & Slag*	0
Other waste, inert*	0

The content of degradable organic matter, DOC_i values, in each waste type is shown separately in Table 8.2.2 and has been kept constant for the whole time series. The methane generation potential per unit waste type i is obtained from the equation:

$$\frac{L_{o,i}}{W_i} = DOC_f \cdot MCF \cdot F \cdot 16/12 \cdot DOC_i$$
$$\Rightarrow \frac{L_{o,i}}{W_i} = 0.27 \cdot DOC_i$$

Eq. 8.2.9

where the yearly decomposable fraction of the organic carbon content, DOC_f, are set equal to 0.5, the methane conversion factor, MCF are set equal to 1 and the volume fraction of CH_4 in generated landfill gas, F, are 0,41 (DGC, 2009). The methane generation potential according to waste types are reported in Table 8.2.5. A detailed description of the reallocation of waste statistics according to the 18 waste types is presented in Thomsen and Hjelgaard, 2014.

The annual amounts of the waste types (Table 8.2.3) and their emission generation potentials per mass unit (Eq. 8.2.9 and Table 8.2.6) 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. 8.2.6).

Figure 8.2.1 shows the time trend in annual amounts of deposited methane generation potential for each of the deposited waste type per year.

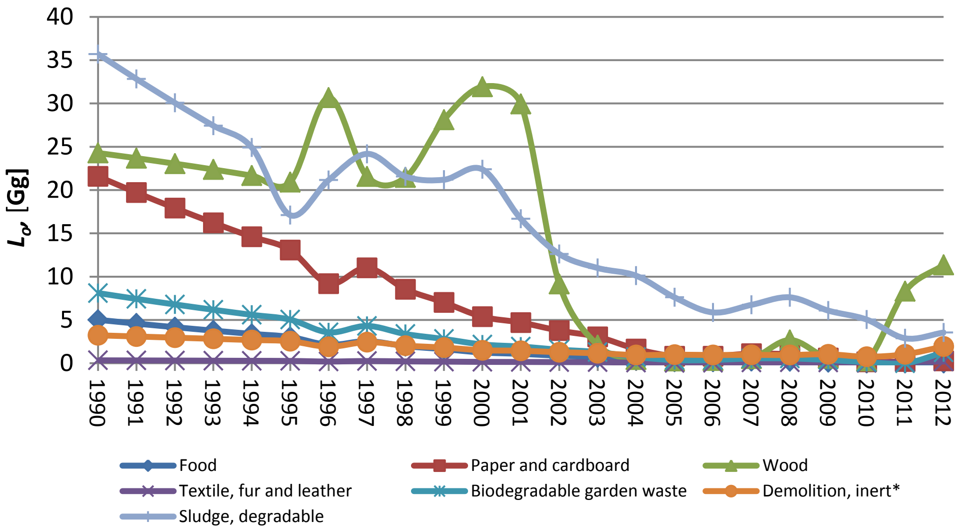

Figure 8.2.1 Annual amounts of deposited methane generation potential per waste type.

As shown from Figure 8.2.1, there is a general tendency for decreasing solid waste deposition in Denmark. Also, significant fluctuations are observed; fluctuations that are even bigger for the inert waste types; i.e. waste fraction with a methane generation potential of zero (cf. the introduction section of chapter 8.2). The same fluctuations may be observed from the amount of deposited waste types, meaning that the amount of deposited waste types influences the yearly deposited methane generation potential more than the variation in degradable organic carbon for the individual waste types, DOC_i values.

However, only a fraction of the methane generation potential is release per year; i.e. a function of the waste type specific degradation rate constants, the content of degradable organic carbon and according to first order degradation kinetics for each waste type (Eq. 8.2.1 to 8.2.6 and Table 8.2.2). These seemingly significant fluctuations in the yearly amounts of deposited waste and methane generation potentials becomes insignificant when looking at the annual methane emission factors as illustrated in Figure 8.2.2.

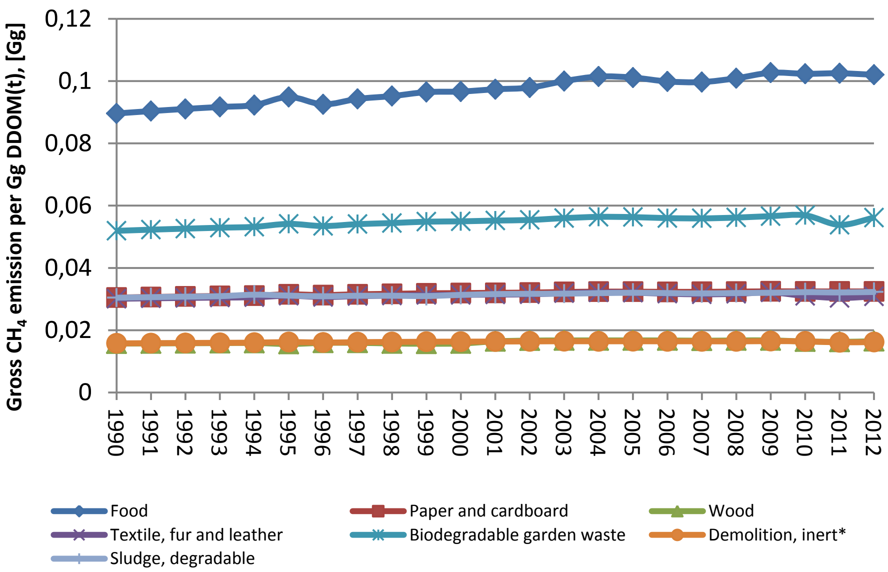

Figure 8.2.2 Annual gross emission factors for each waste type.

Figure 8.2.2 shows the time trend in the gross methane emission factor calculated as the gross methane emission divided by the remaining amount of degradable organic carbon within each waste type. As may be observed from comparing Figure 8.2.2 with 8.2.1, food waste has the highest gross methane emission factor and one of the lowest yearly methane generation potentials. The highest methane emission factor (Figure 8.2.2) for food waste throughout the time series may be explained by the lowest half-life (high CH_4 release rate) and content of degradable organic carbon for food waste compared to other waste types. Still, the yearly amounts of deposited food waste is low and so is the yearly methane generation potential (Eq. 8.2.9).

The net CH_4 emission (Eq. 8.2.7) is obtained upon subtraction of the recovered CH_4, utilised for energy production by biogas combustion installations at some of the sites, and the amount of oxidised 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 8.2.6.

Table 8.2.6 Waste deposited, total organic degradable matter, amounts of annual degraded organic matter and resulting CH_4 emissions for 1990-2012.

Year	Total Deposited Waste	Accumulated amount of decomposable DDOCm Eq. 8.2.4	Annual amount of degraded DDOCm, Eq. 8.2.5	Annual deposited CH_4 potential	Annual Gross CH_4 emission, Eq. 8.2.6	Recovered methane	Annual net emission before oxidation	Annual net emission after oxidation. Eq. 8.2.7	Implied emissions factor	
		[Gg]				[Gg CH_4]			Gg CH_4/Gg waste	Gg CH_4/Gg DDOCm
1990	3190	942	123	98.2	72.8	0.5	72.3	65.0	0.020	0.026
1995	1969	900	123	62.0	71.6	7.6	64.0	57.6	0.029	0.023
2000	1489	847	117	64.8	66.7	11.3	55.4	49.9	0.033	0.020
2005	983	710	99	10.3	55.6	9.9	45.6	41.1	0.042	0.020
2006	1002	682	95	8.6	53.0	5.6	47.4	42.7	0.043	0.021
2007	984	658	91	10.2	50.8	5.5	45.2	40.7	0.041	0.021
2008	1072	632	87	13.2	48.7	5.0	43.8	39.4	0.037	0.021
2009	779	606	84	8.9	46.6	4.7	41.9	37.8	0.048	0.021
2010	1786	577	80	6.4	44.5	6.4	38.1	34.3	0.019	0.020
2011	2439	551	77	12.6	42.7	4.0	38.7	34.8	0.014	0.021
2012	1107	524	74	18.6	41.2	4.3	36.9	33.2	0.030	0.020

The total waste amount in the second column of Table 8.2.6 is the sum of the amounts of the 18 different waste types (Table 8.2.3). The total waste amount is reported as the activity data for the Annual Municipal Solid Waste (MSW) at SWDSs in the CRF Table 6.A.

The implied emission factor (IEF) in the CRF tables reflects an aggregated emission factor for the model calculated as the net methane emission divided by respectively the total amount of waste deposited in the current year (tenth column in Table 8.2.6) and the total amount of decomposable degradable organic matter, D*DOCm*, (eleventh column in Table 8.2.6).

The time trend for the total decomposable DOC and annual degraded organic matter are provided in the third and fourth column in Table 8.2.6 and visualised in Figure 8.2.3.

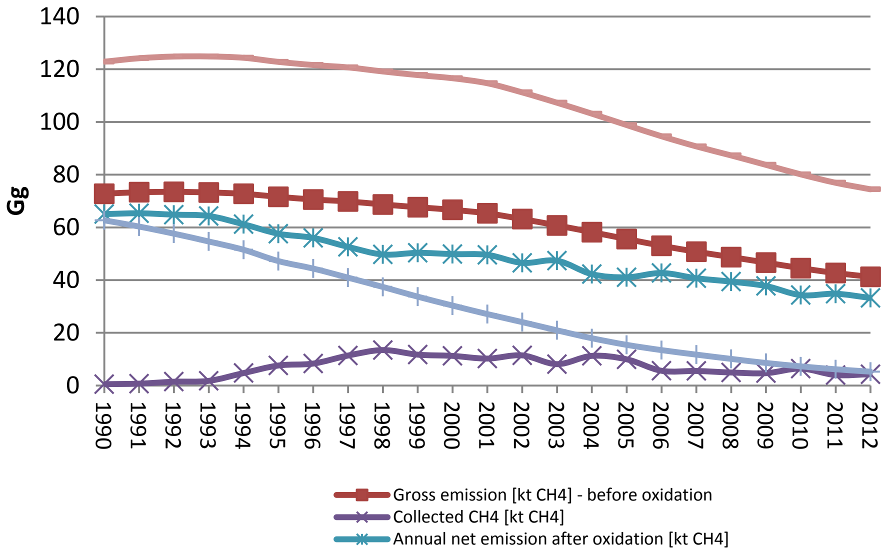

Figure 8.2.3 Time trend in gross methane emission, collected methane, annual net methane emission, annual D*DOCm* (decomposable degradable organic matter) and remaining D*DOCm*.

In total a reduction in the net methane emission from 1990 to 2012 of 49 % is observed. This reduction in the methane emission is accompanied by an increase in the degraded amount of decomposable degradable organic matter, D*DOCm* of 39 % and a 92 % decrease in the remaining amount of D*DOCm* from 1990 to 2012. The fluctuation in the net methane emission is explained by the fluctuations in the amount of recovered methane.

8.3 Wastewater handling (CRF source category 6B)

The Danish wastewater treatment system is characterised by few big and advanced wastewater treatment plants (WWTPs) and many smaller WWTPs. From 1993 to 2012 the amount of wastewater treated at the most advanced technological WWTPs in Denmark has increased from 53 % to more than 90 %. Improvements of the decentralised wastewater treatment system as well as the sewer system are on-going in Denmark (DEPA, 2010b). For this part of the population, i.e. scattered houses, sludge from septic tanks are collected once per year or as appropriate by judgement of the local authorities (DEPA, 1999b). Municipal collection and transportation of sludge from septic tanks for treatment at the centralised WWTPs occurs to some extent, the frequency set by the authorities and in general septic tanks are emptied one time each year.

A presentation of methodological approach, emission factors, activity data and recalculations are presented in the following sub-chapters.

8.3.1 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).

No distinction between emissions from industrial and municipal WWTPs is made, as Danish industries to a great extent are connected to the municipal sewer system. Wastewater streams from households and industries are therefore 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 to around 40% from 1987 to 2010 with the highest influent contribution occurring at the biggest and most advanced technological WWTPs in Denmark (Thomsen & Lyck, 2005; ASEP 2010). Monitoring data on the biological oxygen demand (BOD) for the mixed household and industrial influent are available for all WWTPs with a capacity above 30 PE treating more than 90 % of the Danish wastewater (DEPA, 1989, 1999c, 2001d, 2003c, 2004d, 2009; Niero et al., 2014).

Documentation for a decreased fraction of the population not connected sewer system is still missing, and therefore the fraction of the population not connected to the collective sewer system is kept at 10%.

Regarding diffuse emissions from the sewer system, very little data are available (e.g. Lyngby-Taarbæk Kommune, 2013). 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. The sewer system is, however, hydraulically designed to prevent the accumulation of bottom sediments and under such conditions, temporary anaerobic processes will be dominated by fermentation and sulfate reduction, which means that the possibility of methane formation may be ignored (Danva, 2008; Hvitved-Jacobsen, 2001).

It should be mentioned that no activity data are available for industrial WWTPs. Therefore, the emissions from industries having separate wastewater treatment is unknown and i.e. not included in the Danish inventory for category 6.B. Wastewater handling. Only the indirect N_2O emissions are included as effluent N data are available from DEPA reports (DEPA. 1994, 1996b, 1997, 1998b, 1999b, 2000, 2001c, 2002b, 2003b, 2004c, 2005b, 2005c and ASEP 2007, 2010, 2011, 2012, 2013).

Methane emission

The unspecified fugitive methane emission has this year been specified according to the identified systems and processes contribution to the fugitive methane emission from wastewater handling in Denmark. 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 generation and combustion for energy production and 3) septic tanks. The individual contribution to the net methane emission is given in Table 8.3.1 and Annex 3G, Table 3G-3.1.

Table 8.3.1 Produced, recovered and emitted CH_4 from wastewater treatment, Gg.

	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012
CH_4 emitted from sewer system and WWTP	0.17	0.21	0.27	0.25	0.26	0.27	0.22	0.25	0.26	0.27	0.24
CH_4 emission from anaerobic treatment	0.13	0.16	0.29	0.23	0.23	0.24	0.20	0.23	0.24	0.25	0.23
CH_4 emitted from septic tanks	2.81	2.86	2.92	2.96	2.97	2.98	3.00	3.02	3.03	3.04	3.06
Net CH_4 emission	3.12	3.23	3.48	3.45	3.46	3.49	3.41	3.50	3.53	3.56	3.52
CH_4 gross anaerobic processes	13.30	16.03	29.04	22.94	23.17	24.23	19.69	22.81	23.63	24.63	22.62
CH_4 recovered	13.17	15.87	28.75	22.71	22.94	23.99	19.49	22.58	23.40	24.38	22.39

The emission from the sewer system and WWTP processes (including anaerobic treatment) has increased by 53 % from 1990 to 2012. Regarding the fraction of the population not connected to the collective sewer system (CH4 emitted from septic tanks) an increase of 9 % is observed from 1990 to 2012.

Lastly, the amount of recovered methane for energy production has increased 70 % from 1990 to2012 (cf. chapter 8.5.5 for further documentation).

Nitrous oxide emission

N_2O formation and releases both during the treatment processes at the WWTPs and also 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 and from sewage effluents. The emission from effluent wastewater, i.e. indirect emissions, includes separate industrial discharges, rainwater-conditioned effluents, effluents from scattered houses, from mariculture and fish farming. In Table 8.3.2, emission of N_2O from effluent and the contribution from direct N_2O emissions to the total N_2O emission, i.e. the sum of indirect and direct N_2O emissions, is presented.

Table 8.3.2 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 1990-2011 is shown in Annex 3G, Table he full time series 1990-2011 is shown in Annex 3G, Table G-3.2.

Table 8.3.2 N_2O emissions from wastewater, Mg.

	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012
N_2O, indirect	265	238	157	111	109	116	103	108	109	106	104
N_2O, direct	73	111	134	161	127	154	214	127	136	150	131
N_2O, total	339	350	292	272	236	270	317	235	246	256	235

Regarding the time trend, the indirect N_2O emission has decreased 61 % N_2O from 1990 to 2012, while the direct N_2O emission has increased 79 %. In absolute figures the indirect emission is a major contributor and the resulting total N_2O emission has decreased 31 % from 1990 to 2012.

8.3.2 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, 1997) and the IPCC Good Practice Guidance (IPCC, 2000). No methodological changes have occurred compared to 2010 (Nielsen et al., 2011a). For the methane emissions from anaerobic digestion, the methane correction factor was decreased from 1 to 0.8, which is in accordance to the IPCC guidelines 2006, and which have been further justified by plant specific data as described in Thomsen and Hoffmann (2014 and chapter 8.5.5). Besides the correction of MCF, smaller corrections in plant inlet TOW data have occurred corresponding to a change below 2 % throughout the time series (cf. Table 8.8.1).

This 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 WWTP 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, $CH_{4,AD}$:

$$CH_{4,WWTP} = CH_{4,sewer+MB} + CH_{4,AD} \qquad \text{Eq. 8.3.1}$$

The fugitive emissions from the sewer system, primary settling tank and biological N and P removal processes, $CH_{sewer+MB}$, are estimated as:

$$CH_{4,sewer+MB} = EF_{sewer+MB} \cdot TOW_{inlet}$$

$$\Downarrow$$

$$CH_{4,sewer+MB} = B_o \cdot MCF_{sewer+MB} \cdot TOW_{inlet} \qquad \text{Eq. 8.3.2}$$

where

TOW_{inlet} equals the influent organic degradable matter measured as biological oxygen demand (BOD) in the influent wastewater flow,

Bo is the default maximum CH_4 producing capacity, i.e. 0.6 kg CH_4 per kg BOD (IPCC, 1997),

$MCF_{sewer+MB}$ is the fraction of DOC that is anaerobically converted in sewers and WWTPs. MCF_{WWTP} equals 0.003 based on an expert judgement (personal communication: Professor Jes Vollertsen) 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 BOD, while the fugitive emission from the sewer system is judged to be negligible or zero (DANVA, 2008).

The emission factor, ***$EF_{sewer+MB}$***, for these three processes and systems equals **0.0018 kg CH_4 per kg BOD.**

The methane emission from anaerobic digestion is calculated as:

$$CH_{4,AD} = EF_{AD} \cdot TOW_{inlet} \cdot (1 - MR_{AD})$$

$$\Downarrow$$

$$CH_{4,AD} = B_o \cdot MCF_{AD} \cdot f_{AD} \cdot TOW_{inlet} \cdot (1 - MR_{AD}) \qquad \text{Eq. 8.3.3}$$

where

Bo is the default maximum CH_4 producing capacity, i.e. 0.6 kg CH_4 per kg BOD (IPCC, 1996; 2006),

MCF_{AD} is extent to which degradation occurs under anaerobic conditions is set equal to 0.8 (IPCC, 2006),

TOW_{inlet} equals the influent organic degradable matter measured as biological oxygen demand (BOD) in the influent wastewater flow,

f_{AD} is the fraction of sludge treated in anaerobic closed systems.

MR_{AD} is the methane generation and combustion efficiency = 99 %

The methane recovery, MR_{AD}, for the anaerobic wastewater treatment with biogas production has been set to 99 % according to expert knowledge (personal communication, Professor Jes Vollertsen; ASEP, 2010) which is further verified in Chapter 8.5.5.

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 no measurements of the methane emissions from septic tanks and the pumping and management of septage, including its transportation to a wastewater treatment facility exist. Methane emission from septic tanks is calculated as:

$$CH_{4,st} = EF_{st} \cdot f_{nc} \cdot P \cdot DOC_{st}$$
$$\Downarrow$$
$$CH_{4,st} = B_o \cdot MCF_{st} \cdot f_{nc} \cdot P \cdot DOC_{st} \qquad \text{Eq. 8.3.4}$$

where

Bo is the default maximum CH_4 producing capacity, i.e. **0.6 kg CH_4 per kg BOD** (IPCC, 1996).

MCF_{st} is the methane conversion factor. It depends on the extent to which BOD settles in the septic tanks. MCF_{st} has been set **equal to 0.5** (IPCC, 2006) assuming that degradation for the settled DOC occurs under 100 % anaerobic conditions.

F_{nc} is the fraction of the population that are not connected to the sewer system, i.e. scattered houses which is set equal to **10 %.**

DOC_{st} is the per capita produced degradable organic matter (DOC) which equals **18.250 kg BOD per 1000 persons per year** (IPCC, 2000).

P is the population number.

Using the default maximum methane producing capacity and a methane conversion factor of 0.5 (IPCC guidelines, 2006, Table 6.3) results in an emission factor, **EF_{st}, equal to 0.03**.

Annual activity data and emission factors used for calculation the net methane emission

Monitoring data on the influent biological oxygen demand (BOD) 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 1998, the IPPC default methodology for household wastewater has been applied by accounting and correcting for the industrial influent load (Thomsen & Lyck, 2005). For the years 1999 to 2012 monitoring data from the national monitoring program exists. The time series for activity data on TOW are presented in Table 8.3.3.

Table 8.3.3 presents the total degradable organic waste (TOW) calculated by use of the default IPCC method corrected for contribution from industry to the influent TOW (1990-1998) (Thomsen and Lyck, 2005) and country-specific data (1999-2012). The full time series is presented in Annex 3G, Table 3G-3.3.

Table 8.3.3 Calculated total degradable organic waste in the influent wastewater (TOW).

	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012
Contribution from industrial inlet BOD	2.5	22.2	42.0	40.5	40.5	40.5	40.5	40.5	40.5	40.5	40.5
Population (1000)	5135	5216	5330	5411	5427	5447	5476	5511	5535	5561	5581
TOW [Gg] corrected IPCC method	96.5	116.3									
TOW [Gg]; country-specific data			148.5	140.9	142.3	148.8	120.9	140.1	144.5	150.9	134.6

*TOW = (1+I/100) x (P x D_{dom}), where P is the Population number, D_{dom}= 18 250 kg BOD per 1000 persons per year and I is the per cent contribution from industry to the influent wastewater TOW content.

A country-specific emission factor for calculating the amount of methane produced during anaerobic treatment processes, the gross methane emission (cf. Table 8.3.4), at the Danish WWTPs has been derived. From this emission factor the fugitive emissions from anaerobic treatment processes has been calculated according to Equation 8.3.3. The emission factor varies according to the national statistics on the fraction of wet weight sludge treated anaerobic as reported in the Danish sludge database and presented in Table 8.3.4.

Table 8.3.4 shows the country-specific emission factor for estimating the methane generated during anaerobic treatment processes. The full time series is presented in Annex 3G, Table 3G-3.4.

Table 8.3.4 Emission factor for estimating the methane generation, kg CH_4 per kg BOD.

	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012
$MCF_{AD} * f_{AD}$ *	0.23	0.23	0.33	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.28
$EF_{AD} = B_o*MCF_{AD}*f_{AD}$ [kg CH4/kg BOD] *	0.14	0.14	0.20	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.17

* (Eq.8.3.3).

The Danish sludge database have incomplete statistics due to lack of facility reporting for the years 2006-2011 why the fraction of sludge treated anaerobic have been set equal to the reported fraction in 2005.

Overall methane emission time trends

The trends in the CH_4 emission from the Danish WWTPs, as summarised in Table 8.3.1, are presented graphically in Figure 8.3.1.

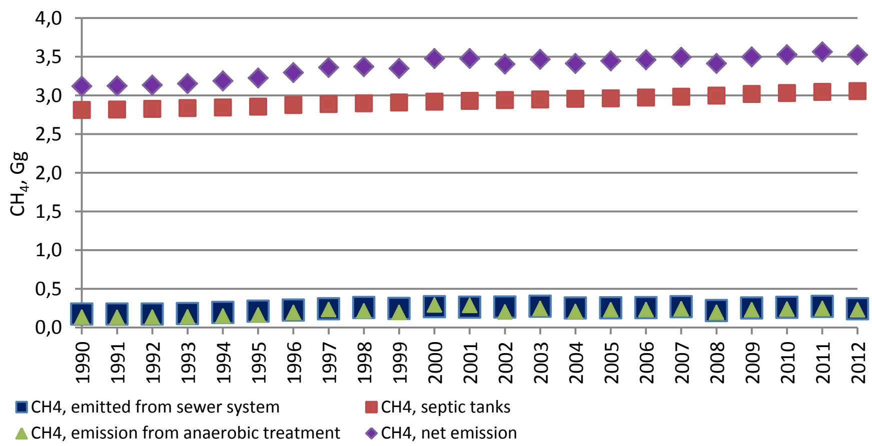

Figure 8.3.1 Time trends for net methane emission, methane emission from sewer systems, from septic tanks and from anaerobic treatment processes.

The net methane emissions has increased from 3.2 Gg in 1990 to 3.52 Gg methane in 2012 corresponding to an increase in net methane emissions from wastewater handling of 13 %.

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 (Gejlsberg et al., 1999). 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 used to derive a national EF for the direct emission of nitrous oxide.

The direct N_2O emission from wastewater treatment processes is calculated according to Equation 8.3.5:

$$E_{N_2O} = EF_{N_2O,direct} \cdot m_{N,\inf luent} \cdot \frac{M_{N_2O}}{2 \cdot M_N} \qquad \text{Eq. 8.3.5}$$

where

$EF_{N2O,direct}$ is set equal to a fraction of 0.0032 of the N load in the influent wastewater.

$m_{N,influent}$ is the annually reported N load in the Danish Water Quality Parameter Database provided in Table 8.3.5.

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.

The country-specific EF value of 0.0032 may be expressed as ***$EF_{N2O,direct}$*** = 4.99 g N_2O per kg N load in the influent wastewater by reducing eq. 8.3.5 to:

$$E_{N_2O} = EF_{N_2O,direct} \cdot m_{N,\inf luent} \qquad \text{Eq. 8.3.6}$$

The methodology here adopted for estimating the direct N_2O emission only relies on the influent N load as activity data.

The indirect N_2O emission from WWTPs is calculated according to Equation 8.3.7:

$$E_{N_2O,WWTP,effluent} = D_{N,WWTP} \cdot EF_{N_2O,WWTP,effluent} \cdot \frac{M_{N_2O}}{2 \cdot M_N} \qquad \text{Eq. 8.3.7}$$

where

$D_{N.WWTP}$ is the effluent discharged sewage nitrogen load consisting of contributions from municipal wastewater treatment plants, the separate industry, effluent from mariculture and fish farming, rainwater conditioned effluents and scattered houses not connected to the sewage system (cf. Table 8.3.5).

$EF_{N2O.WWTP.effluent}$ is the IPCC default emission factor of **0.01 kg N_2O-N per kg sewage-N** produced (IPCC, 1997, p 6.28)

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 8.3.5. 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 mariculture and fish farming, rainwater conditioned effluents and scattered houses. For the entire time series 1990-2011 cf. Annex 3G, Table 3G-3.5.

Table 8.3.5 Nitrogen content in the influent and effluent wastewater, Mg.

	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012
Influent wastewater to WWTPs*	14679 ***	22340	26952	32288	25401	30899	42808	25519	27357	30049	26316
Effluent wastewater from WWTP**	10268	8938	4653	3831	3634	4358	3575	4025	4025	3916	3849
Effluent wastewater, total**	16884	15152	10005	7038	6935	7381	6557	6878	6960	6770	6597

*Data on the influent wastewater N load from municipal WWTPs are available from the Danish Water Quality Parameter Database held by the Agency for Spatial and Environmental Planning ** Effluent wastewater, total includes separate industrial discharges, rainwater conditioned effluent, scattered houses, mariculture and fish farming and effluents from WWTPs (DEPA. 1994, 1996b, 1997, 1998b, 1999b, 2000, 2001c, 2002b, 2003b, 2004c, 2005b, 2005c and ASEP 2007, 2010, 2011, 2012, 2013).*** The significant lower number in 1990 compared to 1995 is due to step increase in the number of WWTPs above 30 PE after implementation of the first Water Action Plan in 1987 (Thomsen and Lyck, 2005; Annex 3G, Table 3G-3.5).

The reduction of N in the effluent wastewater from municipal WWTP compared to in influent wastewater has increased from a reduction efficiency of 30% in 1990 to a reduction efficiency of around 85% in 2012. 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 og Jørgensen, 2008).

Overall nitrous oxide emission trends

The trends in the direct N_2O emission from WWTPs, the indirect emission from wastewater effluent and the total, as summarised in Table 8.3.2, are presented graphically in Figure 8.3.2.

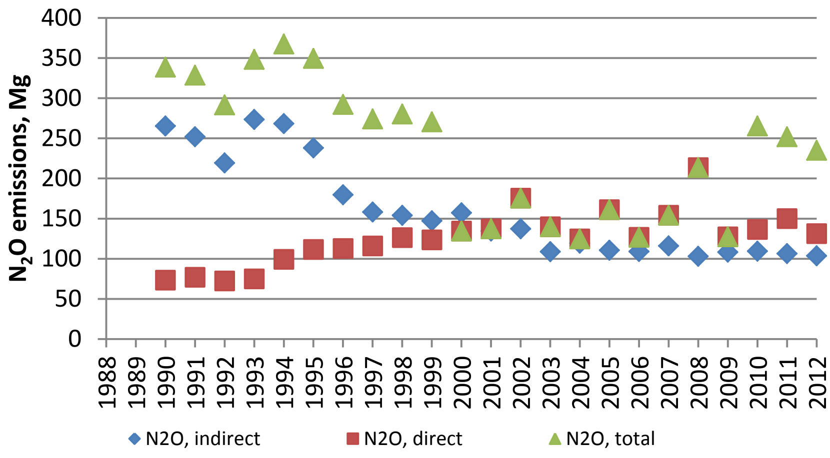

Figure 8.3.2 Time trends for direct emission of N_2O, indirect emission, i.e. from wastewater effluents, and total N_2O emission.

The annual fluctuations may be caused by several factors such as 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. 1994, 1996b, 1997, 1998b, 1999b, 2000, 2001c, 2002b, 2003b, 2004c, 2005b, 2005c; ASEP 2007, 2010, 2011; Vollertsen et al., 2002), may contribute to the "noise" or fluctuation in the trend of the calculated indirect N_2O emission.

The direct emission shows an increasing trend increases from 1900 to 2002, where a stable but fluctuating level is reached. Comparing 2012 with the base year 1990 an increase of 79 % is observed.

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 265 tonnes N_2O in 1990 to 104 tonnes N_2O in 2012 corresponding to a reduction of 61%.

The indirect emission is the major contributor to the emission of nitrous oxide in the period 1990-1997. However, from around year 2000, the direct N_2O emission is the major contributor to the total N_2O emission. Overall, a net reduction of 31 % is observed for the total N_2O emission from wastewater handling.

8.4 Waste incineration (CRF source category 6C)

The CRF source category 6.C. Waste Incineration, includes cremation of human bodies and cremation of animal carcasses.

Incineration of municipal, industrial, clinical and hazardous waste takes place with energy recovery, 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.

Table 8.4.1 gives an overview of the Danish greenhouse gas emission from the CRF source category 6.C waste incineration.

CO_2 emissions from cremations of human bodies and animal carcasses are biogenic.

While emissions from human cremations have been steady over the last two decades, emissions from animal cremations have increased. In 1990, incineration of animal carcasses stood for 5 % of the total emission of CO_2 eqv. from cremations. In 2012 this number has increased to 32 %. GHG emissions from cremations are very small; 0.21 Gg in 1990 and 0.29 Gg in 2012. GHG emissions are shown in Table 8.4.1, for the full time series, see Annex 3G, Table 3G-4.1.

Table 8.4.1 Overall emission of greenhouse gases from the incineration of human bodies and animal carcasses.

Year		199	199	2000	2005	2010	2011	2012
CH_4 emission from								
Human cremation	Mg	0.48	0.52	0.49	0.48	0.49	0.49	0.48
Animal cremation	Mg	0.03	0.04	0.08	0.14	0.26	0.22	0.22
Total	Mg	0.51	0.55	0.57	0.62	0.76	0.71	0.70
N_2O emission from								
Human cremation	Mg	0.60	0.64	0.61	0.60	0.62	0.61	0.60
Animal cremation	Mg	0.03	0.05	0.10	0.17	0.33	0.28	0.28
Total	Mg	0.64	0.69	0.71	0.77	0.95	0.88	0.88
6C. Waste incineration								
CO_2 equivalents	Gg	0.21	0.23	0.23	0.25	0.31	0.29	0.29

8.4.1 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 air flow and regulations for coffin materials.

Emissions from human cremation are calculated for greenhouse gases CH_4 and N_2O.

Methodological issues

During the 1990es 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 burn-out 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 8.4.2 shows a comparison of the emission limit values from February 1993 and the new standard limits.

Table 8.4.2 Emission limit values mg per Nm^3 at 11 % O_2 (Schleicher et al., 2008).

Component	Report 2/1993	Standard terms (1/2011)
	Emission limit value mg per normal m^3 at 11 % O_2	
CO_2	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 2012, there were 26 operating crematoria in Denmark, some with multiple furnaces. In 2010 there were 31 operating crematoria (DKL, 2013).

Crematoria that are not closed are equipped with flue gas cleaning (bag filters with activated carbon). The 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 8.4.3 shows the time series of total number of nationally deceased persons (Statistics Denmark, 2013), number of cremations and the fraction of cremated corpses in relation to the total number of deceased (DKL, 2013). Annex 3G, Table 3G-4.2 presents data for the entire time series 1990-2012.

Table 8.4.3 Data human cremations, DKL (2013), Statistics Denmark (2013)

Year	1990	1995	2000	2005	2010	2011	2012
Nationally deceased	60926	63127	57998	54962	54368	52516	52325
Cremations	40991	43847	41651	40758	42050	41248	40909
Cremation fraction, %	67.3	69.5	71.8	74.2	77.3	78.6	79.6

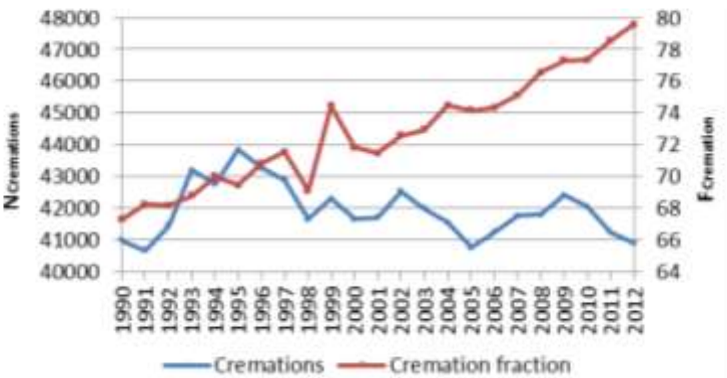

Figure 8.4.1 Illustration of the development in cremations (DKL 2013), where the number of cremations, $N_{cremations}$, is shown at the left Y-axis. The cremation percentage, $F_{cremations}$, shows the percentage of cremated deceased of the total number of deceased for the years 1990-2012.

Even though the total number of annual cremations is fluctuating, the cremation percentage has been steadily increasing since 1990, and is likely to continue to increase.

The average body weight is assumed to be 65 kg (EEA, 2009).

Figure 8.4.2 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 8.4.2 also shows the effect of the increasing fraction of cremations per deceased, as the number of cremations is not decreasing along with the number of deceased. The cremation fraction has increased from 67 % in 1990 to 80 % in 2012; the trend of this fraction is shown in Figure 8.4.1.

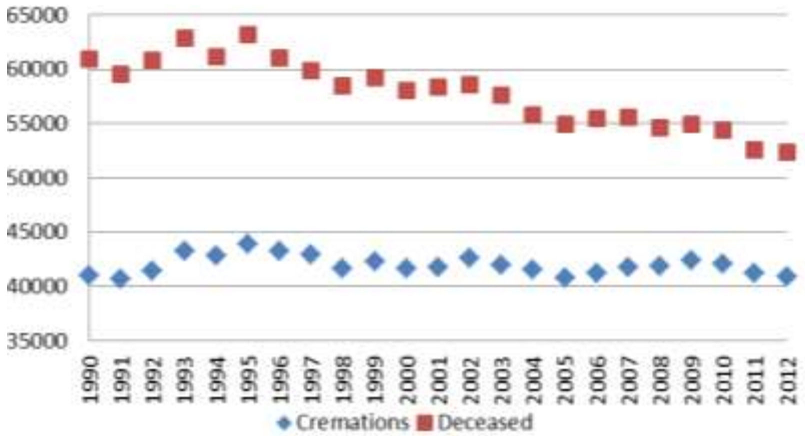

Figure 8.4.2 Trends of the activity data for cremation of human corpses and the national number of deceased persons.

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 8.4.4. It has not been possible to find any additional data to validate the emission factors.

Table 8.4.4 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

8.4.2 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 but 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) on waste incineration or with Regulation (EC) No. 1069/2009 (EC, 2011).

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.

Emissions from pet cremations are calculated for CH_4 and N_2O.

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 8.4.5 lists the four Danish animal crematoria, their foundation year and provides each crematorium with an id letter.

Table 8.4.5 Animal crematoria I Denmark.

Id	Name of crematorium	Founded in
A	Dansk Dyrekremering ApS	May 2006
B	Ada's Kæledyrskrematorium ApS	Unknown, existed in more than 30 years
C	Kæledyrskrematoriet	2006
D	Kæledyrskrematoriet v. Modtage-station Vendsyssel I/S	-

Crematoria 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 8.4.6 lists the activity data for animal crematoria A-C. The entire dataset for 1990-2012 is available in Annex 3G, Table 3G-4.3.

Table 8.4.6 Activity data. Source: direct contact with all Danish crematoria.

	1990	1995	2000	2005	2010	2011	2012
Total, Mg	150	200	443	762	1449	1219	1238

Crematorium B delivered exact annual activity data for the years 1998-2011. They were not certain about the founding year but believe to have existed since the early 1980es. Activity data for 1990-1997 and 2012 has therefor been estimated by the authors expert judgement. 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.

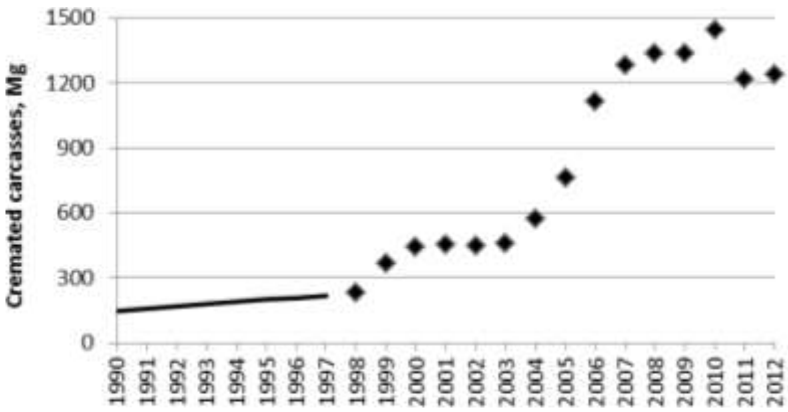

Figure 8.4.3 The amount of animal carcasses cremated, in Mg. Data from 1998-2012 are delivered by the crematoria and is considered to be exact; these data are marked as points. Data from 1990-1997 are estimated and are shown as the thick line in the figure.

It is not possible to extrapolate data linearly back to 1980 because the activity, due to the steep increase, in this case would become negative from 1993 and back in time.

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, emission per Mg.

Table 8.4.7 lists the emission factors and their respective references.

Table 8.4.7 Emission factors for animal cremation.

Pollutant name	Unit	Emission factor	Reference
CH_4	g/Mg	182	Aasestad, 2008
N_2O	g/Mg	226	Aasestad, 2008

8.5 Waste Other (CRF Source Category 6D)

This category is a catch all for the waste sector. Emissions in this category could stem from compost production, accidental fires, sludge spreading, biogas production and other combustion without energy recovery. In the Danish inventory emissions from accidental fires, compost production and biogas production are included in this category.

Table 8.5.1 gives an overview of the Danish greenhouse gas emission from the CRF source category 6.D waste other.

CO_2 emissions from compost production are biogenic. For accidental fires in buildings, there is a high content of wood both in the structure and in the interior; this leads to 82 % of the CO_2 emission from accidental building fires to be biogenic, see Table 8.5.1.

Emissions from accidental fires are quite constant, with a peek in 2008 of 23 Gg CO_2 equivalents. Compost production is the largest source of greenhouse gas emissions in this sector. In 1990 composting stood for 69 % (42 Gg CO_2 equivalents) of the total greenhouse gas emission in CO_2 equivalents from the other waste category, in 2012 this number has increased to 92 % (217 Gg CO_2 equivalents). The full time series is shown in Annex 3G, Table 3G-5.1a-c.

Table 8.5.1 Overall emission of greenhouse gasses from accidental fires and composting.

		1990	1995	2000	2005	2010	2011	2012
CO_2 emission from								
Accidental building fires	Gg	63.1	72.2	63.8	62.4	61.7	67.6	60.5
- of which non-biogenic	Gg	11.4	13.1	11.5	11.3	11.1	12.2	10.8
Accidental vehicle fires	Gg	6.1	6.5	6.9	6.9	7.3	6.3	5.6
Total, non-biogenic	Gg	17.5	19.6	18.4	18.1	18.3	18.4	16.4
CH_4 emission from								
Compost production	Mg	1386.1	1860.2	3240.0	3419.9	4094.6	4204.3	4306.3
Accidental building fires	Mg	64.1	73.4	64.9	63.8	64.6	68.5	61.7
Accidental vehicle fires	Mg	12.8	13.6	14.3	14.3	15.1	13.1	11.6
Total	Mg	1463.0	1947.2	3319.2	3497.9	4174.3	4285.9	4379.6
N_2O emission from								
Compost production	Mg	41.5	72.8	515.7	200.2	355.2	381.4	409.1
Accidental building fires	Mg	NAV	NAV	NAV	NAV	NAV	NAV	NAV
Accidental vehicle fires	Mg	NAV	NAV	NAV	NAV	NAV	NAV	NAV
Total	Mg	41.5	72.8	515.7	200.2	355.2	381.4	409.1
6D. Waste other								
CO_2-eqvivalents	Gg	61.1	83.0	248.0	153.6	216.1	226.7	235.2

8.5.1 Compost production

This section covers the biological treatment of solid wastes called composting. Greenhouse gasses that are emitted from this process are CH_4, N_2O and CO_2.

Methodological issues

Emissions from composting have been calculated according to a country specific Tier 1 method. However, a Tier 1 default methodological guidance is available in the 2006 IPCC Guidelines (IPCC, 2006).

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.

In 2001, 123 composting facilities treated only garden and park waste (type 2 facilities), nine facilities treated organic waste mixed with GPW or other organic waste (type 1 facilities) and 10 facilities treated GPW mixed with sludge and/or "other organic waste" (type 3 facilities). 92 % of these facilities consisted entirely of windrow composting, which is a simple technology composting method with access to only natural air. It is assumed that all facilities can be considered as using windrow composting. (Petersen & Hansen, 2003)

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 ISAG waste information system, which contain data for 1995-2009 (ISAG, 2010). The new waste data system that was supposed to replace ISAG in 2010 is not yet functioning; activity data for 2010-2012 has therefore been estimated by extrapolation.

Figure 8.5.1 illustrates the composted amount of waste divided in the four categories mentioned earlier.

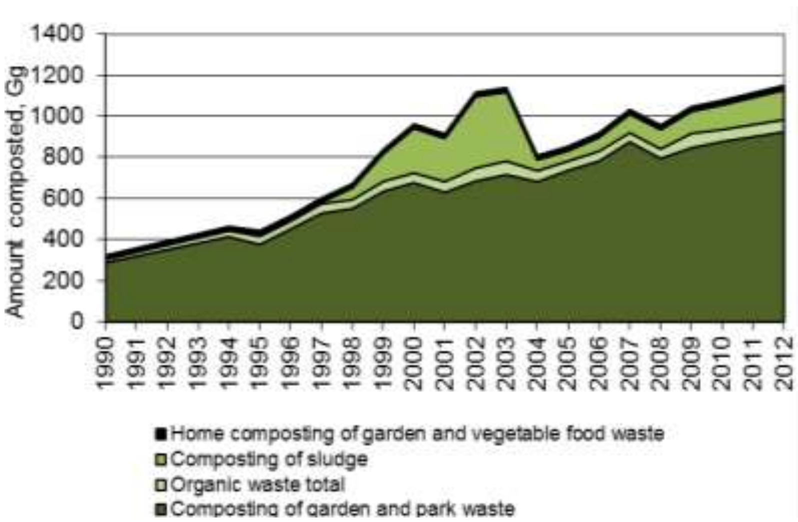

Figure 8.5.1 National amount of composted waste, these data are also shown in Table 8.5.3.

Activity data for the years 1995-2009 are collected from the ISAG database for the categories: “sludge”, “organic waste from households and other sources” and “garden and park waste”. Activities for 2010-2012 are calculated by using the trend from earlier years.

The Danish legislation on sludge (DEPA, 2006c) was implemented in the summer of 2003. This stated that composted sludge may 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 trend in composting of sludge does not demonstrate a convincing trend that can be used for estimation of activity data for previous years. Since this activity is insignificant for 1995-1997 (1-2 %) it is assumed to be “not occurring” for 1990-1994.

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 Gg per facility per year). The following Table 8.5.2 shows the number of composting sites divided in the three types described in “Methodological issues” (Petersen, 2001 and Petersen & Hansen, 2003).

Table 8.5.2 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	126	130	139	138	149

Type 1 waste treatment sites normally includes biogas producing facilities, but these have been excluded in Table 8.5.2.

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 ISAG activity data for GPW. Activity data for GPW for the years 1985-1994 and 2010-2011 are estimated by extrapolating the trend.

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 Gg in 2001. It is assumed that the following estimates made by Petersen & Kielland (2003) are valid for all years 1990-2012.

- 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.
- 50 kg waste per year will in average be composted at every contributing residential building.
- 10 kg waste per year will in average be composted at every contributing multi-dwelling house.

Multi-dwelling houses include apartment buildings, it is very 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 found at the Statistics Denmark's website.

The calculated activity data for composting are shown in Table 8.5.3 and in Annex 3G, Table 3G-5.2.

Table 8.5.3 Activity data composting, Gg.

	1990	1995	2000	2005	2010	2011	2012
Composting of garden and park waste	288	376	677	737	877	901	924
Composting of organic waste from house_holds and other sources	16	40	47	45	58	59	59
Composting of sludge	NO	7	218	50	120	132	145
Home composting of garden and vegetable food waste	20	21	21	22	23	23	23
Total	324	444	963	854	1078	1115	1151

NO = Not occurring

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 8.5.4 are considered the best available for the calculation of Danish emissions from composting.

Table 8.5.4 Composting emission factors.

	Garden and park waste (GPW)	Organic waste from households and other sources	Sludge	Home composting of garden and vegetable food waste
Unit	kg per Mg	kg per Mg	kg per Mg	kg per Mg
CH_4	4.20	4.00	0.41	5.63
N_2O	0.12	0.30	1.92	0.11
Source	Boldrin et al., 2009	EEA, 2009	MST, 2013	Boldrin et al., 2009

Emission factors for composting of GPW and for home composting of garden and vegetable food waste are derived from Boldrin et al. (2009). No other sources were found that describe the emission from home composting.

Boldrin et al. (2009) and MST (2013) do not directly provide any emission factors, the following assumptions were made to derive the factors shown in Table 8.5.4;

- 0.5 % N per dry matter waste water sludge
- 25 % moisture in waste water sludge.
- 2 % N per dry matter garden waste (incl. home composting)
- 25-50 % DOC per dry matter garden waste (incl. home composting)
- 50 % moisture in garden waste (incl. home composting)

The CO_2 produced and emitted during composting is short-cycled C and is therefore regarded as CO_2 neutral. (Boldrin et al., 2009).

8.5.2 Accidental building fires

Emissions from accidental fires are categorised under CRF category 6D Other Waste. Emissions that escape 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 houses, 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, ODIN is developed and run by* the Danish Emergency Management Agency (DEMA, 2007).

Activity data for accidental building fires are given by ODIN (DEMA, 2013). 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 fire hoses 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 fire-fighting and will typically involve a part of a single room in an apartment or house. And 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 1990-2012. For the years 2007-2012 the total number of registered building fires is known with a very high degree of detail.

Table 8.5.5 shows the occurrence of all types of fires (registered for 1990-2012) and the occurrence of building fires (2007-2012) registered at DEMA. In 2007-2010 the average per cent of building fires, in relation to all fires, was 60 %. The total numbers of building fires 1990-2006 are calculated using this percentage. The full time series is presented in Annex 3G, Table 3G-5.3.

Table 8.5.5 Occurrence of all fires and building fires.

	1990	1995	2000	2005	2010	2011	2012
All fires	17025	19543	17174	16551	16728	16157	14084
Building fires	10187	11694	10276	9903	9325	11447	9932

The building fires that occurred in the years 2007-2012 are subcategorised into six building types; detached houses, undetached houses, apartment buildings, industrial buildings, additional buildings and container fires.

Table 8.5.6 presents the calculated averages of the registered activity data for building fires for the years 2007-2010, divided in both damage size and building type. These data describe the average share of building fires from 2007-2010 of a certain type and size, in relation to all building fires in the same four years period.

Table 8.5.6 Average registered occurrence of building fires for 2007-2010. (DEMA).

	Size	Detached	Undetached	Apartment	Industry	Additional	Container	All building fires
Average, %	full	2.46	0.50	0.31	0.73	0.44	0.17	4.61
	large	4.01	1.14	1.09	1.69	3.08	1.92	12.93
	medium	5.24	2.33	6.15	2.92	4.30	18.46	39.40
	small	11.77	4.24	12.64	5.36	4.79	4.27	43.06
	all	23.47	8.21	20.19	10.70	12.61	24.82	100.00

It is assumed that the average percentages provided by the years 2007-2010 shown in Table 8.5.6 are compliable for the years 1990-2006. Hereby, similar activity data for building fires can be estimated back to 1990.

By applying the damage rates of 100 %, 75 %, 30 % and 5 % corresponding to the damage sizes full, large, medium and small, a full scale equivalent can be determined. Table 8.5.7 shows the calculated full scale equivalents (FSE). The full time series is shown in Annex 3G, Table 3G-5.4.

Table 8.5.7 Accidental building fires full scale equivalent activity data.

	1990	1995	2000	2005	2010	2011	2012
Container fires	750	861	756	729	594	729	584
Detached house fires	777	892	784	755	833	818	742
Undetached house fires	231	265	233	224	194	206	181
Apartment building fires	367	421	370	357	348	362	327
Industry building fire	320	368	323	311	281	334	298
Additional building fires	437	501	440	424	429	740	610

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 do 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 8.5.8 lists the emission factors that were chosen for 2012 as the best reliable and their respective references.

Table 8.5.8 Emission factors building fires, per FSE fire, 2012.

Compound	Unit /fire	Detached house	Undetached house	Apartment building	Industrial building	Additional building	Container	Source
CO_2 - total	Mg	32.4	26.2	15.2	78.1	3.9	1.8	Blomqvist et al., 2002
CO_2 - biogenic	Mg	26.4	21.4	12.4	67.6	3.2	0.2	Blomqvist et al., 2002
CO_2 - non-biogenic	Mg	6.0	4.9	2.8	10.5	0.7	1.7	Blomqvist et al., 2002
CH_4	kg	43.0	34.7	20.2	52.0	2.1	0.3*	NAEI, 2009

*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 annual average floor space; see Table 8.5.9. 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 1990-2012 are shown in Annex 3G, Table 3G-5.5a-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 8.5.9. The data are collected from Statistics Denmark and takes into account possible multiple building floors but not attics and basements. For the full time series see Annex 3G, Table 3G-5.6. 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 8.5.9 Average floor space in building types (Statistics Denmark, 2013).

	1990	1995	2000	2005	2010	2011	2012
Detached houses	156	155	156	162	163	164	165
Undetached houses	129	129	131	131	134	132	134
Apartment buildings	75	75	75	76	77	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 8.5.10.

Table 8.5.10 Building mass per building type.

	Unit	Detached house	Un-detached house	Apartment building	Industry building	Additional building	Container
Average floor area*	m^2	165	134	78	500	20	-
Building mass per floor area	kg per m^2	40	40	35	30	30	-
Total building mass	Mg per fire	6.6	5.4	2.7	15.0	0.6	1

* 2012 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 Mg and covers all types of containers, from small residential garbage containers to large shipping containers and waste/goods in storage piles.

No data was available for N_2O.

For more information on the emission factors, please refer to Hjelgaard (2013).

8.5.3 Accidental vehicle fires

Emissions that escape 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

As with accidental building fires, data for accidental vehicle fires are available through the Danish Emergency Management Agency (DEMA). DEMA provides very detailed data for 2007-2012; the remaining years back to 1990 are estimated by using surrogate data.

Table 8.5.11 shows the occurrence of fires in general and vehicle fires registered at DEMA. In 2007-2010 the average per cent of vehicle fires, in relation to all fires, was 20 %. The total numbers of vehicle fires in 1990-2006 are calculated using this percentage. The full time series is presented in Annex 3G, Table 3G-5.3.

Table 8.5.11 Occurrence of all fires and vehicle fires.

	1990	1995	2000	2005	2010	2011	2012
All fires	17025	19543	17174	16551	16728	16157	14084
Vehicle fires	3354	3850	3383	3260	3459	3255	2889

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 2007-2012 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 each of the fourteen vehicle categories for 2007-2012.

The total number of registered vehicles is known from Jensen et al. (2013) and Statistics Denmark (2013). 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 1990-2006.

Table 8.5.12 states the total number of national registered vehicles and the number of full scale equivalent vehicle fires. The full time series 1990-2012 is shown in Annex 3G, Table 3G-5.7a-c.

Table 8.5.12 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	1645454	479	8109	12	192317	19	45664	58
1995	1733242	504	14371	21	228074	22	48077	61
2000	1916364	557	15051	22	272386	27	50227	64
2005	2012216	585	15131	22	372674	36	49311	63
2010	2246675	646	14577	23	362385	38	44813	60
2011	2281539	584	13915	13	343355	43	43640	54
2012	2326778	514	13177	11	318668	32	42326	53

Continued

	Motorcycles/Mopeds		Caravans		Train		Ship	
	Registered	FSE fires	Registered	FSE fires	Registered	FSE fires	Registered	FSE fires
1990	163133	58	86257	24	7156	9	2324	26
1995	165272	58	95831	26	6854	8	1911	21
2000	233309	82	106935	29	4907	6	1759	19
2005	273904	97	121350	33	3195	4	1792	20
2010	301562	83	142354	37	2740	2	1773	16
2011	295488	91	142764	34	2943	3	1768	21
2012	295798	82	142654	33	3055	2	1772	14

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	1055	1	131880	82	33594	56			
1995	1058	1	130028	81	27986	46			
2000	1070	1	111736	69	23272	39			
2005	1073	1	104551	65	20965	35			
2010	1152	1	102619	77	18889	32	4	58	94
2011	1132	0	102619	59	18889	21	3	50	111
2012	1111	0	102619	68	18889	18	2	50	115

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, 2012). 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 8.5.13 and Annex 3G, Table 3G-5.8.

Table 8.5.13 Average weight of different vehicle categories, kg.

Year	Cars	Buses	Vans	Trucks	Motorcycles/ Mopeds
1990	850	10000	2000	15000	86
1995	923	10807	2492	14801	97
2000	999	11195	3103	15214	103
2005	1068	11560	3793	13258	116
2010	1144	11804	4498	11883	133
2011	1154	11907	4296	11291	135
2012	1160	11625	4150	10844	136

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 8.5.14 and in Annex 3G, Table 3G-5.9a-c.

Table 8.5.14 Burnt mass of different vehicle categories, Mg.

Vehicle category	1990	1995	2000	2005	2010	2011	2012
Passenger cars	407	466	557	625	739	674	592
Buses	116	223	242	251	266	160	130
Light duty vehicles	37	55	82	138	171	185	133
Heavy duty vehicles	869	902	969	829	715	606	579
Motorcycle, moped	5	6	8	11	11	12	11
Other transport	-	-	-	-	33	29	29
Caravan	30	36	44	53	63	59	57
Train	128	121	89	51	24	28	23
Ship	257	228	218	229	189	249	160
Airplane	12	11	12	10	7	3	5
Bicycle	-	-	-	-	0	0	0
Tractor	164	202	216	247	347	254	283
Combine harvester	530	476	425	409	398	271	236
Machine	-	-	-	-	43	51	53
Total	2555	2727	2863	2858	3025	2624	2319

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 8.5.15 lists the accepted emission factors and their respective references.

Table 8.5.15 Emission factors for vehicle fires, per Mg.

	Unit	Emission factor	Source
CO_2	Mg	2.4	Lönnermark et al., 2006
CH_4	kg	5	NAEI, 2009
N_2O	-	NAV	-

NAV = not available

8.5.4 Sludge spreading

Sludge from wastewater treatment plants is only spread out in the open with the purpose of fertilising crop fields. Greenhouse gas emissions from this activity are included in the agricultural sector, see Chapter 6.

8.5.5 Biogas production

Emissions from biogas production are divided and reported in different sections of this inventory according to the waste type and method.

Emissions from the combustion of biogas regardless of the origin are included in the energy sector and are allocated to the appropriate subsector in the Danish energy statistics. For the biogas production from organic waste with the purpose of energy production, the fuel consumption rate of the biogas production plants refers to the Danish energy statistics. The applied emission factors are the same as for biogas boilers (see Chapter 3, Energy).

Biogas production from manure and the reduced emissions of CH_4 and N_2O from gasification of manure is included in Chapter 6, Agriculture.

Fugitive emissions of CH_4 from anaerobic digestion of sludge have been kept equal to last year's NIR submission, i.e. 1% of the biogas production, and are included in Chapter 8.3. In the below section a presentation of status for available plant level data supporting a methane generation and combustion efficiency of 99% (cf. Eq. 8.3.3) is presented.

Flaring and venting from biogas production at WWTPs

Flaring and venting may occur in different degrees at WWTPs which have implemented anaerobic treatment of sludge for biogas generation. Venting may occur intentionally or unintentionally if there are technical problems at the plant. Flaring is intentional combustion of biogas and occurs for regulation of the gas pressure.

Table 8.5.16 presents available information on the amount of flared and vented biogas in absolute numbers as well as in per cent of the recovered biogas at three of the biggest wastewater treatment plants in Denmark.

Table 8.5.16 Biogas production data for the WWTPs Lynetten, Avedøre and Damhusåen.

WWTP		2007	2008	2009	2010	2011	2012
Lynetten[1]							
Biogas produced	Nm^3/year		6330381	5942571	5792838	6695142	7154932
Flaring	Nm^3/year		284615	659576	494972	946468	903613
	%		4,50%	11,10%	8,54%	14,14%	12,63%
Venting	Nm^3/year		NR	NR	NR	NR	NR
	%		NR	NR	NR	NR	NR
Biogas consumed at plant	Nm^3/year		6045766	5282995	5297866	5748674	6251319
Biogas reported to DEA[3]	Nm^3/year	4417670	4953913	4650708	4533525	3969338	6251318
	%		82%	88%	86%	69%	100%
Avedøre[3]							
Biogas produced	Nm^3/year	3300000	3400000	3100000	3300000	3100000	3300000
Flaring	Nm^3/year	140000	140000	54000	170000	36000	10000
	%	4,24%	4,12%	1,74%	5,15%	1,16%	0,30%
Venting	Nm^3/year	0	2661	9179	54400	130063	50246
	%	0%	0,08%	0,30%	1,65%	4,20%	1,52%
Biogas consumed at plant	Nm^3/year	3200000	3300000	3000000	3200000	2900000	3300000
Biogas reported to DEA[3]	Nm^3/year	2874932	3161242	2813589	2769597	2581438	2966742
	%	90%	96%	94%	87%	89%	90%
Damhusåen[2]							
Biogas produced	Nm3/year		2690037	1665416	2123357	1997333	1918325
Flaring	Nm3/year		57750	57750	307335	94150	236950
	%		2,15%	3,47%	14,47%	4,71%	12,35%
Venting	Nm3/year		NR	NR	NR	NR	NR
	%		NR	NR	NR	NR	NR
Biogas consumed at plant	Nm3/year		2632287	1607666	1816022	1903183	1681375
Biogas reported to DEA[3]	Nm3/year		NR	NR	NR	NR	NR
	%		NR	NR	NR	NR	NR

[1]Lynettefællesskabet (2009, 2010, 2011, 2012, 2013);[2]Spildevandscenter Avedøre (2012, 2013);[3]DEA (2013);[4]NR:Not Reported.

As may be observed from Table 8.5.16, the amount of flaring is varying from year to year for the same plant as well as between WWTPs. The average flaring is 10 % at Lynetten (data for five years), 2.8 %at Avedøre (data for six years), and 7.4 % at Damhusåen (data for five years). Venting is only reported for Avedøre and constitute in average 1.3 % of the produced amount of biogas. Work is ongoing to extent the documentation for flaring and venting at biogas producing WWTPs (cf. Chapter XX).

The methodology used for estimating the CH_4 and N_2O emissions from wastewater handling are described in Chapter 8.3, Wastewater Handling.

Methodological issues

Biogas production in this sector covers fugitive emissions from the handling of biological waste, sludge and manure. This includes activities like storage, pre- and post-treatment during which anaerobic conditions may occur, and fugitive emissions from the anaerobic digestion that is the actual production. However, emissions from these activities are not currently included in the inventory.

This source also covers emissions from combustion of biogas in biogas production plants (mentioned as Gasification of biogas in the CRF tables) for the years 1994-2005 where these emissions existed. This activity is not occurring in 2006 - 2012. Pollutants from this activity are CH_4 and N_2O.

Activity data

Activity data for this source category are collected from the energy statistics (DEA, 2012). Combustion of biogas in biogas production plants occurred for the years 1994-2005[1].

Table 8.5.16 Combusted biogas.

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
GJ	857	4711	4503	4447	35416	43688	40990	27270	30567	35544	28744	22034

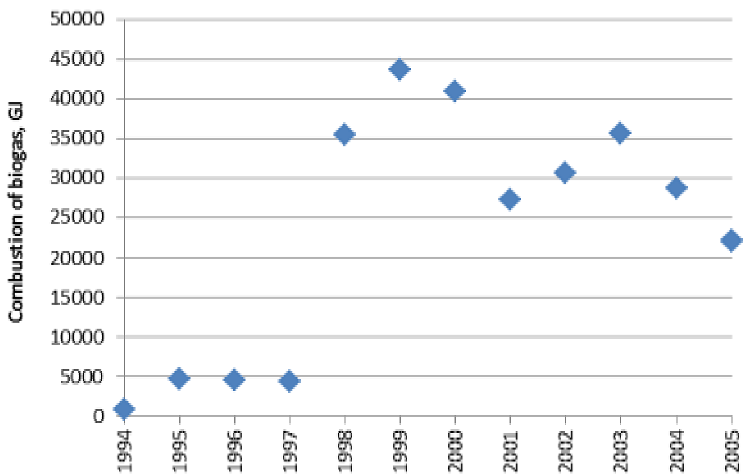

Figure 8.5.2 Combusted biogas at biogas production plants.

[1] Activity data for combustion of biogas is in need of an updating, this will be done as soon as the energy statistics for 2013 is available.

Emission factors

Emission factors for combustion of biogas in biogas production plants are presented in Table 8.5.17. These are outdated emission factors for biogas boilers and will be updated in the next sector report.

Table 8.5.17 Emission factors for combustion of biogas, per GJ.

Pollutant	Unit	Emission factor
CH_4	g	4
N_2O	g	2

8.5.6 Other

Other combustion sources included under Waste Other are the open burning of yard waste and bonfires.

Due to the cold and wet climatic conditions in Denmark wild fires very seldom occur. Controlled field burnings and the occasional wild fires are categorised under the Chapters on 6 Agriculture and 7 Land Use, Land Use Change and Forestry (LULUCF) respectively.

In Denmark, the open burning of private yard waste is under different restrictions according to the respective municipality. These restrictions involve what can be burned but also the quantity, how, when and where, or in some cases a complete ban is imposed. The burning of yard waste is not allowed within urban areas (DEPA, 2011b). There is no registration of private waste burning and the activity data on this subject are very difficult to estimate. Citizens are generally encouraged to compost their yard waste or to dispose of it through one of the many waste disposal/recycling sites.

The occurrence of bonfires at Midsummer's Eve and in general are likewise not registered, therefore it has not been possible to obtain activity data and consequently, bonfires are not included in this inventory.

8.6 Uncertainties and time series consistency

Two set of uncertainty estimates are made for the Danish emission inventory for greenhouse gases based on Tier 1 and Tier 2 methodology, respectively. The uncertainty models follow the methodology in the IPCC Good Practise Guidance (IPCC, 2000). Tier 1 is based on the simplified uncertainty analysis and Tier 2 is based on Monte Carlo simulations.

8.6.1 Input data

Solid Waste Disposal on Land

The waste amounts for solid waste disposal on land 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 2000, page 5.12, Table 5.2) default values and provided in Table 8.6.1.

Table 8.6.1 Tier 1 input parameter uncertainty, %.

Parameter	Parameter ID	Uncertainty %	Note
The Waste amount sent to SWDS	*W*	10	Since the amounts are based on weighing at the SWDS the lower value in IPCC (2000), is used
Degradable Organic Carbon	DOC_i	50	Highest value, IPCC 2000, page 5.12, Table 5.2
Fraction of DOC dissimilated	DOC_f	30	Highest value, IPCC 2000, page 5.12, Table 5.2
Methane Correction Factor	*MCF*	10	IPCC, 2006
Fraction of CH_4 in landfill gas		10	Medium value, IPCC 2000, page 5.12, Table 5.2
Methane Generation Rate Constant	*k*	100	IPCC 2000, page 5.12, Table 5.2

The waste amounts for solid waste disposal on land 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 %. The default uncertainty range for the methane generation constant, k, is: -40 % to +300 %.; for the Tier 1 uncertainty calculation it has been set to 100 % (Limpert et al., 2001). For the remaining parameters default uncertainties are used until country-specific parameters becomes available.

The uncertainty on the implied emission factor, U_{ief}, is based on uncertainty estimates in Table 8.6.1 and is approximated with IPCC (2000) Equation 6.4 equals

U_{ief} % = SQRT($50^2+30^2+10^2+10^2+100^2$) = 117.9 %

These uncertainties give the combined Tier 1 uncertainty on the emission from SWDS of: SQRT($10^2+117.9^2$) = 118.3 %.

Wastewater Handling

The uncertainty levels used in the Tier 1 and 2 uncertainty models are shown in Table 8.6.2.

Table 8.6.2 Estimated uncertainty rates for activity data and emission factors, %.

95 % confidence interval uncertainties	Activity data	Emission factor
N_2O, WWT, direct	20	53
N_2O,WWT, indirect	42	42
CH_4, Sewer system and WWTP processes	24	32
CH_4, Anaerobic digestion	24	39
CH_4, Septic tanks (scattered houses)	31	32

Default IPCC values are assumed to be given at 95 % confidence level. For the country-specific activity data, the standard deviation of different data sources has been used for deriving per cent uncertainty estimates. Annex 3G, Table 3G-3.6 elaborates on the different values and their references.

Uncertainties have been derived from IPCC default values and uncertainties in country-specific parameters, respectively (cf. Annex 3G, Table 3G-3.6).

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 %. The uncertainty of the activity data from animal cremations is also minimal for the most recent years (1998-2012) but is increasing back in time (to 67 % in 1990). The uncertainty is set to 67 % in 1990 and 5 % for 2012 (Authors expert judgement).

Table 8.6.4 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 8.6.4 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	-	5/67	5/67
Emission factor	-	150	150

Waste Other

Activity data for composting are estimated for the years 1990-1994 and 2010-2012 resulting in a higher level of uncertainty these years; this is set at 40 %.

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 (2007-2012) (Authors expert judgement).

Activity data for combustion of biogas at biogas production facilities are available from the national energy statistics; the uncertainty for this activity is set to 5 %. However, this activity only exists in 1994-2005 and is therefore not part of the uncertainty calculations.

Table 8.6.5 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 1990-2011.

Table 8.6.5 Estimated uncertainty rates for activity data and emission factors, %.

95 % confidence interval uncertainties	CO_2	CH_4	N_2O
Compost production			
Activity data	-	40	40
Emission factor	-	100	100
Accidental building fires			
Activity data	10	10	-
Emission factor	300	500	-
Accidental vehicle fires			
Activity data	10	10	-
Emission factor	500	700	-

The input parameter uncertainties are at the same aggregation level as reported in last year's NIR (Nielsen et al., 2013).

8.6.2 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 8.6.6.

The overall uncertainty interval for greenhouse gases (GHG) is estimated to be ±86.8 % and the trend in GHG emission, calculated as the per cent change in GHG emissions in 2011 compared to 1990, is -37.8 % ±13.6 %.

Table 8.6.6 National Tier 1 uncertainty estimates for the waste sector.

Pollutant	National emission, 2012, Gg	Total emission uncertainty, %	Trend* 1990-2011, %	Trend uncertainty, %
GHG**	1063.97	±78.3	-32.4	±20.7
CO_2	16.36	±261.1	-6.7	±11.0
CH_4	41.14	±89.1	-38.7	±14.0
N_2O	0.64	±73.9	69.4	±175.4

*Per cent change in emission in 2011 with respect to the base year 1990.

**GHG emissions are calculated in units of CO_2 equivalents.

8.6.3 Tier 2 uncertainty results

The Tier 2 uncertainty estimates for the waste sector are calculated from the input data presented in Section 8.6.1; results are shown in Table 8.6.7. The calculations are based on a Monte Carlo approach as described in Chapter 1.7.

Table 8.6.7 National tier 2 uncertainty estimates for the waste sector, [Gg]

	1990 National emission, [Gg]			2012 National emission, [Gg]			1990-2012 Trend, [Gg]		
	Mean	Uncertainty interval, [%]		Mean	Uncertainty interval, [%]		Mean	Uncertainty, [%]	
		lower (-)	upper (+)		lower (-)	upper (+)		lower (-)	upper (+)
GHG	1629	-56	162	1138	-45	116	-454	-97	159
CO_2	27	-66	355	25	-67	344	-2	-6	32
CH_4	88	-62	179	31	-51	137	-54	-76	180
N_2O	0.04	-53	139	0.43	-51	118	0.38	-1134	457

Greenhouse gas (GHG) emissions are calculated in CO_2 equivalents.

8.6.4 Time series consistency and completeness

Solid Waste Disposal on Land

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. The activity data are, therefore, 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 emission factor 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 (1997) and IPCC (2000).

As regards completeness, the waste amounts used, as registered in the ISAG system, do not only include traditional Municipal Solid Waste (MSW), but also non-MSW such as Industrial Waste, Building and Construction Waste and Sludge. The composition of these waste types is, according to Danish data, used to estimate DOC values for the waste types (refer IPCC 2000, page 5.10). Improvement are planned to increase completeness and appropriateness of waste types as described in Chapter 8.9

Wastewater Handling

Consistency and completeness have been improved by access to the Danish Water Quality Parameter Database (www.miljoeportal.dk) and the Danish Sludge Database held by DEPA.

Data regarding industrial on-site wastewater treatment processes is not available at a level that allows for calculation of the on-site industrial contribution to CH_4 or N_2O emissions. The degree to which industry is covered by the estimated emission is, therefore, dependent on the amount of industrial wastewater connected to the municipal sewer system. Any direct emissions from pre-treatment on-site are not covered in this inventory.

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 1998-2012 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.

Waste Other

For compost production, activity data are not consistent as data are only available for 1995-2009. Data for 1990-1994 and 2010-2012 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.

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.

For accidental fires, DEMA provides detailed data for 2007-2012 and the total number of nationally registered fires for 1990-2012. 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 6 Agriculture.

8.7 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.

8.7.1 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 8.7.1a 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 U:\ST_ENVS-Luft-Emi\Inventory\2012\6_Waste\Level_1a_Storage*	Inventory data storage system	AD and EF	DCE		
Report series published and available from the Danish Environmental Protection Agency www.mst.dk	Reported sludge and water quality parameters	AD	Report series from DEPA: "*Wastewater sewage sludge from municipal and private wastewater treatment plants*" (1997-2005) "*Point sources*" (1993-2005)	Marianne Thomsen (mth@dmu.dk)	Public available reports
Report series published by the Agency for Spatial and Environmental Planning (ASEP) and available from the Danish Nature Agency (DNA): www.nst.dk			Report series: "*Point sources*" (2006-2012)	Naturstyrelsen Vestjylland Anna Gade Holm (angho@nst.dk) Marianne Thomsen (mth@dmu.dk)	Public available reports
Danish Water Quality parameter Database	Annually reported wastewater characteristics at plant level which includes all years 1990- 2012	AD	www.miljoeportalen.dk	Naturstyrelsen Vestjylland Anna Gade Holm (angho@nst.dk) Marianne Thomsen (mth@dmu.dk)	Authorised access
Danish Sludge Database	Annually reported sludge characteristics at plant level	AD	DEPA	Linda Bagge (bagge@mst.dk) Marianne Thomsen(mth@dmu.dk)	none
I:\ROSPROJ\LUFT_EMI\Inventory\2011\6_Waste\Level_1a_Storage\6A Solid Waste Disposal	U:\ST_ENVS-Luft-Emi\Inventory\2012\6_Waste\Level_1a_Storage\6A SWDS	Activity data	The Danish Environmental Protection Agency, database on all registered Danish waste. Available at: http://www2.mst.dk	Unit for Soil and Waste Eik Kristensen (eikri@mst.dk)	The amounts are registered due to statutory requirements

Continued					
I:\Rosproj\LUFT_EMI\Energy\2011	Basic data DS1 Dataset for energy-producing SWDS	CH_4 recovery data	The Danish Energy Agency (DEA)	Peter Dal (pd@ens.dk)	Prepared due to the obligation of DEA
I:\ROSPROJ\LUFT_EMI\Inventory\2011\6_Waste\Level_1b_Processes\6A Solid Waste Disposal	Excel file with the FOD model swds_fod_model 2011.xls DP1	Parameters of the FOD model	IPCC 1997 and 2000	Marianne Thomsen (mth@dmu.dk)	
http://www.dkl.dk	Number for cremations	AD	Association of Danish Crematories	Hanne Ring hr@dkl.dk	Public access
http://www.statistikbanken.dk	Statistics for population, buildings and vehicles	AD	Statistics Denmark		Public access

*The data storage level 1 consists of DEPA reports and data extracted from other sources listed in the Table.

Table 8.7.1b Overview of annually stored external data sources at DS level1 (Continued).

http, file or folder name	Description	AD or EF	Reference	Contact	Data agreement/ Comment
U:\ST_ENVS-Luft-Emi\Inventory\2012\6_Waste\Level_1a_Storage\6C Waste Incineration	Cremated animal carcasses	AD	Dansk Dyrekremering ApS	Knud Ribergaard info@danskdyrekremering.dk	Personal contact
U:\ST_ENVS-Luft-Emi\Inventory\2012\6_Waste\Level_1a_Storage\6C Waste Incineration	Cremated animal carcasses	AD	Ada's Kæledyrskrematorium ApS	Anders Oxholm anders@adakrem.dk	Personal contact
U:\ST_ENVS-Luft-Emi\Inventory\2012\6_Waste\Level_1a_Storage\6C Waste Incineration	Cremated animal carcasses	AD	Kæledyrskrematoriet	Annette Laursen dyrepension@skylinemail.dk	Personal contact
https://statistikbank.brs.dk	Categorized fires	AD	The Danish Emergency Management Agency	Steen Hjere Nonnemann shn@beredskabs styrelsen.dk	Public access
http://www2.mst.dk/udgiv/publikationer/2010/978-87-92668-21-9/pdf/978-87-92668-22-6.pdf	Waste categories for composting	AD	Danish Environmental Protection Agency (DEPA), Waste Statistics		Public access

8.7.2 Data Processing Level 1

This level comprises a stage where the external data extracted from the waste data system (DEPA, 2013) are processed internally. For SWDS 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 Thomsen et al., 2014 and in Annex 3G, Table 3G-2.4. The model runs in excel and the output are stored inside the excel file. For Wastewater Handling data are prepared for the input to the country-specific models. Programming as to automatically calculations based on activity data and emission factors are not yet fully operational. 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, this year's improvements are documented in Chapter 8.3.1.

For the CRF categories 6C and 6D, 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.

8.7.3 Data Storage Level 2

Data Storage Level 2 is the placement of selected output data from the calculation of emissions as inventory data on SNAP levels in the Access (CollectER) database.

8.7.4 Data Storage Level 4

Data Storage Level 4 is the placement of the calculated output data from the calculation of emissions as data on SNAP levels in the CRFs.

8.7.5 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. 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 8.6.1. Due to the statutory environment for these data, while the distribution of waste fractions according to waste type and their content of DOC is more uncertain (per cent uncertainty set equal to 50 %, cf. Table 8.6.1). 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 in the FOD models is an important parameter with some uncertainty (cf. Table 8.6.1).

The input parameter uncertainties for Wastewater Handling have been derived from standard deviations between activity data extracted from national databases and reported national statistics as shown in Table 8.6.2. Uncertainties on defaults numbers are taken from the IPCC (1997 and 2000). Uncertainty of activity data are based on simple standard deviations accompanying the annual reported monitoring data.

For Waste Incineration and Waste Other the level of uncertainty is generally low for activity data but higher for emission factors, cf. Table 8.6.4 and 8.6.5. Expert judgments are used whenever default uncertainties are not available.

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., 2007 and 2014 and in the methodology report by Thomsen & Lyck, 2005 and Thomsen and Hjelgaard (2014).

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 the new waste data system: amounts of the various waste fractions deposited (refer to Section 8.2.1).
- A Danish investigation and verification of the overall mass balance upon allocating waste fractions within the old ISAG and the new waste data system into 18 definedwaste types (Thomsen and Hjelgaard, 2014).
- 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 each year, no later than January 31. Registration is made by mass for the individual waste categories. A New waste reporting system has been implemented and the nine waste types reported in the last NIR extended to 18 waste fractions of which 11 are characterised as inert. The individual waste type characteristics have been documented in Table 8.2.2 and Table 8.2.3 as well as in Annex 3G, Table G3-2.3 and G3-2.4.

For recovery data, the DEA registers the energy produced from plants where installations recover CH_4 for the energy statistics (cf. chapter 8.9 on planned improvements for the waste category 6.A..

For the parameters of the FOD model, references are made to IPCC (1997, 2000 and 2006).

WWT

- The Danish sludge database (Table 8.3.4)
- The Danish Water Quality Parameter Database (www.miljoeportal.dk)

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.

Waste Other

- Waste Statistics (DEPA, 1996, 1998, 1999, 2001a, 2001b, 2002, 2004a, 2004b, 2005, 2006a, 2006b, 2008, 2010a, 2011a)
- Danish Emergency Management Agency (DEMA) database
- Emission factors from literature

The waste statistics are based on data from the ISAG database, which is the only Danish registration of waste amounts. Also the DEMA database is the only provider of data on accidental fires; data for newer years (2007-2011) 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 (ISAG, Water Quality Parameter, sludge, 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 is 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 January 31 for the previous year. No explicit agreements have been made with external institutions.

However for Wastewater Handling, this point may still be critical due to the missing timing full reporting and completeness of the databases held by the ASEP and DEPA respectively with respect to the submission date of the annual NIR.

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 8.7.1a and b.

For a listing of all archived external datasets, see 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 8.6.

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 (1997, 2000 and 2006). For WWT the calculations follow the IPCC (1997 and 2000). 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.

For SWDS there is no quantitative knowledge in the methodology on either (1) the shift in waste fractions within waste categories for 1960-1984 and 1986-1993, (2) the development over time of the DOC content in individual waste fractions or (3) possible individual conditions relating to the SWD sites. On-going research might change this lack.

Data on separate industrial WWTPs. Information on methane emissions for separate industries may be of importance.

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.

Activity data for accidental fires for the years 1990-2006 are not subcategorised into vehicles, buildings or sizes.

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 of the time series. Any changes in calculation procedures are noted for each year's inventory, cf. Section 8.6.4.

Data Processing level 1	5.Correctness	DP.1.5.1	Verification of calculation results using time series

The time series of activities and emissions in the model output, in the SNAP source categories and in the CRF format have been prepared. The time series are examined and significant changes are checked and explained. Comparison is made with the previous year's estimate 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 "Methodological issues", Section 8.2.1, 8.3.2, 8.4.1, 8.4.2, 8.5.1, 8.5.2 and 8.5.3.

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 (8.7.1a and b).

The calculation principle and equations are described in "Methodological issues", Section 8.2.1, 8.3.2, 8.4.1, 8.4.2, 8.5.1, 8.5.2 and 8.5.3.

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 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.

See DP.1.5.1 and DP.1.5.2.

8.8 Source specific recalculations

Table 8.8.1 presents the recalculations to the waste sector for this year's inventory. Tables with the full time series 1990-2011 are shown in Annex 3G, Table 3G-6.1, 3G-6.2, 3G-6.3, 3G-6.4 and 3G-6.5.

Table 8.8.1. Changes in emissions from the waste sector compared with last year´s submission.

	Unit	1990	1995	2000	2005	2010	2011	2012
Solid Waste Disposal on Land								
CH_4, previous inventory	Gg	70.4	60.5	0.57	40.8	34.3	33.3	
CH_4, recalculated	Gg	65.0	57.6	0.57	41.1	34.3	34.8	33.2
Change, CO_2-equivalents	Gg	-112.0	-60.1	0.71	5.9	0.2	32.3	
Change	%	-7.6	-4.7	0.71	0.7	0.0	4.6	
Wastewater Handling								
CH_4, previous inventory	Gg	3.15	3.27	3.52	3.54	3.59	3.62	
CH_4, recalculated	Gg	3.12	3.23	3.48	3.45	3.53	3.56	3.52
N_2O, previous inventory	Gg	0.34	0.35	0.29	0.27	0.25	0.26	
N_2O, recalculated	Gg	0.34	0.35	0.29	0.27	0.25	0.26	0.23
Change, CO_2-equivalents	Gg	-0.70	-0.84	-0.90	-1.93	-1.24	-1.29	
Change	%	-0.41	-0.48	-0.55	-1.21	-0.82	-0.83	
Waste Incineration								
CH_4, previous inventory	Mg	0.51	0.55	0.57	0.62	0.76	0.71	
CH_4, recalculated	Mg	0.51	0.55	0.57	0.62	0.76	0.71	0.70
N_2O, previous inventory	Mg	0.64	0.69	0.71	0.77	0.95	0.88	
N_2O, recalculated	Mg	0.64	0.69	0.71	0.77	0.95	0.88	0.88
Change, CO_2-equivalents	Gg	0.00	0.00	0.00	0.00	0.00	0.00	
Change	%	0.00	0.00	0.00	0.00	0.00	0.00	
Waste Other								
CO_2, previous inventory	Gg	18.28	20.11	18.77	18.20	18.19	18.21	
CO_2, recalculated	Gg	17.54	19.60	18.40	18.14	18.35	18.45	16.36
CH_4, previous inventory	Gg	1.40	1.80	3.06	3.31	3.91	4.02	
CH_4, recalculated	Gg	1.46	1.95	3.32	3.50	4.17	4.29	4.38
N_2O, previous inventory	Gg	0.04	0.05	0.13	0.10	0.14	0.14	
N_2O, recalculated	Gg	0.04	0.07	0.52	0.20	0.36	0.38	0.41
Change, CO_2-equivalents	Gg	1.61	9.18	123.38	33.42	73.10	79.76	
Change	%	2.70	12.43	99.03	27.80	51.10	54.28	
Total Waste								
CO_2, previous inventory	Gg	18.3	20.1	18.8	18.2	18.2	18.2	
CO_2, recalculated	Gg	17.5	19.6	18.4	18.1	18.3	18.4	16.4
CH_4, previous inventory	Gg	74.9	65.5	57.2	47.6	41.8	40.9	
CH_4, recalculated	Gg	69.6	62.8	56.7	48.0	42.0	42.7	41.1
N_2O, previous inventory	Gg	0.4	0.4	0.4	0.4	0.4	0.4	
N_2O, recalculated	Gg	0.4	0.4	0.8	0.5	0.6	0.6	0.6
Change, CO_2-equivalents	Gg	-111.1	-51.7	107.5	37.4	72.0	110.8	
Change	%	-6.5	-3.4	8.0	3.3	7.1	11.1	

8.8.1 Solid waste disposal on land recalculations

The recalculation of emissions from Solid Waste Disposal on Land is caused by an in depth 1) disaggregation and re-allocation of the old ISAG waste categories according to 18 characterised waste types and 2) allocation of waste amounts reported in the new waste data system into the same 18 defined waste types within this years NIR. The 18 waste types are characterised I terms of their content of degradable organic matter, DOCi, and half-life times, t½, as provided in Table X. A detailed description of the waste characterisation of ISAG and EWC waste types and the weights used for allocation into the new 18 waste types have been according to mass conservation. The impacts of all changes made to the input parameters and waste amounts (according to types) on the calculated emissions from SWDS are provided in Table 8.8.1.

8.8.2 Wastewater Handling recalculations

For Wastewater Handling recalculations have been made to the N_2O emission. Minor changes in the effluent tonnes N for the years 2007-2010 have been made due to updated information from the Danish EPA and updated data on amount of biogas produced from the anaerobic digestion of sludge. The major reason for the observed reduction of the total emission from Sector 6.B is due to the elimination of a correction factor that was not justified after verification of nitrogen effluent data with the newest reporting of effluent data in the report series "point sources" published by the Danish EPA (DEPA, 2012). As mentioned in Section 8.9 a verification of completeness in the activity data throughout the time series has been initiated and will be published in a sector report (Chapter 8.9).

The effect of the correction is shown in Table 8.8.1.

8.8.3 Waste Incineration recalculations

No recalculations were made for Waste Incineration.

8.8.4 Waste Other recalculations

For sector 6.D. Waste Other several recalculations were made. Changes were made in the vehicle fires and composting source categories.

For vehicle fires; the time-series for vehicle population delivered from an external source has been updated along with the estimated average weights of some vehicle types, the result is a decrease of CH_4 and CO_2 emissions from 1990-2006 and an increase for 2007-2011.

Emission factors have been updated for composting of sludge and organic municipal waste which have resulted in increased emissions of CH_4 and N_2O.

The joint effect of these recalculations is an increase in CH_4 emissions between 2 % (1990) and 12 % (2002), for CO_2 emissions have decreased from 1990 (4 %) to 1997 (0.4 %) and increased from 1998 (14 %) to 2011 (1 %), and finally the N_2O emissions have increased for all years with between 10 % (1990) and 370 % (2002).

8.9 Source specific planned improvements

For the category 6a.SDWS, plant specific data was made available from the new waste reporting system in November 2013, which forms the basis for exploring the possibility of obtaining model input parameter data at plant level. The first step towards a plant level emission model for SWDS in Denmark is to review available data on methane emissions and recovery data as well as plant specific input parameters for the FOD model (e.g. DEPA, 2011). Special focus before the next reporting year, will be to verify plant level emission data, using the 18 defined waste types, against emission data reported to the National PRTR reporting system, as well as to verify plant level recovered emissions against the Energy statistics and Energy Producer Accounting system produced by the Danish Energy Agency.

Regarding 6B. Wastewater Handling, new data on extension of the collective sewerage system in Denmark have not yet become available. We plan still to document reduced emissions from scattered settlements and to include such documentation in the next inventory in terms of a reduction in the fraction of the population not connected to the municipal sewer system.

Likewise, alternative solutions to the treatment of wastewater from scattered houses as well as development in aquaculture and marine fish farming activities in Denmark will influence indirect N_2O emissions, why improvements are expected. However, these improvements are long term aspects realised as the necessary documentation becomes available.

There are no other planned improvements for the waste sector.

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9 Other (CRF sector 7)

In CRF Sector 7, there are no activities and emissions for the inventories of Denmark. Until the 2009 submission in the inventories of the Kingdom of Denmark (Denmark, Faroe Islands and Greenland) emissions from Faroe Islands and Greenland were reported in Sector 7. This has been changed so that Greenland and Faroe Islands are included in full CRF's.

For further detail on the emissions from Greenland and the Faroe Islands please see Chapter 16 and Annex 9.

10 Recalculations and improvements

Previously the recalculation tables in the CRF have been incorrect due to the different geographical scopes of the inventory and technical limitations in the CRF Reporter software. However, by running five different installations of the CRF Reporter software, the data presented in Table 8 of the CRF are accurate. Explanations for the recalculations of the Danish inventory are included in Chapter 10.1.1.

The overall impact of recalculations is shown in Table 10.1. A more detailed overview is provided in Tables 10.2 – 10.5.

Information on recalculations for the aggregated submission of Denmark and Greenland under the Kyoto Protocol are included in Chapter 17.

10.1 Explanations and justifications for recalculations

Explanations and justifications for the recalculations performed in this submission, since submission of data to the UNFCCC due April 15, 2013 for Denmark, are given in the following sector chapters:

Energy:	
• Stationary Combustion	Chapter 3.2.8
• Transport	Chapter 3.3.7
• Fugitive emissions	Chapter 3.5.8
Industry:	
• Mineral products	Chapter 4.2.5
• Chemical industry	Chapter 4.3.4
• Metal production	Chapter 4.4.4
• Food and drink	Chapter 4.5.4
• Consumption of f-gases	Chapter 4.7
Solvents and Other Product Use	Chapter 5.6
Agriculture	Chapter 6.10
LULUCF	
• Forest Land	Chapter 7.2.1, 7.2.2
• Cropland	Chapter 7.3
• Grassland	Chapter 7.4
• Wetlands	Chapter 7.5
• Settlements	Chapter 7.6
Waste	
• Solid Waste Disposal on Land	Chapter 8.8.1
• Wastewater	Chapter 8.8.2
• Waste incineration	Chapter 8.8.3
• Waste, Other	Chapter 8.8.4
KP-LULUCF	
• ARD	Chapter 11.3.5

- FM Chapter 11.4.5
- CM Chapter 11.5.5
- GM Chapter 11.6.4

The main recalculations since the 2013 submission are:

10.1.1 Energy

Stationary Combustion

For stationary combustion plants, the emission estimates for the years 1990-2011 have been updated according to the latest energy statistics published by the Danish Energy Agency. The update included both end use and transformation sectors as well as a source category update. The changes in the energy statistics are largest for the years 2009, 2010 and 2011.

For CO_2 the largest recalculation is in source category Manufacturing industries and constructions. The recalculation is related to liquid fuels and is a result of correction of an error. The consumption of residual oil was underestimated in the former inventories. The CO_2 emission from liquid fuels applied in manufacturing industries and construction for 2011 is 7% higher in the 2014 reporting than in the 2013 reporting.

The CH_4 emission from residential wood combustion has been recalculated based on improved emission factors for stoves. This has caused a 16 % increase of the CH_4 emission reported for biomass fuels in residential plants for 2011.

For N_2O the largest recalculation is in source category Manufacturing industries and constructions. This recalculation is also related to the former underestimate for residual oil. The N_2O emission from liquid fuels applied in manufacturing industries and constructions for 2011 is 13 % higher in the 2014 reporting than in the 2013 reporting.

Mobile sources

The following recalculations and improvements of the emission inventories have been made since the emission reporting in 2013.

Road transport

Based on the updated version of COPERT IV launched in 2013, new vehicle sub categories have been introduced in the emission inventories for mopeds and passenger cars. For mopeds a division is now made between 2-stroke and 4-stroke engine technologies and for passenger cars small engine sizes below 0.8 l. for gasoline and below 1.4 l. for diesel have been included. Also NO_x emission factors for euro 5 diesel passenger cars have been updated in the model based on the new COPERT IV version.

Small errors in input gasoline fuel consumption for the years 2009-2011 and for input diesel fuel consumption in the years 2010-2011 have been corrected.

The percentage emission change interval and year of largest percentage differences (low %; high %, year) for the different emission components are: CO_2 (-0.5 %; -0.05 %, 2008), CH_4 (-0.2 %; 2.4 %, 2011) and N_2O (-0.4 %; 0.3 %, 2008).

Navigation

Minor changes in ferry input data has been made for the years 2008-2011 causing minor emission changes for domestic navigation. The following largest percentage differences (in brackets) for domestic navigation are noted for: CO_2 (-1.0 %), CH_4 (-0.8 %) and N_2O (-1.1 %).

Agriculture/forestry/fisheries

The number and engine size of machine pool tractors has been updated for the years 2007-2011. The number of ATV's has been changed for the years 2009-2011. Errors in the fuel consumption for fisheries in 2000, 2010 and 2011 have been corrected.

In 2000 the following percentage differences (in brackets) for agriculture/forestry/fisheries are noted for: CO_2 (9.1 %), CH_4 (3.7 %) and N_2O (11.9 %) due to fuel consumption changes in fisheries.

For other years than 2000, the following largest percentage differences (in brackets) are noted for: CO_2 (-3.7 %), CH_4 (5 %) and N_2O (-4.9 %).

Industry

The number of mini loaders has been updated for the years 2004-2011.

The following largest percentage differences (in brackets) for industrial non road machinery are noted for: CO_2 (1.0 %), CH_4 (1.6 %) and N_2O (1.6 %).

Civil aviation

An error in the CH_4 emission factor has been corrected for the years 1985-2000. The emission factors are now in line with the factors proposed by the EMEP/EEA emission inventory guidebook. The CH_4 emission percentage differences are between -31 % and -42 %.

Military

Emission factors derived from the new road transport simulations have caused some emission changes from 1985-2010.The following largest percentage differences (in brackets) for military are noted for: CO_2 (0 %), CH_4 (0.6 %) and N_2O (0.2 %).

Fugitive emissions

In the emission inventory reported in 2014 for the years 1990-2012 the following recalculations regarding fugitive emissions from fuels have been applied:

Natural gas transmission and distribution

Activity data and IEF for the time series 1990-2011 has been updated for transmission and distribution according to annual environmental reports and the latest national energy statistics, respectively. Further, the CH_4 EFs are updated for one town gas distribution company following an update of the estimated fugitive losses per distribution. The recalculation has changed the CO_2 emission by 0.01 ktonnes and CH_4 emission by (-0.09) - 0.07 ktonnes, corresponding to < 0.003% and (-2) % - 2% of the total fugitive CO_2 and CH_4 emission.

Venting

EFs for CH4 have been added for the years 1990-1993 for one gas storage plant. In these years the plant is treated as an area source in the national system, while it is treated separately as a point source in the following years.

EFs are based on data from annual reports for 1995-1999, as no data are available for the years 1990-1994. Further, a minor error has been applied for venting in 2011, according to the annual report from one of the natural gas storage facilities. The recalculation has changed the CH_4 emission by 0.06 ktonnes, corresponding to 2% of the total fugitive CH_4 emission.

Flaring in gas storage and treatment plants

EFs for CO_2 and CH_4 have been added for the years 1990-1993 for the gas treatment plant. In these years the plant is treated as an area source in the national system, while it is treated separately as a LPS in the following years. EFs are based on data from annual reports for 1995-1999, as no data are available for the years 1990-1994. The recalculation has changed the CO_2 emission by 2.2 ktonnes and the CH_4 emission by 0.01 ktonnes, corresponding to 0.4 % and 0.4 % of the total fugitive CO_2 and CH_4 emission.

Flaring in refineries

The CO2 EF for one refinery has been updated for the years 1994-2006 and now reflects the average EF from the first five EU-ETS reports (2007-2011). The NOx EF for two refineries has been changed to the standard EF in the EMEP/EEA Guidebook, as references to the previously applied EFs are outdated or not existing.

The CO2 EF for a refinery that was shut down in 1996 has been changed for the years 1990-1996 to match the existing refineries, as no better data is available. CO2 EF for 2010-2011 has been updated and now corresponds to the EU-ETS reporting. The recalculation has changed the CO2 emission by (-0.05) – 0.49 ktonnes and CH4 emission by (-0.06) ktonnes, corresponding to (-0.01) – 0.1% and (-2) % of the total fugitive CO2 and CH4 emission.

10.1.2 Industrial Processes

Lime production

EU-ETS data have been implemented for one lime production plant for the years 2011 and 2012 leading to a minor decrease in the overall emission of CO_2 emission by 5.51 ktonnes. This change in methodology will be implemented for the previous years in the next submission.

Limestone and Dolomite Use

Activity data for flue gas cleaning have been changed for three power and waste incineration plants in 2011. Consumption of $CaCO_3$ has increased with 236 tonnes and $CaCO_3$ containing residues have increased with 669 tonnes resulting in an increased CO_2 emission of 162 tonnes.

An error in transferring data from the emission database to CRF Reporter has been corrected for 1995-2011 for two individual plants.

Chemical industry

The process emission has been adjusted to reflect the total emission reported in environmental reports minus the energy related emissions reported to EU-ETS.

Consumption of Halocarbons and SF_6 – SF_6 – Other

A minor correction has been made to emission of SF_6 from double glazed windows for 2010.

Potential emissions revised for 2005-7 to reflect the fact that potential emission of SF_6 is the same as yearly consumption. Consumption of SF_6 for double glaze windows stopped in 2001.

10.1.3 Solvents and Other Product Use

Recalculations have been made for Other Product Use, where changes were made for the activity data of all four emission sources; candles (2009-2011), fireworks (2009-2011), tobacco (1980-1999, 2011) and charcoal used for barbeques (1980-1987, 2009-2011). These changes have caused recalculations for NMVOC, N_2O and CO_2. NMVOC emissions for the years 1980-1999 have increased between 6.0 % (1997) and 9.1 % (1982) and decreased for 2009-2011 with 2.1 % (2009) to 5.7 % (2011). CO_2 emissions have decreased for the years 2009 (13.4 %) and 2010 (6.1 %) and increased for 2011 (0.7 %), no or minor recalculations were performed for 1980-2008. N_2O emissions have increased for 1980-1999 with between 0.5 % (1999) and 2.8 % (1982) and decreased for the years 2009-2011 with between 0.3 % (2011) and 1.0 % (2009).

10.1.4 Agriculture

Some changes of emissions from the agricultural sector have taken place. These changes reflect decreased emissions in the years 1990-2011 up to 0.2 % compared to the total CO_2-equivalent emission from the agricultural sector. The decrease in 1990-2011 is due to a decrease in the emissions of both N_2O and CH_4.

The CH_4 emission decreases both for emission from enteric fermentation and manure management. The number of geese has been changed for all years and the number of weaners and fattening pigs has been changed for 2011, this affects both emissions from enteric fermentation and manure management. The amount of straw used for bedding for heifers has been changed for 1990-2002 and the amount of biogas treated manure in 2010 has been changed. This affects the emission of CH_4 from manure management.

For the N_2O emission a range of changes have been made, which have both increasing and decreasing effect. EF for NH_3 from synthetic fertiliser has been changed for all years and this affects the emission of N_2O. The emission of N_2O from atmospheric deposition increases due to the change for NH_3 from synthetic fertiliser while the emission of N_2O from synthetic fertiliser decreases. Change in the number of geese decrease the emission of N_2O from grazing for all years. The change of amount of biogas treated manure decreases the N_2O emission in 2010. The emission from manure, manure on soil and leaching is decreased in 2011 due to updated numbers of weaners and fattening pigs.

10.1.5 LULUCF

An update of the LULUCF matrix has taken place for all years. The update was necessary because there were errors in the maps received last year from the Danish Geodata Agency. The problems were especially allocated to a misclassification of recreational areas and a misclassification of parks inside some cities as being forests.

The forest area has been decreased slightly in 2011 (app. 0.3%) compared to the submission last year. This has only had a very limited effect on the total carbon stock in the Danish forest as the carbon stock is estimated in the National Forest Inventory, which is independent of the LULUCF matrix. Furthermore has some unclassified areas inside and around the cities which previous was classified as grassland now been removed to Settlement.

Forestry

Since the NFI was initiated in 2002 and have a 5-year rotation, a full measurement is available from 2006. Calculation of carbon stock in the period 2000-2005 is based on interpolation between the carbon stock observed in the NFI in 2006 and the carbon stock as calculated for 2000. For 2006-2012 carbon stock is calculated solely on the basis of the NFI - with additional information about the total forest area from satellite image mapping. Reported values from the NFI correspond to the last year of a five year measurement cycle (i.e. reported values for 2010 rely on data from 2006-2010). Same approach was applied in the 2014 submission.

Cropland, grassland, wetlands and settlements

As the land use matrix is slightly changed the emissions from land use conversion for all sectors are changed slightly for the whole time series. These changes have no effect on the emissions from agricultural soils as these are based information from the EU Land Parcel Information System, i.e. the actual land use. Two minor technical errors have been found in the accounting estimate and corrected: living biomass in Settlements and the area accounted for in Cropland Management and Grassland Management under article 3.4. These errors have only a small impact on the inventory.

10.1.6 Waste

For the category 6A SWDS, an in depth disaggregation of deposited waste for the years 2010, 2011 and 2012 have been performed based on the new waste reporting system in Denmark. 18 categories have been identified of which eleven have been evaluated as inert waste. A detailed description of the waste characterisation, allocation into 18 categories and back casting from 2010 to 1990 are described in Nielsen et al. and Thomsen et al., (2014a and b). The overall results of this detailed characterisation and reallocation of the deposited waste results in a decrease in the CH4 emission in 1990 of 7.6% and an increase in the CH_4 emission in 2011 of 4.6%.

For the category 6B wastewater handling, no recalculations were made for N_2O. For the methane emissions, the methane correction factor was decreased from 1 to 0.8, which is in accordance to the IPCC guidelines 2006, and which have been further justified by plant specific data as described in Nielsen et al. and Thomsen et al. (2014a, b). Besides the correction of MCF, smaller corrections in plant inlet TOW data have occurred corresponding to a change below 1% throughout the time series.

There are no recalculations in the waste incineration category, however; a correction in the rounding of decimals has caused an increase of 0.07 % of the N_2O emissions from animal cremation for all years 1990-2011.

For the category waste other; changes were made in the vehicle fires and composting source categories. For vehicle fires; the time-series for vehicle population has been updated along with the estimated average weights of some vehicle types, the result is a decrease of CH_4 and CO_2 emissions from 1990-2006 and an increase for 2007-2011. Emission factors have been updated for composting of sludge and organic municipal waste which have resulted in increased emissions of CH_4 and N_2O. The joint effect of these recalculations is a decrease in CH_4 emissions from 1980 (2.4 %) to 1984 (2.0 %) and an increase from 1985 (16.7 %) to 2011 (275 %), for CO_2 emissions have decreased from 1980 (1.1 %) to 2006 (0.004 %) and increased from 2007 (0.1 %) to 2011 (0.2 %), finally the N_2O emissions have increased for all years between 1985 (1.1 %) and 2011 (238 %).

10.1.7 KP-LULUCF

A recalculation for KP-LULUCF has been performed for all areas as a consequence of the new land area matrix, see the section on LULUCF.

10.2 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 small and the changes for the whole time-series are between -0.09 % (1990) and 0.48 % (2011). Therefore, the implications of the recalculations on the level and on the trend, 1990-2011, of the national total are small, see Table 10.1.

For the national total CO_2 equivalent emissions with Land-Use, Land-Use Change and Forestry, the general impact of the recalculations is larger due to recalculations in the LULUCF sector. The changes vary between –0.34 % (1990) and +0.55 % (2010), see Table 10.1.

Table 10.1 Recalculation performed in the 2014 submission for 1990-2011. Differences in pct. of CO_2 equivalents between this submission and the May 2013 submission for DK, excluding Greenland and 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	-0.34	-0.03	-0.02	-0.01	0.01	0.03	0.03	0.06	0.10	0.17	0.46
Total CO_2 eqv. Emissions without Land-Use Change and Forestry	-0.09	-0.07	-0.06	-0.04	-0.02	0.00	0.01	0.04	0.08	0.16	0.46
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total CO_2 eqv. Emissions with Land-Use Change and Forestry	0.18	0.29	0.35	0.17	-0.11	-0.05	0.27	-0.26	0.54	0.55	0.36
Total CO_2 eqv. Emissions without Land-Use Change and Forestry	0.23	0.35	0.40	0.21	0.23	0.24	0.29	0.22	0.37	0.30	0.48

10.3 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 10.2-10.5.

Table 10.2 Recalculation for CO_2 performed in the 2014 submission for 1990-2011. Differences in Gg CO_2 eqv. between this and the May 2013 submission for DK. Excluding Greenland and Faroe Islands.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total National Emissions and Removals	-128	89	88	88	86	84	82	86	84	84	232
1. Energy	63	63	63	65	64	62	62	64	63	64	211
1.A. Fuel Combustion Activities	61	61	61	62	64	62	62	64	63	64	211
1.A.1. Energy Industries	-	-	-	1	68	5	12	11	11	12	12
1.A.2. Manufacturing Industries and Construction	59	59	60	60	48	56	50	52	51	52	52
1.A.3. Transport	0	0	0	0	0	0	0	0	0	0	0
1.A.4. Other Sectors	2	1	1	1	-52	0	1	1	1	0	147
1.A.5. Other	-	-	-	-	-	-	-	-	-	-	-
1.B. Fugitive Emissions from Fuels	2	3	2	3	0	0	0	0	0	0	0
2. Industrial Processes	-	-	-	-	-	1	0	3	2	3	5
2.A. Mineral Products	-	-	-	-	-	1	1	2	2	3	5
2.B. Chemical Industry	-	-	-	-	-	-	-1	1	-	-	0
2.C. Metal Production	-	-	-	-	-	-	-	-	-	-	-
2.D. Other Production	-	-	-	-	-	-	-	-	-	-	-
2.G. Other	-	-	-	-	-	-	-	-	-	-	-
3. Solvent and Other Product Use	-	-	-	-	-	-	-	-	-	-	-
4. Agriculture	-	-	-	-	-	-	-	-	-	-	-
5. Land Use, Land-Use Change and Forestry (net)	-190	26	25	24	23	22	21	20	19	18	17
5.A. Forest Land	7	7	7	7	7	7	7	7	7	7	7
5.B. Cropland	-192	26	26	27	27	27	27	27	27	27	28
5.C. Grassland	0	0	0	0	0	0	0	0	0	0	0
5.D. Wetlands	-3	-5	-6	-7	-8	-9	-10	-11	-12	-13	-14
5.E. Settlements	-3	-3	-3	-3	-4	-4	-4	-4	-4	-4	-4
5.F. Other Land	-	-	-	-	-	-	-	-	-	-	-
5.G. Other	-	-	-	-	-	-	-	-	-	-	-
6. Waste	-1	-1	-1	-1	-1	-1	-1	0	0	0	0
6.C. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-
6.D. Other	-1	-1	-1	-1	-1	-1	-1	0	0	0	0
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total National Emissions and Removals	41	42	82	80	-121	-106	99	-247	239	248	66
1. Energy	65	64	102	100	99	108	108	50	136	100	145
1.A. Fuel Combustion Activities	65	64	102	100	99	108	108	50	136	100	145
1.A.1. Energy Industries	11	11	34	12	11	7	6	13	34	29	8
1.A.2. Manufacturing Industries and Construction	54	53	84	88	90	86	125	110	108	153	133
1.A.3. Transport	0	0	0	0	0	0	0	-69	0	-4	-13
1.A.4. Other Sectors	0	0	-16	0	-2	15	-23	-3	-5	-78	18
1.A.5. Other	-	-	-	-	-	-	-	-	-	-	-
1.B. Fugitive Emissions from Fuels	0	0	0	0	0	0	0	0	0	0	0
2. Industrial Processes	2	1	1	-1	-1	3	1	1	1	4	-2
2.A. Mineral Products	2	1	1	1	1	3	2	3	2	4	-2
2.B. Chemical Industry	0	0	-1	-2	-2	-1	-1	-1	-1	-	-1
2.C. Metal Production	-	-	-	-	-	-	-	-	-	-	-
2.D. Other Production	-	-	-	-	-	-	-	-	-	-	-
2.G. Other	-	-	-	-	-	-	-	-	-	-	-
3. Solvent and Other Product Use	-	-	-	-	-	-	-	-	-12	-7	1
4. Agriculture	-	-	-	-	-	-	-	-	-	-	-
5. Land Use, Land-Use Change and Forestry (net)	-25	-23	-21	-19	-219	-216	-10	-299	114	150	-78
5.A. Forest Land	-34	-30	-27	-23	-51	-49	157	-132	280	316	88
5.B. Cropland	28	27	27	27	-181	-181	-181	-181	-181	-181	-181
5.C. Grassland	0	0	0	0	32	31	31	31	30	30	29
5.D. Wetlands	-15	-16	-17	-18	-14	-13	-13	-12	-11	-11	-10
5.E. Settlements	-4	-4	-4	-4	-5	-5	-5	-4	-4	-4	-4

Continued											
5.F. Other Land	-	-	-	-	-	-	-	-	-	-	-
5.G. Other	-	-	-	-	-	-	-	-	-	-	-
6. Waste	0	0	0	0	0	0	0	0	0	0	0
6.C. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-
6.D. Other	0	0	0	0	0	0	0	0	0	0	0

Table 10.3 Recalculation for CH_4 performed in the 2014 submission for 1990-2011. Differences in Gg CO_2 eqv. between this and the May 2013 submission for DK. Excluding Greenland and Faroe Islands.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total National Emissions and Removals	-113.9	-108.2	-101.0	-89.3	-74.7	-60.7	-50.6	-37.5	-28.3	-20.5	-17.2
1. Energy	5.6	6.8	6.4	7.3	7.3	8.6	7.7	7.0	6.1	4.7	5.7
1.A. Fuel Combustion Activities	4.8	5.6	5.8	6.4	6.8	7.1	7.5	6.6	5.7	6.2	7.5
1.A.1. Energy Industries	0.0	0.0	0.0	0.0	0.6	1.9	3.4	2.2	2.0	2.2	2.3
1.A.2. Manufacturing Industries and Construction	0.0	0.0	0.0	0.0	0.0	-1.2	-2.8	-2.5	-2.3	-2.4	-2.8
1.A.3. Transport	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.A.4. Other Sectors	4.9	5.7	5.9	6.5	6.2	6.4	6.9	6.9	6.1	6.3	8.1
1.A.5. Other	-	-	-	-	-	-	-	-	-	0.0	0.0
1.B. Fugitive Emissions from Fuels	0.8	1.2	0.6	0.9	0.5	1.5	0.2	0.4	0.4	-1.5	-1.8
2. Industrial Processes	-	-	-	-	-	-	-	-	-	-	-
3. Solvent and Other Product Use	-	-	-	-	-	-	-	-	-	-	-
4. Agriculture	-8.0	-8.9	-9.6	-10.4	-10.8	-11.6	-12.7	-12.7	-12.6	-12.3	-12.4
4.A. Enteric Fermentation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.B. Manure Management	-8.0	-8.9	-9.6	-10.4	-10.8	-11.6	-12.7	-12.7	-12.6	-12.3	-12.4
4.F. Field Burning of Agricultural Residues	-	-	-	-	-	-	-	-	-	-	-
5. Land Use, Land-Use Change and Forestry (net)	-	-	-	-	-	-	-	-	-	-	-
6. Waste	-111.5	-106.2	-97.8	-86.2	-71.3	-57.7	-45.6	-31.8	-21.8	-12.9	-10.5
6.A. Solid Waste Disposal on Land	-112.0	-106.9	-98.9	-87.5	-72.7	-60.1	-47.6	-34.3	-24.5	-16.4	-14.9
6.B. Waste-water Handling	-0.7	-0.7	-0.7	-0.7	-0.8	-0.8	-1.0	-1.2	-1.1	-1.3	-0.9
6.C. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-
6.D. Other	1.2	1.5	1.8	2.0	2.2	3.2	3.0	3.7	3.8	4.9	5.4
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total National Emissions and Removals	-15.2	-6.8	13.8	15.5	21.3	28.5	37.4	36.7	42.3	22.2	53.4
1. Energy	7.8	7.9	9.9	11.1	13.4	16.2	20.6	18.3	16.7	18.7	16.9
1.A. Fuel Combustion Activities	7.9	7.9	9.7	11.0	13.4	16.1	20.3	18.5	16.9	19.1	16.9
1.A.1. Energy Industries	1.9	2.1	1.9	2.2	2.0	2.0	1.8	1.7	2.0	2.0	2.1
1.A.2. Manufacturing Industries and Construction	-3.0	-3.5	-3.0	-3.5	-3.3	-2.3	-1.8	-2.0	-2.2	-0.9	-0.8
1.A.3. Transport	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.3	0.3	0.3
1.A.4. Other Sectors	9.0	9.3	10.8	12.3	14.6	16.4	20.2	18.7	16.9	17.8	15.2
1.A.5. Other	0.0	0.0	0.0	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	0.1	0.1	0.1	0.1	0.3	-0.2	-0.2	-0.4	0.0
2. Industrial Processes	-	-	-	-	-	-	-	-	-	-	-
3. Solvent and Other Product Use	-	-	-	-	-	-	-	-	-	-	-
4. Agriculture	-13.0	-12.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-0.2
4.A. Enteric Fermentation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
4.B. Manure Management	-13.0	-12.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-0.2
4.F. Field Burning of Agricultural Residues	-	-	-	-	-	-	-	-	-	-	-
5. Land Use, Land-Use Change and Forestry (net)	-	-	-	-	-	-	-	-	-	-	-
6. Waste	-10.0	-2.4	4.0	4.5	7.9	12.3	16.8	18.5	25.6	4.4	36.7
6.A. Solid Waste Disposal on Land	-14.4	-8.2	-1.9	2.0	5.9	9.6	13.9	17.1	21.2	0.2	32.3
6.B. Waste-water Handling	-1.4	-1.8	-1.9	-2.1	-1.9	-1.6	-1.3	-3.0	-1.9	-1.2	-1.3
6.C. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-
6.D. Other	5.7	7.7	7.8	4.6	3.9	4.3	4.2	4.3	6.3	5.5	5.7

Table 10.4 Recalculation for N_2O performed in the 2014 submission for 1990-2011. Differences in Gg CO_2 eqv. between this and the May 2013 submission for DK. Excluding Greenland and Faroe Islands.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total National Emissions and Removals	-7.6	-6.9	-6.1	-7.4	-6.8	-2.3	-1.2	0.7	26.1	69.6	-7.6
1. Energy	1.7	2.3	1.9	1.4	1.4	0.9	1.6	1.8	0.6	2.2	1.7
1.A. Fuel Combustion Activities	1.8	2.4	1.9	1.5	1.4	0.9	1.6	1.8	0.6	2.2	1.8
1.A.1. Energy Industries	0.7	1.2	0.8	0.4	0.4	0.3	0.9	1.2	0.0	1.5	0.7
1.A.2. Manufacturing Industries and Construction	1.1	1.1	1.1	1.1	1.1	0.6	0.7	0.6	0.6	0.6	1.1
1.A.3. Transport	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.A.4. Other Sectors	-	0.0	0.0	0.0	-0.1	0.0	0.0	0.1	0.0	0.0	-
1.A.5. Other	-	-	-	-	-	-	-	-	-	0.0	-
1.B. Fugitive Emissions from Fuels	-0.1	-0.1	-0.1	-0.1	-	-	-	-	-	-	-0.1
2. Industrial Processes	-	-	-	-	-	-	-	-	-	-	-
3. Solvent and Other Product Use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4. Agriculture	-10.5	-10.5	-9.7	-10.7	-10.3	-9.8	-8.7	-8.2	-7.6	-6.8	-10.5
4.A. Enteric Fermentation	-	-	-	-	-	-	-	-	-	-	-
4.B. Manure Management	-	-	-	-	-	-	-	-	-	-	-
4.D. Agricultural Soils	-10.5	-10.5	-9.7	-10.7	-10.3	-9.8	-8.7	-8.2	-7.6	-6.8	-10.5
4.F. Field Burning of Agricultural Residues	-	-	-	-	-	-	-	-	-	-	-
5. Land Use, Land-Use Change and Forestry (net)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0
5.A. Forest Land	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
5.B. Cropland	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
5.C. Grassland	-	-	-	-	-	-	-	-	-	-	-
5.D. Wetlands	-	-	-	-	-	-	-	-	-	-	-
5.E. Settlements	-	-	-	-	-	-	-	-	-	-	-
5.F. Other Land	-	-	-	-	-	-	-	-	-	-	-
5.G. Other	-	-	-	-	-	-	-	-	-	-	-
6. Waste	1.1	1.3	1.6	1.8	2.1	6.5	5.9	7.0	33.1	74.2	1.1
6.B. Waste-water Handling	-	-	-	-	-	-	-	-	-	-	-
6.C. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-
6.D. Other	1.1	1.3	1.6	1.8	2.1	6.5	5.9	7.0	33.1	74.2	1.1
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total National Emissions and Removals	115.2	108.6	181.7	176.5	26.4	24.9	36.5	48.7	49.7	59.7	65.2
1. Energy	2.9	-1.0	-1.5	-0.6	-0.2	0.2	2.0	1.9	1.5	1.9	2.1
1.A. Fuel Combustion Activities	2.9	-1.0	-1.5	-0.6	-0.2	0.2	2.0	1.9	1.5	1.9	2.1
1.A.1. Energy Industries	0.0	0.1	0.0	0.4	0.7	0.8	0.6	0.0	0.1	0.3	0.0
1.A.2. Manufacturing Industries and Construction	0.0	-1.1	-1.6	-0.5	-1.0	-1.0	1.4	2.2	1.7	1.9	3.8
1.A.3. Transport	0.0	0.0	0.1	0.1	0.2	0.4	-0.2	-0.1	-0.6	0.0	0.0
1.A.4. Other Sectors	2.9	0.0	0.0	-0.6	0.0	0.0	0.2	-0.4	0.2	-0.3	-1.8
1.A.5. Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.B. Fugitive Emissions from Fuels	-	-	-	-	-	-	-	-	-	-	-
2. Industrial Processes	-	-	-	-	-	-	-	-	-	-	-
3. Solvent and Other Product Use	-	-	-	-	-	-	-	-	-	0.0	0.0
4. Agriculture	-6.1	-5.6	-5.0	-5.0	-5.2	-4.8	-4.2	-4.2	-4.6	-3.5	-4.3
4.A. Enteric Fermentation	-	-	-	-	-	-	-	-	-	-	-
4.B. Manure Management	-	-	-	-	-	-	-	-	-	-	-0.6
4.D. Agricultural Soils	-6.1	-5.6	-5.0	-5.0	-5.2	-4.8	-4.2	-4.2	-4.6	-3.5	-3.7
4.F. Field Burning of Agricultural Residues	-	-	-	-	-	-	-	-	-	-	-
5. Land Use, Land-Use Change and Forestry (net)	0.1	0.1	0.1	0.1	0.1	-0.1	-0.1	-0.1	0.0	0.0	0.0
5.A. Forest Land	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
5.B. Cropland	0.2	0.2	0.2	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.2
5.C. Grassland	-	-	-	-	-	-	-	-	-	-	-
5.D. Wetlands	-	-	-	-	-	-	-	-	-	-	-
5.E. Settlements	-	-	-	-	-	-	-	-	-	-	-

Continued											
5.F. Other Land	-	-	-	-	-	-	-	-	-	-	-
5.G. Other	-	-	-	-	-	-	-	-	-	-	-
6. Waste	118.4	115.0	188.1	182.0	31.7	29.6	38.8	51.1	52.9	61.4	67.4
6.B. Waste-water Handling	-	-	-	-	-	-	-	-	-	-	-
6.C. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-
6.D. Other	118.4	115.0	188.1	182.0	31.7	29.6	38.8	51.1	52.9	61.4	67.4

Table 10.5 Recalculation for HFCs, PFCs and SF_6 performed in the 2014 submission for 1990-2011. Differences in Gg CO_2 eqv. between this and the May 2013 submission for DK. Excluding Greenland and Faroe Islands.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
HFC	-	-	-	-	-	-	-	-	-	-	-
PFC	-	-	-	-	-	-	-	-	-	-	-
SF_6	-	-	-	-	-	-	-	-	-	-	-
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
HFC	-	-	-	-	-	-	-	-	0,0	0,0	-
PFC	-	-	-	-	-	-	-	-	-	-	-
SF_6	-	-	-	-	-	-	-	-	-	-0,4	-

10.4 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 April 15, 2009. For the 2009 submission the review report was finalised and published April 15 2010. The review report of the in-country review of the 2010 submission was published March 3 2011. The draft review report for the review of the 2011 submission was available February 9, 2012. The final review report was published April 30 2012. The draft review report of the 2012 submission was made available April 30 2013 and the final review report was dated August 2 2013. The significant delay made it impossible to ensure that all findings by the ERT were addressed in the 2013 submission and with the late publication even the inclusion in the 2014 submission was challenging.

As of April 7 2014 Denmark has not received a draft of the review report from the centralised review carried out in September 2013. Therefore, it has not been possible to address the outcome of the 2013 review in this report. The main recommendations from the reviews of the 2008, 2009, 2010, 2011 and 2012 submissions are listed in Table 10.6.

To keep the table transparent the recommendations that have been completed from the review of the 2008, 2009, 2010 and 2011 submissions have been deleted.

Table 10.6 Main recommendations from the reviews of the 2008, 2009, 2010, 2011 and 2012 submissions.

CRF	ERT Comment	Denmark's response	Reference
2008 submission (Review report: http://unfccc.int/resource/docs/2009/arr/dnk.pdf)			
Energy, road transport – Paragraph 41	The change of non-CO_2 EFs associated with the use of bioethanol in gasoline blends has not been taken into account when estimating the corresponding emissions. The ERT suggests that Denmark assess probable changes to these EFs in its next annual submission.	No data has previously been available indicating different CH_4 and N_2O emission factors for blends of fossil and biogenic fuels. This issue is being followed in case new research indicates otherwise.	Chapter 3.3.2.
2009 submission (Review report: http://unfccc.int/resource/docs/2010/arr/dnk.pdf)			
CRF	ERT Comment	Denmark's response	Reference
Industrial Processes, limestone and dolomite use – Paragraph 62	The ERT noted that estimates for more recent years could be underestimated in comparison to previous years in the time-series, and the full time-series may not be consistent. Besides, the ERT also found some potential inconsistencies in the time-series of AD: an increase of 28.1 per cent in 2005–2006 and a 28.8 per cent decrease in 2006–2007.The ERT recommends that Denmark provide in the NIR of its next annual submission information on the specific procedures and verifications the Party used.	The sector (2A3) comprises a number of different processes: consumption of $CaCO_3$ to flue gas cleaning at power plants and waste incineration plants, production of mineral wool and refining of sugar. The activity data are not comparable or even confidential or lacking for part of the period. The inventory team are working on improvement of the documentation of AD. 2014 update: The limestone use in sugar production was reallocated so that the category now only comprises flue gas desulphurisation and production of stone wool. When implementing the 2006 IPCC Guidelines for the 2015 submission the allocation of emissions from the use of limestone and dolomite will be further analysed.	
Solvent and other product use, use of N_2O – Paragraph 64	The ERT encourages the Party to provide estimates of emissions of N_2O from use as anaesthesia for the period 1990–2004 in order to complete the time-series.	The producers and distributors of N_2O will be contacted again and if data cannot be given for 1990-2004 this will be clearly explained in the report. 2013 update: Based on contact with the industry, data for 2000-2004 have been obtained and included in the inventory.	
Agriculture, manure management – Paragraph 74	Denmark treats some of its animal slurries in biogas plants, capturing the CH_4 generated and using it for electricity and CHP production. In response to a question from the ERT, Denmark stated that some of the information in table 6.12 of the NIR might be misleading with regard to the energy production values expressed in TJ, as they are not directly related to the estimation of CH4 captured, but rather	DK agree that the information on the energy production can be misleading. The calculation of the lower CH_4 emission as a consequence of biogas treatment is based on the amount of biogas treated slurry, which is received from the Danish Energy Agency. Table 6.1 includes data concerning the amount of slurry, the VS content in the treated slurry and the reduced emission. DK has planned to improve the possibilities to verify the calculation of the reduced emission from biogas treated slurry. This could be done by contacting a biogas plant in preparation for potential data based on	Chapter 6.4.2 Table 6.18

Table 10.6 Main recommendations from the reviews of the 2008, 2009, 2010, 2011 and 2012 submissions.

CRF	ERT Comment	Denmark's response	Reference
	were obtained independently from the Danish Energy Agency. The ERT recommends that the Party report estimates of energy production and CH_4 recovery in a consistent way, and correct table 6.12 in the next annual submission. The ERT recommends that Denmark, for the sake of improving transparency, provide plant-specific data regarding energy output and quantities of slurry treated from one or more of the larger biogas plants. The ERT also recommends that Denmark use the energy output from plants to assess the validity of the CH_4 reduction potentials for cattle and swine slurry as an additional QC check.	measurement from slurry. 2014 update: The Danish Energy Agency (DEA) provides annually the Danish energy statistics and from 2012 we succeed to receive plant specific data for the energy production based in biogas. Next step is to investigate the possibilities to improve the data regarding the energy potential in order to improve the estimate of biogas treated manure.	
2010 submission (Review report: http://unfccc.int/resource/docs/2011/arr/dnk.pdf)			
Energy, Country-specific issues – Paragraph 55	To improve accuracy, the ERT recommends that Denmark make efforts to estimate CO_2 emissions from gas oil used in Greenland by using country-specific EFs that are already available.	This issue will be investigated further with the aim of revising the CO_2 emission factor for gas oil combusted in Greenland. 2014 update: Based on fuel analysis the CO_2 emission factor for gas oil in Greenland has been updated.	Chapter 16
LULUCF, Land converted to cropland – Paragraph 123	For land converted to cropland, net carbon stock change of mineral and organic soils is reported as "IE" for many conversions. During the review, Denmark explained that these have been included in cropland remaining cropland. To improve transparency, the ERT recommends that Denmark report net carbon stock change of mineral and organic soils separately under cropland remaining cropland and land converted to cropland in the next annual submission.	The recommendation from the ERT is difficult to follow. Although we have very detailed information on the individual fields it will be a very time consuming task with little effect. The area with soil in agricultural use is based on the detailed information on the position of the field and the actual crop grown in that field. The minor areas which is converted to cropland and its use is included in the modelling with C-TOOL and for the organic soils we use an overlay of the current used fields to see their position in relation to the organic soil map.	
2011 submission (Review report: http://unfccc.int/resource/docs/2012/arr/dnk.pdf)			
Industrial processes, cement produc-	The ERT also questioned the Party, during the	The work is on-going.	Chapter 4.2.2

Table 10.6 Main recommendations from the reviews of the 2008, 2009, 2010, 2011 and 2012 submissions.

CRF	ERT Comment	Denmark's response	Reference
tion – Paragraph 71	review, as to whether it accounts for imports and exports for the early years of the time series, which are required to be taken into account when using a tier 1 approach. The Party responded to the ERT that it believes that clinker production at that time was solely for the company's own use, but that it will research this further and confirm in its next annual submission. The ERT recommends that Denmark conduct this research to ensure that the tier 1 approach is being implemented in accordance with the IPCC good practice guidance for estimating emissions for the early years of the time series.	2014 update: Denmark has collected the data for import/export of clinker and documented it in the NIR.	
Industrial processes, cement production – Paragraph 72	The ERT further questioned Denmark on its consideration of cement kiln dust (CKD) in the time series of emission estimates, in particular for the earlier years. Denmark responded that, although it is known that the emission estimates are based on the different types of clinker used, there is no information to indicate whether CKD is included in the emission estimates. The ERT recommends that Denmark continue to pursue any information that could clarify whether CKD is included in the emission estimates for all years of the time series.	The ERT has been informed that no further information is available for the years1990-1997. The work with including CKD in the emission estimates is on-going. 2014 update: According to information from the plant CKD is included in the emission calculation for 1990-1997.	
Industrial processes, Consumption of halocarbons – Paragraph 74	The ERT concluded that Denmark has provided complete estimates for these disposal emissions. However, the ERT recommends that Denmark be more transparent and provide the rationale for this determination in the NIR of its next annual submission.	This work is on-going. 2014 update: Denmark has expanded the discussion regarding decommissioning of f-gas containing products.	Chapter 4.7.2
2012 submission (Review report: http://unfccc.int/resource/docs/2013/arr/dnk.pdf)			
General, completeness – Paragraph	Provide a complete set of CRF tables, includ-	By mistake the explanations for recalculation were not included in the	

Table 10.6 Main recommendations from the reviews of the 2008, 2009, 2010, 2011 and 2012 submissions.

CRF	ERT Comment	Denmark's response	Reference
10	ing complete information in CRF table 8(b), in accordance with the requirements of the "Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part I: UNFCCC reporting guidelines on annual inventories"	aggregate CRF. However, all recalculations were thoroughly explained and documented in the NIR. It will be ensured that it is checked in the future that the table is com-pleted.	
Energy, International bunker fuels – Paragraph 39	Provide explanations in the NIR on the large inter-annual variations in CO_2 emissions from international bunker fuels for the years 2008–2010	Explanations on the fluctuations in the trend have been included in the NIR.	Chapter 3.3.1
Energy, International bunker fuels – Paragraph 40	Include data on international bunkers for lubri-cants in CRF table 1.C and improve the asso-ciated QC procedures	Data for lubricants used in international bunkers were included in the 2014 submission. The QC procedures have been updated.	CRF
Energy, Feedstocks and non-energy use of fuels – Paragraph 42	Include a reference in CRF table 3.A-D to clarify the reporting of CO_2 emissions from white spirits	A reference was added in the CRF.	CRF
Energy, Feedstocks and non-energy use of fuels – Paragraph 43	Document and justify in the NIR why a carbon storage factor of 1.00 has been used	The documentation in the NIR Chapter 3.4 has been improved as has the documentation in the CRF In CRF Table 1A.(c) a reference to NIR chapter 3.4 have been added. In CRF Table 1A (c) the following comment have been added: Non-energy use of fuels is not included in sector 1A in the Danish Na-tional Approach (IE). Fuel consumption for non-energy is subtracted in Reference Approach to make results comparable. This have been done by setting the fraction stored equal to 1. In CRF Table 1A(d) the following comments have been added: 1.AD.2 Lubricants:All emissions from the non-energy use of the three fuels identified in the Danish energy statistics are included in the Indus-trial Processes and the Solvent and Other Product Use sectors. In order to make the reference approach comparable with the sectoral approach the fraction of carbon stored has been set to 1. This is to exclude it from the comparison with the sectoral approach. The relevant emissions are included in the sectors identified in the table. 1.AD.3 Bitumen:All emissions from the non-energy use of the three fuels identified in the Danish energy statistics are included in the Indus-	Chapter 3.4 CRF Table 1.A(d) and CRF Table 1.A(c)

Table 10.6 Main recommendations from the reviews of the 2008, 2009, 2010, 2011 and 2012 submissions.

CRF	ERT Comment	Denmark's response	Reference
		trial Processes and the Solvent and Other Product Use sectors. In order to make the reference approach comparable with the sectoral approach the fraction of carbon stored has been set to 1. This is to exclude it from the comparison with the sectoral approach. The relevant emissions are included in the sectors identified in the table. 1.AD.10 White Spirit:All emissions from the non-energy use of the three fuels identified in the Danish energy statistics are included in the Industrial Processes and the Solvent and Other Product Use sectors. In order to make the reference approach comparable with the sectoral approach the fraction of carbon stored has been set to 1. This is to exclude it from the comparison with the sectoral approach. The relevant emissions are included in the sectors identified in the table.	
Energy, Stationary combustion: solid and liquid fuels – Paragraph 44	Reflect the results of the analysis of the CO_2 EFs for fuel oil in the NIR	The analysis of the CO_2 emission factors for fuel oil like in the case of coal did not yield any useable results.	Chapter 3.2.5
Energy, Road transportation: liquid fuels – Paragraph 45	Provide brief descriptions of the methods used to obtain the fleet and mileage data necessary for the COPERT IV model	The description has been improved in the NIR.	Chapter 3.3.2
Energy, Aviation: liquid fuels - Paragraph 48	Provide information on the number of domestic landings and take-offs (LTOs) per representative aircraft type for each of the Danish airports, including flights between Denmark and Greenland/the Faroe Islands, the average LTO fuel consumption and the EFs per representative aircraft type	Information has been included.	Annex 3B-10
Industrial processes, Cement production – Paragraph 55	Provide information on the imports and exports of cement for the years 1990–1997, in order to ensure that the tier 1 method is being implemented in accordance with the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (the IPCC good practice guidance)	The information has been included.	Chapter 4.2.2
Industrial processes, Cement production – Paragraph 56	Provide relevant information to clarify whether cement kiln dust is included in the emission estimates for the years prior to 1998	The work is ongoing.	
Agriculture, Sector overview - Paragraph 66	Provide a description of the use of the biogas and the associated energy output	More descriptive text has been implemented and furthermore annex 3E now includes two tables with detailed information on data used to calcu-	Annex 3E-12a and 3E-12b

Table 10.6 Main recommendations from the reviews of the 2008, 2009, 2010, 2011 and 2012 submissions.

CRF	ERT Comment	Denmark's response	Reference
		late the reduction from biogas treated manure.	
Agriculture, Manure management – Paragraph 70	Follow the methodology provided in the IPCC good practice guidance, make further efforts to obtain the necessary AD, as outlined in the planned inventory improvements in the 2012 NIR, and make recalculations for 2010	The Danish Energy Agency (DEA) provides annually the Danish energy statistics and from 2012 we succeed to receive plant specific data for the energy production based on biogas.	Chapter 6.4.2 Table 6.18
Agriculture, Manure management – Paragraph 71	Provide explanations for the inter-annual changes in the NH_3 IEF	The main documentation for the Danish NH_3 emission inventory is the Informative Inventory report. This is reported annually to the UNECE Convention on Long-Range Transboundary Air Pollution. This report is included with a direct link in the list of references.	
Agriculture, Manure management – Paragraph 72	Explain whether the reduction in the EF for ammonium sulphate was the result of using different methodologies and protocols for the national review of for other reasons	The main documentation for the Danish NH_3 emission inventory is the Informative Inventory report. This is reported annually to the UNECE Convention on Long-Range Transboundary Air Pollution. This report is included with a direct link in the list of references.	
Agriculture, Direct emissions from soils – Paragraph 73	Improve transparency by providing disaggregated data on the amount of crop residues that are used for each purpose (i.e. feeding, bedding and energy production)	Additional description is included in the NIR and a new table in Annex 3E, which shows the amount of harvested straw used for fodder, fuel and bedding.	Annex 3E-18 Chapter 6.5.2
Agriculture, Direct emissions from soils – Paragraph 74	Include, in the NIR, an explanation to substantiate the reduction in N_2O emissions from nitrogen-fixing crops	Additional documentation was added in the NIR regarding the basis for estimating N_2O emissions from N-fixing crops.	Chapter 6.5.2 Annex 3E-15
LULUCF, Sector overview – Paragraph 78	Improve the QA/QC processes for the LULUCF sector and report on the improvements made, particularly those related to the NFI in terms of sampling procedures and estimation methods	The QC procedures have been further expanded for all parts of the LULUCF sector.	QC chapters within Chapter 7
LULUCF, Forest land remaining forest land – Paragraph 80	Make continuous efforts to ensure time-series consistency	The work to improve time-series consistency is continuously ongoing. Any changes will be reflected in the NIR.	
LULUCF, Forest land remaining forest land – Paragraph 81	Provide additional information to explain the large inter-annual variations in the carbon stock in forest land remaining forest land (i.e. information on changes in the composition of tree species and the age structure of forest stands; the area and volume of clear cutting; and the area subject to destructive disturb-	Additional information has been provided in the NIR.	Chapter 7.2

Table 10.6 Main recommendations from the reviews of the 2008, 2009, 2010, 2011 and 2012 submissions.

CRF	ERT Comment	Denmark's response	Reference
	ance)		
LULUCF, Cropland remaining cropland – Paragraph 83	Include the underlying data that support the explanations of the emissions from cropland remaining cropland, particularly those that demonstrate the link between temperature and yield	There is not clear relationship between temperature and crop yield. The crop yield depends on many different factors where precipitation and sun hours combined with decent temperatures are the most important. The temperature is only used in the degradation model for organic matter in the soil. Here are used monthly mean values for the different years. More detailed data e.g. on a daily basis has very little influence on the output from the degradation C-TOOL. Annual average temperature file has been included in Annex 3F table 14.	Annex 3F table 14
Waste, Sector overview – Paragraph 86	Provide more complete information on the assumptions made and methodologies used, and on the choice of EFs and AD	More information has been provided in the NIR.	Chapter 8
Waste, Sector overview – Paragraph 87	Verify all data used for the estimation of emissions in the waste sector in the next annual submission, including verifying that the provided expert judgement is conservative with reference to the default value for flowing sewers, which is zero according to the IPCC 2006 guidelines. If data are not available, to verify that the chosen MCF is conservative, perform direct source testing to verify existing relevant literature on fugitive emissions from sewer systems	A descriptive section on available data on VOC (e.g. HS) emissions from sewer systems has been included in chapter 8. The estimated fraction of the population not connected to the sewer system has been kept at 10% (unrealistic high) until the ongoing mapping of extension of the sewer system in Denmark I finalised. As the contribution to the methane emission is dominated by the contribution from septic tanks, the methane emissions from 6B is conservative and overestimated. However, updated information documenting any fugitive emissions from the Danish sewer system will be included as soon as data becomes available.	Chapter 8.3
Waste, Solid waste disposal on land – Paragraph 89	Analyse and report, in the next annual submission, updated information on the composition of the waste category "other combustibles", divide it into different well characterised waste types, in order to document and assign each type a DOC value	The information regarding the waste characterisation in the new waste database has been improved.	Chapter 8.2
Waste, Wastewater handling - Paragraph 91	Perform a review of the biogas production data from plants for the entire time series, consistent with the requirements of the IPCC good practice guidance, and include a time trend for the amount of recovered methane, in its next	Data collection has been done for a number of plants. However, the work to collect the data is substantial and therefore ongoing. The results achieved so far are documented in the NIR.	Chapter 8.3.2 and 8.5.5

Table 10.6 Main recommendations from the reviews of the 2008, 2009, 2010, 2011 and 2012 submissions.

CRF	ERT Comment	Denmark's response	Reference
	annual submission		
Waste, Wastewater handling - Paragraph 91	Provide information on the physical characteristics of the sewer systems in the NIR	A descriptive section on structural characteristics and ongoing improvements and extensions of the sewer system have been included in chapter 8	Chapter 8.3

More information on the specific responses to the review has been given in the sectoral chapters of this report.

10.5 Explanations, justifications and implications of recalculations for KP-LULUCF inventory

10.5.1 Recalculations

Almost all sectors in the KP-LULUCF have been recalculated.

This is due to:

- A revision of the land use matrix for the entire period 1990 to 2012
- Updated data from the Danish National Forest Inventory (NFI) for carbon stock changes in above/below ground, dead wood and litter

For more information on KP-LULUCF recalculations please refer to Chapter 11.

Table 10.7 Effect of the recalculations in the KP-LULCUF sector for 1990 and 2011, Net CO_2 equivalents.

	Net CO_2 equivalent emissions/removals					
	1990			2011		
GREENHOUSE GAS SOURCE AND SINK ACTIVITIES	2013 submission	2014 submission	Change, %	2013 submission	2014 submission	Change, %
A. Article 3.3 activities				9.7	-34.1	-450.4
A.1. Afforestation and Reforestation				-73.1	-119.2	63.1
A.2. Deforestation				82.8	85.1	2.7
B. Article 3.4 activities	5.237.8	5088.3	-2.9	-2711.1	-2739.4	1.0
B.1. Forest Management				-6313.6	-6180.0	-2.1
B.2. Cropland Management	5.053.9	4844.7	-4.1	3367.8	3196.1	-5.1
B.3. Grazing Land Management	184.0	177.4	-3.6	234.6	244.5	4.2

10.5.2 Review recommendations

The main recommendations for KP-LULUCF are included in Table 10.8.

Table 10.8 Recommendations from the UNFCCC review process concerning KP-LULUCF.			
CRF	ERT Comment	Denmark's response	Reference
2010 submission (Review report: http://unfccc.int/resource/docs/2011/arr/dnk.pdf)			
2011 submission (Review report: http://unfccc.int/resource/docs/2012/arr/dnk.pdf)			
2012 submission (Review report: http://unfccc.int/resource/docs/2013/arr/dnk.pdf)			
KP-LULUCF, Afforestation and reforestation – Paragraph 97	Provide further and verified information on the rationale for changing the method used to estimate the carbon pools	The methods for the estimations have not been changed since the NFI was started in 2002. Prior to this it was not possible to give precise estimates. The NFI and the data have been reviewed in 2012/2013. The updated land use matrix influences the overall estimates.	
KP-LULUCF, Afforestation and reforestation – Paragraph 98	Provide any available data on harvested areas and the associated estimation of emissions and removals	The method use to estimate forest carbon pools is based on stock change approach, and hence there is no need for direct estimation of harvested areas and related emissions/removals, as they are reflected directly in the measured carbon pools in the forests.	
KP-LULUCF, Forest management – Paragraph 100	Provide further and verified information on the rationale for changing the method used to estimate the carbon pools	The methods for the estimations have not been changed since the NFI was started in 2002. Prior to this it was not possible to give precise estimates. The NFI and the data have been reviewed in 2012/2013. The updated land use matrix influences the overall estimates.	
KP-LULUCF, Cropland management – Paragraph 102	Provide all relevant information on the selection of appropriate EFs	Further information has been implemented in the NIR. More detailed data with examples have been included in Annex3.F_LULUCF	Abnnex3.F_LULUCF Table 3.10-3.12

11 KP-LULUCF

11.1 General information

In the following text the abbreviations is used in accordance with definitions in the IPCC guidelines:

A:	Afforestation
R:	Reforestation
D:	Deforestation
FF:	Forest remaining Forest, areas remaining forest after 1990
FL:	Forest Land meeting the Danish definition of forests
CL:	Cropland
GL:	Grassland
SE:	Settlements
OL:	Other land, unclassified land
FM:	Forest Management, areas managed under article 3.4
CM:	Cropland Management, areas managed under article 3.4
GM:	Grazing land Management, areas managed under article 3.4

11.1.1 Definition of forest and any other criteria

For the estimation of anthropogenic emissions by sources and removals by sinks associated with afforestation (A), reforestation (R) and deforestation (D) since 1990 under Article 3.3 and forest management (FM) under Article 3.4 of the Kyoto Protocol, the following forest definition will be applied:

- Minimum values for tree crown cover: 10 % tree crown cover for forests.
- Minimum values for land area: 0.5 ha.
- Minimum value for tree height: trees must be able to reach a minimum height of 5 m in the site.

In addition, the forest area includes temporarily unstocked areas, smaller open areas in the forest needed for management purposes and fire breaks. Forests in national parks, reserves, or areas under special protection are included. Windbreaks and groves covering more than 0.5 ha and with a minimum width of 20 m are also considered as forests. Farmlands, fruit plantations for commercial purposes, orchards, gardens (houses and summer houses) are NOT included in the forest area. Willow plantations on agricultural soils for bioenergy purposes are included in Cropland (CL).

11.1.2 Elected activities under Article 3, paragraph 4, of the Kyoto Protocol

As regards the possibility of including in the first commitment period emissions and removals associated with land use, land-use change and forestry activities under Article 3.4 of the Kyoto Protocol, it has been decided to include emissions and removals from forest management (FM), cropland management (CM) and grazing land management (GM). The Danish territory covers mainland Denmark and Greenland and not the Faroe Islands.

The tables given below covers only the Danish territory and not data from Greenland and thus only data, which shall be included in the submission

to the European Union (EU). The Danish CRF and KP tables are named: DNM

For Greenland separate CRF and KP tables are produced, see Chapter 15. The Greenlandic tables are named: **GRL.**

The Greenlandic impact on the overall estimates is very low: <0,01 % and thus the figures given below can be regarded as very proximate values for both Denmark and Greenland.

The Danish and the Greenlandic CRF and KP tables are merged into one set of CRF and KP tables and named: **DKE**.

The Faroe Islands has not signed the Kyoto-Protocol and has therefore not submitted KP tables or been included in the Danish and the Greenlandic submission.

The national system has identified land areas associated with the activities under Article 3.4 of the Kyoto Protocol in accordance with definitions, modalities, rules and guidelines relating to land use, land-use change and forestry activities under the protocol by satellite monitoring, use of Land Parcel Information System (LPIS) from the EU subsidiary system as well as the Greenlandic subsidiary system, detailed crop information data on field level, soil mapping and sample plots from the national forest inventory (NFI).

Inventories of emissions and removals under Article 3.3 and Article 3.4 are prepared for 2011, and reported annually in 2013 together with the other greenhouse gas inventory information.

11.1.3 Description of how the definitions of each activity under Article 3.3 and each elected activity under Article 3.4 have been implemented and applied consistently over time

The definition of afforestation, reforestation and deforestation is in accordance with the GPG (IPCC 2003).

Afforestation or reforestation is identified when areas have wooded tree cover and fulfils the forest definition given above. The time of the A is given by the time of action - i.e. planting of trees. For R the time is given by the first spontaneous regeneration of tress, typically either by absence of management or by management inducing natural regeneration. All types of establishment of forest (A or R) is considered human induced, as all land area of Denmark is under management or as minimum specifically left for spontaneous revegetation. Regulations and support for A and R include natural revegetation as a specific method, often supplementing already existing forest areas. (Danish Forest and Nature Agency, Support for Sustainable Forestry - active until 2010.
http://www.skovognatur.dk/Skov/Privat/Tilskud/Baeredygtig/)

Deforestation is identified where areas in 1990 were covered by forest and where subsequent information (through remote sensing or NFI) is recorded to have another land use. Deforestation occurs for a number of reasons, e.g. nature restoration which in the period 1990 - 2011 have been the predominant reason. Other reasons can be urban or infrastructure development.

Temporarily unstocked areas - as integral part of forest management or as result of windthrow - which is expected to continue in forest management is not considered deforestation.

As for the forest management (Article 3.4) - the forest areas fulfilling the definition given above are included under this activity. All forest areas are considered managed due to the intense utilisation of the land area of Denmark. All inventories apply this approach. The Forest Act in Denmark gives the frame for most of the forest area ('Fredskov') - thereby ensuring continued forest cover - or by deforestation at least afforestation of a similar area or in most cases the double area. As described in Chapter 7 the changes in forest floor and mineral soils pools are not significant in the period observed (1990-2011) and are hence not considered being a source of emissions.

For Cropland and Grassland the area accounted for under Art. 3.4 has been estimated with the EO mapping combined with agricultural data from Statistics Denmark, Statistics Greenland and the EU agricultural subsidiary system. Only areas which are reported as CL and GL are included in the accounted area.

11.1.4 Description of precedence conditions and/or hierarchy among article 3.4 activities and how they have been consistently applied in determining how land was classified

All Forest activities have precedence, after this Cropland activities and then Grassland activities.

Afforestation has precedence. All land converted to forest are included as afforested area. Deforestated areas are reported under D. The following categories in the Convention reporting are included under afforestation:

- 5A21 CL to A
- 5A22 GL to A
- 5A23 WE to A
- 5A24 SE to A
- 5A25 OL to A

Deforestation is estimated as:

- 5B21 to CL
- 5C21 to GL
- 5D21 to WE
- 5E21 to SE
- 5F21 to OL

FM activities are only related to:

- 5A1 Forest remaining Forest

CM activities are related to:

- 5B1 CL remaining CL
- 5B22 GL to CL
- 5B23 WE to CL (not occurring)
- 5B24 SE to CL
- 5B25 OL to CL
- 5D22 CL to WE
- 5E22 CL to SE
- 5F22 CL to OL (not occurring)

GM activities are related to:

- 5C1 GL remaining GL
- 5C22 CL to GL
- 5C23 WE to GL (not occurring)
- 5C24 SE to GL
- 5C25 OL to GL
- 5D23 GL to WE
- 5E23 GL to SE
- 5F23 GL to OL (not occurring)

No elected land has left land, which is accounted for. Land conversion between elected activities (FM, CM and GM) has been allowed. FL, CL and GM, which has been converted to WE and SE is still included in the accounted area. No land elected under 3.4 activities has been converted to Other Land. No Other land has been converted to land included in Art. 3.3 and 3.4 activities. As a consequence there has been a small increase in land, which is accounted for under Art. 3.3 and Art. 3.4 (Table 11.1) with two hectares from 1990 to 2012.

Table 11.1 The development in the different KP classes, which are included in the accounting (only Denmark) 1990 to 2012.

	1990	2008	2009	2010	2011	2012
AF	4 187	79 787	84 033	88 279	92 525	94 358
D	117	3 849	4 373	4 896	5 420	5 784
FM	543 856	540 124	539 600	539 076	538 553	538 189
CM	2 715 136	2 628 797	2 631 508	2 634 219	2 636 930	2 643 697
GM	401 414	315 123	308 248	301 373	294 498	285 900
Total area, Hectares	3 664 709	3 567 679	3 567 761	3 567 844	3 567 926	3 567 928

The Land Use matrix developed for the purpose of reporting Art. 3.3 and 3.4 activities for 2012 are shown in Table 11.2.

Table 11.2 Land Use matrix for art. 3.3 and 3.4 activities in 2012, in 1000 hectares.

To current inventory / From previous inventory year		Article 3.3 activities: Afforestation and Reforestation	Article 3.3 activities: Deforestation	Article 3.4 activities: Forest Management (if elected)	Article 3.4 activities: Cropland Management (if elected)	Article 3.4 activities: Grazing Land Management (if elected)	Article 3.4 activities: Revegetation (if elected)	Other [5]	Total area at the beginning of the current inventory year[6]
		(kha)							
Article 3.3 activities	Afforestation and Reforestation	92.52	NO						92.52
	Deforestation		5.42						5.42
Article 3.4 activities	Forest Management (if elected)		0.36	538.19					538.55
	Cropland Management[4] (if elected)	1.73	NA		2,622.53	12.67	NA		2,636.93
	Grazing Land Management[4] (if elected)	0.11	NA		21.16	273.23	NA		294.50
	Revegetation[4] (if elected)	NA			NA	NA	NA		NA
Other [5]		0.00	0.00	NO	0.00	NO	NA	737.62	737.63
Total area at the end of the current inventory year		94.36	5.78	538.19	2,643.70	285.90	NA	737.62	4,305.55

The above given information in the hierarchy between the Contention and the KP-LULUCF activities ensures that emission from activities under article 3.4 are not double counted under both article 3.3 and 3.4 activities.

11.2 Land-related information

11.2.1 Spatial assessment unit used for determining the areas of the units of land under Article 3.3

Afforestation and reforestation is identified where areas in 1990 were not covered by forest and where subsequent information (through remote sensing or NFI) is recorded to have forest cover fulfilling the forest definition.

Even though the definition for A and R refers to the time of establishment, there may be a slight time delay in the actual recording of the A/AR. This will be improved through more frequent land use mapping and improved methods for mapping in the coming years.

Deforestation is identified where areas at the beginning of the commitment period were covered by forest and where subsequent information (through remote sensing or NFI) is recorded to have another land use. The identification of the areas is in most cases supported by reports on e.g. nature restoration or establishment of settlements.

11.2.2 Methodology used to develop the land transition matrix

A land use/land cover map was produced for the Kyoto reference year 1990, 2005 and 2011 based on EO data for the forest land use. For mostly all other land uses the main data comes from detailed vector maps. These include data such as different vector layers from cadastral maps, road maps, wetland areas, agricultural land use data, vector layers of established wetlands, gravel maps etc. as well as aerial photos. The primary data used for the forest land use mapping is Landsat imagery mainly Landsat 5 (TM) and 7 (ETM+) data to classify and estimate the area and in combination with NFI data and other sources of data, including LiDAR data. The product is specified by a Minimum Mapping Unit (MMU) of 0.5 ha, a geometric accuracy of < 15 m RMS and a thematic accuracy of 90% +/- 5%.

The land use was allocated to the six major Kyoto classes: Forest, Cropland, Grassland, Wetland, Settlements, and Other. Highest priority was given to maps having the highest reliability in the production of the land use matrix. To avoid transition artefacts due minor updates in the precision of the vector maps a Minimum Mapping Unit (MMU) for land use change has been set to 0.5 ha which is the same as the elected Danish minimum MMU for forests in the Initial Report under the Kyoto protocol: Initial Report

In Chapter 7, Table 7.1 shows the overall development from 1990 to 2012. The preliminary result is an increase in the afforested area of 94 358 hectares, but also that deforestation has taken place of approximately 5 784 ha. Afforestation is mainly taking place on CL and GL. Areas, which are deforestated, are mainly converted to CL and GL as the far major part of D is a conversion of existing Christmas tree fields to agricultural crops in rotation or permanent grass. Only to a little extend is forest converted to SE.

Since 1990 almost 31 169 hectares have been changed into SE and other infrastructures. No FF, CL and GL are converted into OL by definition.

Based upon the combination of the satellite image classified land use map and the combined vector layer of know information a full land use map for 1990, 2005 and 2011was produced.

11.2.3 Maps and/or database to identify the geographical locations, and the system of identification codes for the geographical locations

The entire Danish territory except the Faroe Islands is included. This chapter includes only the territory of Denmark without Greenland. Denmark is reported as one unit and no sub-geographical locations are used.

Greenland is submitting a full separate NIR and CRF to be included in the submission to UNFCCC (Chapter 16).

11.3 Afforestation, Reforestation & Deforestation (ARD)

11.3.1 Methods for carbon stock change and GHG emission and removal estimates

For afforestation the carbon stock change in the period 1990 - 2011 is based both on the area of afforestation, the information on species composition from the Forest Census 2000 and from the NFI.

In the afforestation a steady increase in carbon stock is found. The species composition is based on the information from the 2000 Forest Census for the period 1990-2000. Subsequently the NFI provides information on the afforestation area and the carbon pools in these areas - up till 2007. The estimates for the carbon pools in the afforestation are similar to previous estimates, with a slight increase due to the new knowledge on species composition and average carbon stock in those areas based on the NFI data.

Carbon stock change caused by deforestation is estimated based on the deforested area and the mean values of carbon stock in the total forest area in the period 1990-2005. Based on analysis by aerial photographs and LiDAR data of the deforested areas in the period 2005-2011 is it estimated that 50 pct. of this deforestation is happening in very young forests or forests with low biomass (e.g. Christmas tree plantations or small open forests on the edge of agricultural land). This biomass carbon removed from these areas is estimated to be 15 t C/ha whereas the remaining deforested areas is assumed to have average carbon pools as the remaining forest area.

Where deforestation is taking place is the living and dead biomass removed and oxidized instantly. This includes also the litter layer in the forest. For the litter layer is further more included a N_2O-emission from nitrogen in the litter layer as well as changes in the C stock in mineral soils multiplied with a C:N ratio of 15 and a EF of 1.25 %. A large part of the deforestation is conversion of forest to create wetlands by removing the forest and closing the drainage system. For land converted to wetlands is assumed an average increase in the soil carbon stock of 0.5 ton C per ha per year which are and reported under mineral soils.

Further details are available in Johannsen et al. 2009.

11.3.2 Description of the methodologies and the underlying assumptions used

The climate in Denmark is cold and wet, which gives limitations to the growth of the forests and therefore afforestation in Denmark are on long rotations (>50 years) to give a reasonable amount of wood and wood products. Furthermore, the afforested areas are in many cases protected against deforestation. Therefore, afforested areas under article 3.3. will seldom be harvested during the commitment period. In the current submission is no estimates for "Units of land harvested since the beginning of the commitment period" in table 5(KP-I)A.1.2 given and stated as IE.

The basic information utilised to give the data for the emission estimates for units of land subjected to afforestation/reforestation is based on National

Forest Inventory (NFI) observations of stock change, specific related to the afforestated areas. This will include all changes in carbon pools - also if affected by harvest - including thinnings of young stands.

Based on the NFI it will be possible - for the next reporting also to give some indications of the frequency of harvesting/thinning occurring on the afforestated areas. Given the fact that the afforestated area still is a relatively small part of the full forest area - there will be more uncertainty on the estimate related to afforestated areas compared to the area of forest remaining forest.

11.3.3 Justification when omitting any carbon pool or GHG emissions/ removals from ARD

When deforestation occurs it is assumed that all dead organic matter will be cleared. The actual amount depends on which type of forest is converted.

11.3.4 Information on whether or not indirect and natural GHG emissions and removals have been factored out

No factoring out has been performed in the emission and removal estimates.

11.3.5 Changes in data and methods since the previous submission (recalculations)

Minor recalculations have been made as updated values from the NFI have become available; also minor changes in the Land Use Matrix have occurred. See more in Chapter 7.3.7.

11.3.6 Uncertainty estimates

The uncertainty has been estimated based on the net changes in the different carbon stock with the IPCC Tier 1 methodology, Table 11.3 and Table 11.4.

The uncertainty in 2012 for Afforestation has been estimated to ± 9.7 Gg CO_2 equivalents and for Deforestation to ± 10.0 Gg CO_2 equivalents. The low uncertainty for afforestation is associated with that the figure is around zero.

Table 11.3 Uncertainty assessment for Afforestation for year 2012.

KP A.1.1 Afforestation and Reforestation		Emission	Activity data, %	Emission factor, %	Combined uncertainty	Total uncertainty, %	Uncertainty 95 %, Gg CO_2 eqv.
Area subject to the activity, ha		94 358					
Area of organic soils, ha		10 251					
Net CO2 emissions/ removals , Gg		37.8				18.8	7.1
Carbon stock change in above-ground biomass	Net change	12.4	15	8.5	17.2	17.2	2.1
Carbon stock change in below-ground biomass	Net change	5.3	15	8.7	17.4	17.4	0.9
Net carbon stock change in litter		-1.4	15	1.0	15.0	15.0	0.2
Net carbon stock change in dead wood		3.2	15	3.3	15.4	15.4	0.5
Net carbon stock change in soils	Mineral soils	-12.6	15	50.0	52.2	52.2	6.6
	Organic soils	3.5	15	50.0	52.2	52.2	1.8

Table 11.4 Uncertainty assessment for Deforestation. 1000 hectares and Gg CO_2 eqv.

KP A.2 Deforestation		Emission	Activity data, %	Emission factor, %	Combined uncertainty	Total uncertainty, %	Uncertainty 95 %, Gg CO_2 eqv.
Area subject to the activity, ha		5 784					
Area of organic soils, ha		NO					
Net CO2 emissions/ removals, Gg CO_2 (1)		109.3				12.1	13.2
Carbon stock change in above-ground biomass	Net change	20.6	15	8.5	17.2	17.2	3.5
Carbon stock change in below-ground biomass	Net change	4.4	15	8.7	17.4	17.4	0.8
Net carbon stock change in litter		4.8	15	1.0	15.0	15.0	0.7
Net carbon stock change in dead wood		0.5	15	3.3	15.4	15.4	0.1
Net carbon stock change in soils	Mineral soils	-0.5	15	50	52.2	52.2	0.3

1) The total emission of 109.3 in this table is slightly lower than the total emission from Deforestation this figure include only CO_2 emissions and not N_2O emissions from deforestation.

11.3.7 Information on other methodological issues

See Chapter 7.

11.3.8 The year of the onset of an activity, if after 2008

Not applicable.

11.4 Forest Management (FM)

11.4.1 Methods for carbon stock change and GHG emission and removal estimates

See Chapter 7 in LULUCF on "Forest remaining forest (5.A.1)".

11.4.2 Methodologies and the underlying assumptions

See Chapter 7 in LULUCF on "Forest remaining forest (5.A.1)".

11.4.3 Omission of pools from FM

No pools omitted.

11.4.4 Factoring out

No factoring out has been made.

11.4.5 Recalculations

Minor recalculations have been made due to updated values from the NFI on carbon stocks. Main change since last reporting is correction of years to which the data refer. This will cause a shift in reported changes. See more in Chapter 7.2.8.

11.4.6 Uncertainty estimates

The uncertainty has been estimated based on the net changes in the different carbon stock with the IPCC Tier 1 methodology. The uncertainty in 2012 for Forest Management has been estimated to ± 686.3 Gg CO_2 equivalents and ± 9.9 Gg CO_2 equivalents from drainage of organic soils in the forest.

Table 11.5 Uncertainty assessment for Forest Management.

KP B.1 Forest Management	Emission	Activity data, %	Emission factor, %	Combined uncertainty	Total uncertainty, %	Uncertainty 95 %, Gg CO_2 eqv.	Emission
Area subject to the activity, ha		538 189					
Area of organic soils, ha		26 267					
Net CO_2 emissions/ removals		-4491.4				10.3	461.1
Carbon stock change in above-ground biomass	Net change	-784.0	15	1.8	15.1	15.1	118.5
Carbon stock change in below-ground biomass	Net change	-176.4	15	2.0	15.1	15.1	26.7
Net carbon stock change in litter		-253.5	15	1.0	15.0	15.0	38.1
Net carbon stock change in dead wood		-20.0	15	3.3	15.4	15.4	3.1
Net carbon stock change in soils	Mineral soils	NO	15	50	52.2	-	-
	Organic soils	8.9	30	90	94.9	94.9	8.5

Table 11.6 Uncertainty assessment associated with drainage of forest soils.

KP-II 2 N_2O from drainage of soils	Emission	Activity data, %	Emission factor, %	Combined uncertainty	Total un-certainty, %	Uncertainty 95%, Gg CO_2 eqv.
Area of drained soils, ha	294 691					
Emission						
	12.1				80.8	9.7
N_2O, Gg CO_2 eqv.	12.1	30	75	80.8	80.8	9.7

11.4.7 Information on other methodological issues

See Chapter 7 in LULUCF on "Forest remaining forest (5.A.1)".

11.4.8 The year of the onset of an activity, if after 2008

Not applicable.

11.5 Cropland Management (CM)

11.5.1 Methods for carbon stock change and GHG emission and removal estimates

CL is subdivided in four classes: agricultural CL, wooded perennial fruit plantations, hedgerows and “other agricultural CL”.

11.5.2 Methodologies and the underlying assumptions used

The area with agricultural CL are given as the agricultural area in Statistics Denmark for cereals, fodder crops, grass for seed, sugar beets, potatoes and other root crops.

Land converted from other Land use categories to CL is included under CL. Land converted to forest is reported under forest (AR). Land which according to the land use matrix is converted to WE and SE are still included in CM. Land conversion to OL is not allowed.

The same methodology as used in the Convention reporting, is used in the KP reporting.

11.5.3 Omission of pool from CM

Aboveground and belowground living biomass, litter and dead organic are only reported for perennial woody crops in accordance with IPCC GPG 2003. No litter and dead organic matter are reported under CL as this is seen as not occurring or as very insignificant as it is only related to the small area with fruit plantations and hedges. Only above- and belowground living biomasses for perennial fruit plantations, hedgerows and willow plantations for bioenergy purposes on agricultural land are therefore reported under cropland. Christmas trees are reported under FL.

11.5.4 Factoring out

The dramatic increase in the temperature in the latter years results in a higher turn-over rate of organic matter in soils leading to an increased emission from soils compared to pre 1990. For agricultural soils Denmark is using a dynamical temperature dependent model (Tier 3), which is expected to give the best estimate of the actual emission from soils compared to most other methods. If Denmark had used the default IPCC Tier 1 or 2 there would likely have been a *negative* factoring out, because the emission factor (EF) in these methods are based on long-term scientific data and thus not having the recent increase in temperatures included. Therefore by using the actual temperature in the Tier 3 no factoring out has been made.

11.5.5 Recalculations

Recalculations has been made due to an updated land use matrix and implementation of N_2O emissions from GL and WE converted to CL. The latter account for a very limited emission. No recalculations have been made for emissions from mineral soils, organic soils, hedgerows, perennial wooden crops and liming which are by far the major sources. The recalculations has reduced the overall emission from CL with 190 Gg CO_2 in the base year and with 180 Gg CO_2 in 2012.

11.5.6 Uncertainty estimates

The uncertainty has been estimated based on the net changes in the different carbon stock with the IPCC Tier 1 methodology. The uncertainty in 2012 for Cropland Management has been estimated to ±2001.1 Gg CO_2 equivalents, ± 0.1 Gg CO_2 equivalents associated with disturbance from land use change and ± 83.2 Gg CO_2 equivalents from lime application, Table 11.7, 11.8 and 11.9, respectively.

Table 11.7 Uncertainty assessment for Cropland Management.

KP B.2 Cropland Management		Emission	Activity data, %	Emission factor, %	Combined uncertainty	Total uncertainty, %	Uncertainty 95 %, Gg CO_2 eqv.
Area subject to the activity, ha		2 643 697					
Area of organic soils, ha		50 886					
Net CO_2 emissions/ removals		2765.3				66.9	1850.6
Carbon stock change in above-ground biomass	Net change	53.8	10	50	51.0	51.0	27.5
Carbon stock change in below-ground biomass	Net change	IE	10	50	51.0	-	-
Net carbon stock change in soils	Mineral soils	160.1	10	75	75.7	75.7	121.2
	Organic soils	540.2	10	90	90.6	90.6	489.2

Table 11.8 Uncertainty assessment for N_2O associated with land use conversion.

KP-II 3 N2O associated from disturbance of land use change	Emis-sion	Activity data, %	Emission factor, %	Combined uncertainty	Total uncertainty, %	Uncertainty 95 %. Gg CO_2 eqv.
Land area converted, ha	5 438					
Emission						
N_2O Gg CO_2 eqv	0.9				76.5	0.7

Table 11.9 Uncertainty assessment for lime consumption.

KP-II 4 Lime consumption	Emission	Activity data, %	Emission factor, %	Combined uncertainty	Total uncer-tainty, %	Uncertainty 95 %. Gg CO_2 eqv.
Total amount of lime applied	437 341					
Emission						
CO_2	192.3				50.2	96.6

11.5.7 Information on other methodological issues

None.

11.5.8 The year of the onset of an activity. if after 2008

Not applicable.

11.6 Grazing land management (GM)

11.6.1 Methods for carbon stock change and GHG emission and removal estimates

Grazing land is defined as land used for permanent grazing as well as dry land not meeting the definitions for FF, CL, WE or SE. GL is subdivided into two types: Land strictly used for grazing and other grassland. Land used for grazing has no wooden vegetation whereas other grassland may have some wooden vegetation that does not meet the forest definition. The area with strict grazing land is remaining area between the grazing area and the grassland area in the land use matrix.

11.6.2 Description of the methodologies and the underlying assumptions used

As all the grazed grassland is more or less unimproved without fertiliser or limited fertilisation no changes in management practice has been applied. This is in accordance with IPCC GPG 2003 (3.4.1.2.1.2).

For land converted to GL and not purely free of wooden trees/bushes it is assumed that there is a living biomass of 2.200 kg DM per ha in above ground biomass and 6.160 kg DM per ha in below ground biomass (IPCC. 2003). In Grassland it is assumed that no changes in soil carbon stock in mineral soils are occurring. For organic soils is assumed an emission as reported in Section 7.

11.6.3 Factoring out

No factoring out has been made.

11.6.4 Recalculations

See section 10.5.5 as this also affect GM.

11.6.5 Uncertainty estimates

The uncertainty has been estimated based on the net changes in the different carbon stock with the IPCC Tier 1 methodology. The uncertainty in 2011 for Grassland Management has been estimated to ± 101.0 Gg CO_2 equivalents.

Table 11.10 Uncertainty assessment for Grassland Management.

KP B.3 Grassland Management		Emission	Activity data. %	Emission factor. %	Combined uncertainty	Total uncertainty. %	Uncertainty 95 %. Gg CO_2 eqv.
Area subject to the activity		285 900					
Area of organic soils		17 171					
Net CO2 emissions/ removals							
Carbon stock change in above-ground biomass	Net change	523.2				44.7	233.7
Carbon stock change in below-ground biomass	Net change	119.0	10	50	51.0	51.0	60.7
Net carbon stock change in soils	Mineral soils	IE	10	50	51.0	-	-
	Organic soils	2.2	10	75	75.7	75.7	1.7

11.6.6 Information on other methodological issues

None.

11.6.7 The year of the onset of an activity, if after 2008

Not applicable.

11.7 Article 3.3

11.7.1 Information that demonstrates that activities under Article 3.3 began on or after 1 January 1990 and before 31 December 2012 and are direct human-induced

The land use mapping in 1990, 2005, 2011 and 2011 is the documentation that activities under Article 3.3 began after 1.1.1990. As all land area is under management all changes are evaluated as direct human induced. This also includes A and R, which are based on approved methods of establishing new forest - both planting and natural revegetation. In some cases the absence of removal of tree growth is an easy and cheap method for establishing new forest. Hence this method has also been supported through public support for establishment of new forest areas.

11.7.2 Information on how harvesting or forest disturbance that is followed by the re-establishment of forest is distinguished from deforestation

Deforestation is detected by analysis of satellite images. Furthermore deforestation of larger areas is confirmed by e.g. projects on nature restoration. Temporarily unstocked areas are typically located within larger forest areas and will in most cases be reforestated within a period of 10 years as according to the Forest Act of Denmark, which applies to all Legal Forest Reserves (Fredsskov) and equals approximately 70 % of the total forest area. Clearcuts outside forests - e.g. small plantations of conifers on former cropland - is considered deforestation.

Most forest areas - including new forest areas - are subject to intermediate thinnings - harvesting of small trees. This is done with the purpose of reducing stem number and often to produce firewood or wood chips. Clearcuts of new forest areas occurs in most cases first at maturity of the stand – after 50-100 years. A subset of the new forest area are managed as coppice like management. e.g. for production of Christmas trees.

11.7.3 Information on the size and geographical location of forest areas that have lost forest cover but which are not yet classified as deforested

This information will be available after the QA/QC analysis of the land use maps of 1990, 2005 and 2011, which will be performed during 2013.

11.7.4 Uncertainty on article 3.3 activities

A Tier 1 uncertainty analysis has been performed for Article 3.3 activities according to the GPG 2000. In total, the overall uncertainty in the year has been estimated to 50.94 %.

Table 11.11 Uncertainty assessment for Article 3.3. activities inclusive trend uncertainty.

		Year 2012 emission Gg CO_2 eqv.
A. Article 3.3 activities		148.03
KP A.1.1 Afforestation and Reforestation		
KP A.2 Deforestation		37.83
	Overall uncertainty in the year	
Total uncertainties (%):		109.26

11.8 Article 3.4

11.8.1 Information that demonstrates that activities under Article 3.4 have occurred since 1 January 1990 and are human-induced

Forest Management

In FM all forest area is under management and changes in carbon stock are hence seen as human induced. The baseline for 1990 is estimated as documented in Johannsen et al. 2009.

Cropland Management

Since 1990 major changes in Danish Agriculture has taken place. Due to environmental demands for "green crops during winter" the previous major crop, spring barley, has been replaced by primarily winter wheat. Furthermore, a ban on field burning was implemented in January 1990 (Executive order NO. 142 of 08/03/1989). This has reduced the burning of field residues, which were widely occurring until then. Furthermore, as part of reducing the leaching of nitrogen, executive order NO. 624 of 15/07/1997 demands of the farmers that a certain percentage of the area shall be grown with an extra crop after harvest of annual crops. Currently about eight per cent of the agricultural area is having an extra crop. From 2003 agricultural areas has been taken out of rotation due to demanded borders along watersheds to protect the watersheds.

Grassland Management

No specific activities have taken place in Grassland to increase or decrease the carbon stock. GM was elected so that all human induced activities affecting the carbon stock in the landscape are included in the Danish commitments under the Kyoto Protocol. Furthermore, it is very difficult to distinguish between activities in CM and GM in the heterogenic patchy Danish landscape.

11.8.2 Information relating to Cropland Management. Grazing Land Management and Revegetation, if elected, for the base year

No further information is available.

11.8.3 Information relating to Forest Management

No further information is available.

11.8.4 Uncertainty on article 3.4 activities

An Tier 1 uncertainty analysis has been performed for Article 3.3 activities according to the GPG 2000. In total the overall uncertainty in the year has been estimated to 170.50 % and the trend uncertainty to 117.52 %.

Table 11.12 Uncertainty assessment for Article 3.4. activities inclusive trend uncertainty.

	Base year 1990 emission	Year 2012 emission	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
	Gg CO_2 eqv.	Gg CO_2 eqv.	%	%	%
B. Article 3.4 activities	5,088.29	-998.39			
KP B.1 Forest Management	NA	-4,491.37	NA	-18.72	NA
KP B.2 Cropland Management	4,221.74	2,765.31	52.53	7.69	53.09
KP B.3 Grassland Management	177.39	523.16	8.22	1.45	8.35
KP-II 2 N_2O from drainage of soils	NA	12.07	NA	0.10	NA
KP-II 3 N_2O associated from disturbance of land use change	0.26	0.94	0.01	0.00	0.02
KP-II 4 Lime consumption	622.92	192.30	3.09	0.27	3.10
Total uncertainties	Overall uncertainty in the year (%):				317.39

11.9 Other information

11.9.1 Key category analysis for Article 3.3 activities and any elected activities under Article 3.4

According to the IPCC Good Practice Guidance for LULUCF a category that is identified as key in the UNFCCC inventory should also be considered key under the Kyoto Protocol (IPCC GPG. 2003).

In 2012 the following LULUCF categories were identified as key categories at the level in the UNFCCC reporting:

- Forest land remaining forest land.
- Cropland remaining cropland – living biomass
- Cropland remaining cropland – organic soils
- Cropland remaining cropland – mineral soils
- Grassland remaining grassland – living biomass

According to Table 5.4.4 in the IPCC GPG for LULUCF this means that the following Kyoto Protocol activities are initially considered key.

Table 11.13 Relationship between activities in the UNFCCC LULUCF and the KP-LULUCF.

LULUCF activity	KP-LULUCF activities
Forest land remaining forest land	FM, GM, CM
Land converted to forest land	AR
Cropland remaining cropland	CM
Grassland remaining grassland	GM

For Denmark the relevant KP-LULUCF activity corresponding to forest land remaining forest land identified as being a key category in the UNFCCC reporting is FM. For land converted to forest afforestation/reforestation is a key category. For cropland remaining cropland the relevant KP-LULUCF activity is CM. For grassland remaining grassland the relevant KP-LULUCF activity is GM.

Therefore AR, FM, CM and GM are considered key categories in the Danish KP-LULUCF inventory.

For the full list of identified key categories please refer to Annex 1.

11.10 Information relating to Article 6

There are no Article 6 projects (Joint Implementation) on the Danish territory.

12 Information on accounting of Kyoto units

Referring to Decision 15/CMP.1 on Guidelines for the preparation of the information required under Articles 7 of the Kyoto Protocol (UNFCCC, 2006), this chapter and chapters 13, 14 and 15 include information and references to Denmark's and Greenland's annual non-inventory information under the Kyoto Protocol.

12.1 Background information

In accordance with paragraph 10 of the annex to Decision 15/CMP.1 information on emission reduction units, certified emission reductions, temporary certified emission reductions, long-term certified emission reductions, assigned amount units and removal units will be reported for the first calendar year in which these units will be transferred or acquired.

12.2 Summary of information reported in the SEF tables

The information required is contained in the UNFCCC Standard Electronic Format (SEF) application version 1.2.1.

12.3 Discrepancies and notifications

Annex 1 parties are also 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.
- Paragraph 13/14 – List of notifications from the CDM Executive Board regarding lCERs.
- Paragraph 15 – List of non-replacement identified by the ITL.
- Paragraph 16 – List of invalid Kyoto units.

The list described in paragraph 12 is contained in Annex 6 as "Report – List of discrepancies identified by the ITL according to paragraph 12 of the annex to decision 15/CMP.1".

The lists described in paragraph 13-15 are not included in this NIR, as there are no tCERs or lCERs in the Danish Registry. For paragraph 16, the Danish Registry has yet to receive invalid Kyoto units. This also renders this list unnecessary to submit. The discrepancies have been found in the daily reconciliation and have all been solved by manual intervention by either the Danish Registry or the CITL/ITL depending on which stage the transaction was in.

12.4 Publicly accessible information

Information to be publically available from the SEF will be included in SEF 2012 Denmark. The SEF report will also be publically available on the Danish Business Authority website (http://www.dba.erhvervsstyrelsen.dk/eu-ets-registry-kyoto).

Other information that is required to be publically available can be found on the EUTL website: http://ec.europa.eu/environment/ets/.

This information includes information on each account as required in paragraph 45 of the annex to Decision 13/CMP.1. Please note that the contact information (paragraph 45 (d) and (e)) requires the consent of the account holder according to EU law. Thus, all of this information is not publically available.

Information required in paragraph 45 (c) of the annex to Decision 13/CMP.1 can be found at the Danish Business Authority webpage:
http://www.dba.erhvervsstyrelsen.dk/eu-ets-registry-kyoto

Information on article 6 projects is not available as Denmark to this date has not approved any Joint Implementation projects in Denmark.

12.5 Calculation of the commitment period reserve

The calculation of the Commitment Period Reserve (CPR) is based on the assigned amount of 276 838 955 tonnes of CO_2 equivalents (UNFCCC, 2007). Subsequently, the CPR calculated as 90 % of the assigned amount is 249 155 060 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 2 November 2007 (UNFCCC, 2007). The commitment period reserve has not changed since the previous submission, as 100 % times the most recent inventory times five would amount to a higher value.

12.6 KP-LULUCF accounting

At the time of preparation for this report Denmark has issued 6 942 723 RMUs and net-source cancelled 597 294 units (552 195 RMUs and 45 099 AAUs).
Referring to the KP-LULUCF inventory the accounting quantity is 8 613 701 tonnes CO_2 equivalent as RMUs on the basis of activities in 2008-2012 under Articles 3.3 and 3.4 of the Kyoto Protocol.

The accounting of RMUs based on the 2013 and 2014 submissions will not begin until after publication of the review report from the review of the submissions.

Table 12.1 Information on accounting for activities under articles 3.3 and 3.4 of the Kyoto Protocol.

Greenhouse gas source and sink activities	Net emissions/-removals							Accounting Parameters	Accounting Quantity
	Base year	2008	2009	2010	2011	2012	Total		
	(Gg CO_2 equivalent)								
A. Article 3.3 activities									
A.1. Afforestation and Reforestation		393.4	-216.2	-279.8	-119.2	37.8	-183.9		-183.9
A.2. Deforestation		81.3	80.9	82.4	85.1	110.2	439.8		439.8
B. Article 3.4 activities									
B.1. Forest Management		-6097.6	259.4	-3754.7	-6180.0	-4479.3	-20252.2		-1172.6
3.3 offset								255.9	-255.9
FM cap								916.7	-916.7
B.2. Cropland Management	4844.7	3768.0	2663.5	3388.5	3196.2	2957.8	15974.0	24223.3	-8249.3
B.3. Grazing Land Management	177.6	236.0	223.4	214.8	245.7	524.5	1444.4	887.9	556.5
Total		-1460.1	-2270.7	-1616.3	-1614.5	-1391.9			-8609.4

Table 12.2 shows the average accounting quantity for 2008-2012.

Table 12.2 Annual average accounting quantity, Gg CO_2 equivalent.

	Average for 2008-2012
Afforestation and Reforestation	-36,78
Deforestation	87,97
Forest Management	-234,52
Cropland Management	-1649,86
Grazing Land Management	111,31
Total	-1721,88

[1] Calculated as the FM cap plus the Article 3.3 offset divided by five.

12.7 References

EC, 2004: COMMISSION REGULATION (EC) No 2216/2004 of 21 December 2004 for a standardised and secured system of registries pursuant to Directive 2003/87/EC of the European Parliament and of the Council and Decision No 280/2004/EC of the European Parliament and of the Council. Available at:
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:386:0001:0077:EN:PDF

UNFCCC, 2006: Report of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol on its first session, held at Montreal from 28 November to 10 December 2005. Available at:
http://unfccc.int/resource/docs/2005/cmp1/eng/08a02.pdf

UNFCCC, 2007: Report of the review of the initial report of Denmark. Available at: http://unfccc.int/resource/docs/2007/irr/dnk.pdf

13 Information on changes in the national system

Since the 2013 submission no changes have been made to the national system.

14 Information on changes in the national registry

The ETS operates in 30 countries: the 27 EU Member States plus Iceland, Liechtenstein and Norway. It covers CO_2 emissions from installations such as power stations, combustion plants, oil refineries and iron and steel works, as well as factories making cement, glass, lime, bricks, ceramics, pulp, paper and board.

The following changes to the national registry of Denmark have occurred in 2013:

Reporting Item	Description
15/CMP.1 annex II.E paragraph 32.(a) Change of name or contact	The Danish Business Authority The Danish Kyoto Registry Dahlerups Pakhus Langelinie Allé 17 DK-2100 København Ø Telephone 1: +45 3529 1000 Telephone 2: +45 7220 0030 E-mail: co2register@erst.dk www.erhvervsstyrelsen.dk/kvoteregisteret http://danishbusinessauthority.dk/eu-ets-registry-kyoto The registry Staff has changed to: Registry Manager Ms. Susanne Petersen Phone: +45 3529 1884 e-mail: susbod@erst.dk Registry staff: Mr. Peter W. Bentzen Phone: +45 3529 1883 e-mail: petben@erst.dk Ms. Hanne Paulli Phone: +45 3529 1881 e-mail: hanpau@erst.dk Ms. Anita Smed Phone: +45 3529 1622 e-mail: anisme@erst.dk Mr Ulrik Barkentin Overby Phone: +45 3529 1636 e-mail: Ulrove@erst.dk
15/CMP.1 annex II.E paragraph 32.(b) Change regarding cooperation arrangement	No change of cooperation arrangement occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(c) Change to database structure or the capacity of national registry	An updated diagram of the database structure is attached as Annex A. Iteration 5 of the national registry released in January 2013 and Iteration 6 of the national registry released in June 2013 introduces changes in the structure of the database. Changes introduced in release 5 and 6 of the national registry were limited and only affected EU ETS functionality. No change was required to the database and application backup plan or to the disaster recovery plan. No change to the capacity of the national registry occurred during the reported period.

Reporting Item	Description
15/CMP.1 annex II.E paragraph 32.(d) Change regarding conformance to technical standards	Changes introduced in release 5 and 6 of the national registry were limited and only affected EU ETS functionality. However, each release of the registry is subject to both regression testing and tests related to new functionality. These tests also include thorough testing against the DES and were successfully carried out prior to the relevant major release of the version to Production (see Annex B). Annex H testing was carried out in February 2014 and the successful test report has been attached. No other change in the registry's conformance to the technical standards occurred for the reported period.
15/CMP.1 annex II.E paragraph 32.(e) Change to discrepancies procedures	No change of discrepancies procedures occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(f) Change regarding security	No change of security measures occurred during the reporting period The Danish Registry staff has made 3 changes to increase the security on the administration: 1. The staff members are not allowed to leave their cell phones un-attended. They are obliged to either have the phones with them, or the phone is locked in a cabinet. Only the staff member has the key to his cabinet. 2. All staff members have been undergoing an extended Police investigation. 3. The building hosting the registry administration has been secured. Only employees in The Danish Business Authority have access to the floor of the Danish Registry Staff.
15/CMP.1 annex II.E paragraph 32.(g) Change to list of publicly available information	EC: No change to the list of publicly available information occurred during the reporting period. DK: UK: http://danishbusinessauthority.dk/public_information http://danishbusinessauthority.dk/danish_emission_trading_registry DK: http://www.erhvervsstyrelsen.dk/offentlig_information http://www.erhvervsstyrelsen.dk/kyoto-registeret The publicly available information is updated on a monthly basis and confidential information is clearly marked as confidential. The information is available in English and Danish. Publicly available information concerning transactions, holdings and total volumes via the EUTL is concerned confidential, this information is not publicly available before year x+5, where "x" is the year of the transaction. Furthermore the following information is considered confidential: • Account identifier, • Representative's identifier, name, and contact information • Holdings of all accounts, • All transactions made, • The unique unit identification code of the allowances • The unique numeric value of the unit serial number of the Kyoto units held or affected by a transaction No public information is available concerning article-6 projects. Denmark has not approved any joint implementation projects in Denmark.
15/CMP.1 annex II.E paragraph 32.(h) Change of Internet address	No change of the registry internet address occurred during the reporting period. The internet address of the Danish registry is: https://ets-registry.webgate.ec.europa.eu/euregistry/DK/index.xhtml
15/CMP.1 annex II.E paragraph 32.(i) Change regarding data integrity measures	No change of data integrity measures occurred during the reporting period.
15/CMP.1 annex II.E paragraph 32.(j) Change regarding test results	Changes introduced in release 5 and 6 of the national registry were limited and only affected EU ETS functionality. Both regression testing and tests on the new functionality were successfully carried out prior to release of the version to Production. The site acceptance test was carried out by quality assurance consultants on behalf of and assisted by the European Commission; the report is attached as Annex B. Annex H testing was carried out in February 2014 and the successful test report has been attached.

Reporting Item	Description
The previous Annual Review recommendations	In response to the previous Annual Review recommendations, the following document was submitted as a second addendum to Chapter 14: 'Information on changes in national registry' of the Annual Inventory Submission for the reporting year 2012. 8. The assessor notes that Denmark is not fully reporting changes in the national registry related to change of test results. While the Party has resubmitted these items during the assessment cycle, the provided test report reveals a test plan which was of insufficient scope. This is evidenced by the limited number of Kyoto processes covered and absence of DES compliance demonstration through Annex H testing. Compliance with the DES requirements is essential to maintain confidence that national registry continues to perform the functions set out in the annex to decision 13/CMP.1 and the annex to decision 5/CMP.1. Therefore, the assessor strongly recommends that the Party test each release thoroughly against the DES as part of each major release cycle and provide the complete results in its annual NIR. Response: The consolidated EU system of registries successfully completed a full certification procedure in June 2012. Notably, this procedure includes connectivity testing, connectivity reliability testing, distinctness testing and interoperability testing to demonstrate capacity and conformance to the Data Exchange Standard (DES). This included a full Annex H test. All tests were executed successfully and led to successful certification on 1 June2012 The October 2012 release (version 4.0) was only a minor iteration and changes were limited to EU ETS functionality and had no impact on Kyoto Protocol functions in the registry. The test script previously provided reflects this. However, each major release of the registry is subject to both regression testing and tests related to new functionality. These tests include thorough testing against the DES and were successfully carried out prior to the relevant major release of the version to Production
	9. The assessor notes that Denmark is not fully reporting changes in the national registry related to the description of database structure. While the Party has resubmitted a simplified data model during the assessment cycle, the information contained within the model is not sufficient. This is evidenced by the lack of descriptions of each entity in the diagram and the omission of some diagram entities mandated in the Data Exchange Standard. The assessor recommends that following major changes, the party provide a data model which contains all DES required entities complete with descriptions in its annual NIR. Response: The complete description of the consolidated registry was provided in the common readiness documentation and specific readiness documentation for the national registry of EU and all consolidating national registries. Since the successful certification of the registry on 1 June 2012, Iteration 4 of the registry, introduced in October 2012, added a limited number of new entities, none of them relating to DES entities. A data model was attached which more clearly shows the relevant entities "RECONCILIATIONS", "NOTIFICATIONS", "RESPONSES"," INTERNAL AUDIT LOG" and "MESSAGE LOG." As specified in the DES (Section VII. Data Logging Specifications/E. Message Archive), a copy of messages sent and received is stored in standalone files in one of two managed servers in the hosting environment. For that reason, the Message Archive is not shown in the model. The "MESSAGE LOG" object holds the location of the entire message, for each Message_ID. Since the successful certification of the registry on 1 June 2012, there has been no change in the capacity of the registry or change of its infrastructure. The recommendations is implemented and the requested reports will be provided by EC

The mentioned Annex A and Annex B contains confidential information and is therefore not part of the NIR. The information has been submitted to the UNFCCC as confidential.

15 Information on the minimization of adverse impacts in accordance with Article 3, paragraph 14

No changes have occurred since the information reported in NIR 2011.

16 Methodology applied for the greenhouse gas inventory for Greenland

16.1 Introduction

The following sections contain a report of Greenland's part of the National Inventory Report (NIR) 2014. The structure of the report follows the UNFCCC guidelines on reporting and review (UNFCCC, 2002).

The report is to a far extent structured according to the recommended outline provided by the UNFCCC secretariat.

Previous to 2010 the greenhouse gas (GHG) inventory and this report were completed exclusively by The Danish Centre for Environment and Energy, Aarhus University (DCE), with input from the Environmental and Nature Protection Agency (APA), Ministry of Domestic Affairs, Nature and Environment (current Ministry of Environment and Nature).

In 2008 an energy statistic was officially initiated at Statistics Greenland with the intention to "… create an important tool, which in regard to political and economical priorities, can contribute to the identification of efforts on energy matters…" and which "… in regard to environmental aspects will create a basis for assessing the development in regard to Greenland's meetings of the Kyoto protocol …". The first results on the new energy statistics, covering the period 2004-2007, were published in November 2008.

The GHG inventory submitted in April 2014 is completed by Statistics Greenland and the Ministry of Environment and Nature, Greenland Government, with technical support from DCE. This report on methodology is written by Statistics Greenland with assistance from the Ministry of Environment and Nature and documental support by DCE.

The annual emission inventories for Greenland for the years 1990-2012, are reported in the full CRF format.

The GHG's reported are:

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

16.1.1 A description of the institutional arrangement for inventory preparation

Statistics Greenland and The Greenland Ministry of Environment and Nature are responsible for the annual preparation of the Greenlandic contribution to the National Inventory Report and the GHG inventories in the Common Reporting Format in accordance with the UNFCCC Guidelines. Statistics Greenland provides the data to DCE. DCE is responsible for aggregating the Danish and Greenlandic CRF submissions and reporting the aggregated CRF and the National Inventory Report to the UNFCCC.

The inventory for LULUCF and KP-LULUCF is carried out by DCE and the documentation of the inventory (Sections 16.7 and 16.11) is completed by the Danish LULUCF experts.

Formerly, the provision of data was on a voluntary basis, but a formal contract between DCE and the Greenland Government came in place for the 2009 GHG inventory report.

The work concerning the annual GHG emission inventory is carried out in co-operation with other Greenlandic ministries, research institutes, organisations and companies:

Statistics Greenland (Ministry of Finance)
Annual energy statistics in a format suitable for the emission inventory work and fuel-use data for the large combustion plants. Since 2009 annual survey on emissions of F-gases.

Agricultural Advisory Service (Ministry of Fisheries, Hunting and Agriculture)
Background data on cropland and grassland, and statistics on livestock (sheep and reindeer).

Ministry of Domestic Affairs, Nature and Environment
Data on waste and emissions of F-gases. Annual Survey carried out by the Ministry of Domestic Affairs, Nature and Environment until 2008 and by Statistics Greenland from 2009 and onwards.

Ministry of Fisheries, Hunting and Agriculture and the Greenlandic Arboretum
Background data on forestry.

Greenland Airport Authority (Ministry of Health and Infrastructure)
Statistics on domestic flights and foreign flights to and from Greenland.

16.1.2 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 format and handled with software from the SAS Institute Inc. The SAS programs are designed by Statistics Greenland. The methodologies and data sources used for the different sectors are described briefly in Section 16.1.4 and more in depth in Sections 16.3 to 16.8 and Section 16.11.

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.

16.1.3 General description of methodologies and data sources used

The GHG inventory for Greenland includes the following sectors:

- Energy sector
- Industrial processes
- Solvent and other product use

- Agriculture
- Land Use, Land-use Change and Forestry
- Waste
- KP-LULUCF

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. More thorough descriptions are included in Sections 16.3-16.8 and 16.11.

Energy sector

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, Statoil and Malik Supply A/S. Polaroil imports fuel and distributes fuel in all parts of Greenland. Statoil 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 then 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, company tax accountings, municipality and the Government of Greenland 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 GER-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 i.e. 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. 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), Royal Arctic Bygdeservice A/S (freight/passengers), and Arctic Umiaq Line A/S (passengers) and the liquidated Assartuivik A/S (passengers).

For further information please refer to Section 16.3.

Fugitive emission

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 scotish company initiated a search for oil along the westcoast of Greenland. Three wells were drilled and tested in 2010. Five wells in 2011. The oil company reported a total fugitive emission of 44 tonnes CO_2-eqv methan from all three wells in 2010. This information has been recognised as the total fugitive emission of CH_4 from fuels in 2010, whereas the calculation of fugitive emission of CO_2 and N_2O in 2010 and all three gases in 2011 has been based on IPCC Guideline emission factors, see Section 16.3. The were no oil exploration activities in 2012.

Furthermore, 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

Mineral products

CO_2 emissions occur from limestone and dolomite use, road paving with asphalt and asphalt roofing. Import statistics of asphalt and limestone are used as activity data for estimating the emissions.

Chemical industry

Greenland has no chemical industry.

Metal production

Greenland has no metal production.

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.

F-gases

Greenland has no production of halocarbons or SF_6. Data on consumption of F-gases (HFCs and SF_6) are obtained from an annual survey on consumption of halocarbons and SF_6 conducted by Statistics Greenland. Information on emission of industrial gases is available from 1995 onwards. Greenland has no consumption of PFCs.

For further information on the methodology for calculating emissions from industrial processes please refer to Section 16.4.

Solvent and other product use

The emission estimates for solvent and other product use are 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 16.5.

Agriculture

Enteric Fermentation 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.

The emissions are given in CRF: Table 4 Sectoral Report for Agriculture and Table 4.A, 4.B(a), 4.B(b) and 4.D Sectoral Background Data for Agriculture. The calculation of emissions from the agricultural sector is based on methods described in the IPCC Guidelines (IPCC, 1996) and the Good Practice Guidance (IPCC, 2000). 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 16.6.

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 40 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 has the emission from the LULUC sector in 2012 been estimated to a net source of 1.32 Gg 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 2012 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.

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 2012 10.5 ha of cropland was 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 hectare reported as grassland. The grassland is located in mountainous areas used for grazing of sheep. Due to the global warming are there some smaller areas which have become improved fertilised grassland. The total area with improved grassland has increased from 490 ha in 1990 to 1,060 ha in 2012.

Wetlands

Reported area with wetlands consists only of water-reservoirs. Due to lack of methodology for methane emissions under arctic conditions has no emission estimates has been made which is in accordance with the IPCC GPG 2003 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 GPG 2003 guidelines.

For a more thorough description of the methodology applied for LULUCF and KP-LULUCF please refer to Section 16.7 and 16.11.

Waste

Solid waste management

The solid waste management in Greenland can be divided in the following processes:

- Managed waste disposal combined with open burning.
- Unmanaged waste disposal combined with open burning.
- Waste incineration with energy recovery.
- Waste incineration without energy recovery.

Waste incineration with energy recovery is according to IPCC Guidelines included under the energy sector.

Information on amount of waste produced pr 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 handling

N_2O emission from human sewage is estimated. The calculation of the N_2O emission uses population data from Statistics Greenland 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 16.8.

Memo Items

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 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 Civil aviation.

International Marine Bunkers

Emissions from international marine bunkers are included from 2004 and onwards. Before 2004 international marine bunkers are considered to be of negligible importance.

KP-LULUCF

Regarding the possibility of including in the first commitment period emissions and removals associated with land use, land-use change and forestry activities under Article 3.4 of the Kyoto Protocol, Greenland as part of the Kingdom of Denmark has included emissions and removals from forest management (FM), cropland management (CM) and grazing land management (GM).

The national system has identified land areas associated with the activities under Article 3.4 of the Kyoto Protocol in accordance with definitions, modalities, rules and guidelines relating to land use, land-use change and forestry activities under the protocol. All land converted from other activities into Cropland and Grassland is accounted for. No land has been allowed to leave elected areas under art. 3.4, see Section 16.11 for further details.

16.1.4 Brief description of key categories

A key category analysis (KCA) for year 1990 and 2012 has been carried out in accordance with the IPCC Good Practice Guidance.

The categorisation used results in a total of 32 categories. In the level KCA for the inventory for 1990, five key categories were identified. In the KCA for 2012, six categories were identified as key categories due to both level and trend. Further, three categories were key categories due to the trend.

Of the six key sources due to level for the reporting year 2012 four are in the energy sector, of which CO_2 from liquid fuels excluding transport in the analysis contributes most with 74.0 % 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). The remaining level key categories in the energy sector are all CO_2 from the transport sector. Civil aviation, road transportation and domestic navigation comprise respectively 7.6 %, 5.4 % and 4.9 % of the national total. The last key categories are N_2O from wastewater handling and the consumption of HFCs.

The trend assessment shows that CO_2 from from Grassland remaining grassland, direct N2O emissions from agricultural soils ans CO2 emission from waste incineration are key categories to the trend.

The categorisation used, results, etc. are included in Section 16.12 (Annex 1).

16.1.5 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.

16.1.6 General uncertainty evaluation

The uncertainty estimates are based on the Tier 1 methodology in the IPCC Good Practice Guidance (GPG) (IPCC, 2000). Uncertainty estimates for the following sectors are included in the current year: fuel combustion, fugitive emissions, industrial processes, solid waste, wastewater treatment and waste incineration, solvents and other product use, agriculture and LULUCF.

The uncertainties for the activity rates and emission factors are shown in Table 16.1.4. The estimated uncertainties for total GHG and for CO_2, CH_4, N_2O and F-gases are shown in Table 16.1.3. 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 ± 3.8 % and the trend in GHG emission since 1990 has been estimated to be -6.1 % ± 2.7 %-age points. The GHG uncertainty estimates do not take into account the uncertainty of the GWP factors.

The uncertainty on CO_2 and N_2O from liquid fuels in fuel combustion, N_2O emission from waste water treatment and CH_4 emission from enteric fermentation are the largest sources of uncertainty for the Greenlandic GHG inventory. 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 16.1.3 Uncertainties 1990-2012.

	Uncertainty [%]	Trend [%]	Uncertainty in trend [%-age points]
GHG	± 3.8	-6.1	± 2.7
CO_2	± 2.8	-7.1	± 2.6
CH_4	± 56	-7.8	± 8.8
N_2O	± 82	-10.1	± 26
F-gases	± 51	+11 808	± 5 250

Table 16.1.4 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	613	562	2	2
1A Municipal waste	CO_2	2	7	2	25
1A Liquid fuels	CH_4	1	1	2	100
1A Municipal waste	CH_4	0	0	2	100
1A Biomass	CH_4	0	0	2	100
1A Liquid fuels	N_2O	2	2	2	500
1A Municipal waste	N_2O	0	0	2	500
1A Biomass	N_2O	0	0	2	200
1B2 Oil Exploration	CO_2	0	0	2	1 000
1B2 Oil Exploration	CH_4	0	0	2	1 000
1B2 Oil Exploration	N_2O	0	0	2	1 000
2A3 Limestone and dolomite use	CO_2	0	0	5	5
2A5 Asphalt roofing	CO_2	0	0	5	25
2A6 Road paving with asphalt	CO_2	0	0	5	25
2F Consumption of HFC	HFC	0	7	10	50
2F Consumption of SF_6	SF_6	0	0	10	50
3A Paint application	CO_2	0	0	10	15
3B Degreasing and dry cleaning	CO_2	0	0	10	15
3C Chemical products, manufacturing and processing	CO_2	0	0	10	15
3D5 Other	CO_2	0	0	10	20
4A Enteric Fermentation	CH_4	6	5	10	100
4B Manure Management	CH_4	0	0	10	100
4B Manure Management	N_2O	1	1	10	100
4D1 Direct N_2O emissions from agricultural soils	N_2O	0	1	20	50
4D2 Pasture range and paddock	N_2O	1	1	20	25
4D3 Indirect N_2O emissions from agricultural soils	N_2O	1	1	20	50
5A Forest	CO_2	0	0	5	50
5B Cropland	CO_2	0	0	5	50
5C Grassland	CO_2	0	1	5	50
6A Solid Waste Disposal on Land	CH_4	4	4	10	100
6B Wastewater Handling	N_2O	15	12	30	100
6C Waste incineration	CO_2	3	3	10	25
6C Waste incineration	CH_4	2	2	10	50
6C Waste incineration	N_2O	1	1	10	100

16.1.7 General assessment of completeness

The present Greenlandic greenhouse gas emission inventory includes all major sources identified by the Revised IPCC Guidelines.

16.1.8 References

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16.2 Trends in Greenhouse Gas Emissions

16.2.1 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 seven main sectors; Energy incl. Transport, Industrial Processes, Solvent and Other Product Use, Agriculture, LULUCF, and Waste. In Figure 16.2.3 and Figure 16.2.4 CO_2 emissions from fuel combustion in the Energy Sector is split into several sub-categories i.e. Energy Industries, Manufacturing Industries and Construction, Commercial and Institutional, Transport, Residential, Agriculture and Fishing.

The greenhouse gases include CO_2, CH_4, N_2O, HFCs, PFCs and SF_6. However, Greenland has no consumption of PFC. In 2012 total emission of greenhouse gases excluding LULUCF was 610.38 Gg CO_2 equivalent, and 611.70 Gg CO_2 equivalent including LULUCF.

Figure 16.2.1 shows total greenhouse gas emission in CO_2 equivalents from 1990 to 2012. The emissions are not corrected for temperature variations. CO_2 is the most important greenhouse gas. In 2012 CO_2 contributed to the total emission in CO_2 equivalent excluding LULUCF (Land Use and Land-Use Change and Forestry) with 93.8 %, followed by N_2O with 3.0 %, CH_4 2.0 % and F-gases (HFCs and SF_6) with 1.2 %. Since 1990 these percentages have been increasing for F-gases, almost constant for CO_2 and falling for N_2O and CH_4.

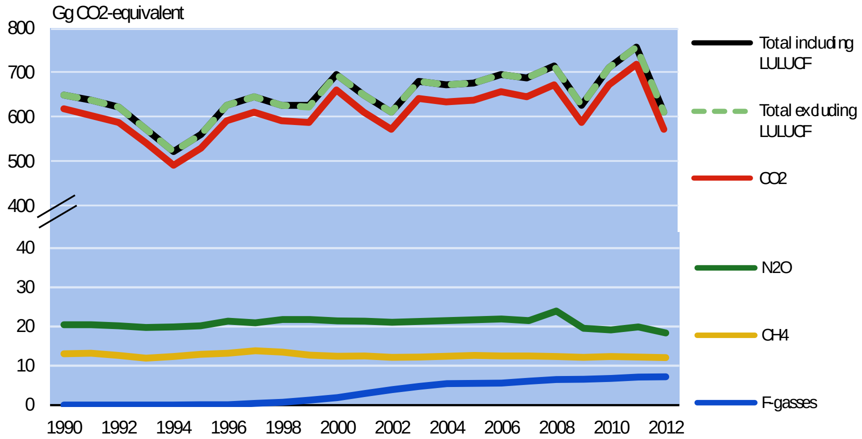


Figure 16.2.1 Greenhouse gas emission in CO_2 equivalents, time series 1990-2012.

Stationary combustion plants and transport represent the largest categories. Energy excluding transport contributed to the total emission in CO_2 equivalents excluding LULUCF with 75.7 % in 2012; see Figure 16.2.2. Transport contributed with 18.1 %. Industrial processes, solvent and other products use, agriculture and waste contributed to the total emission in CO_2 equivalents with 6.2 %.

The net CO_2 emission forestry etc. is 0.2 % of the total emission in CO_2 equivalents in 2012. The total GHG emission in CO_2 equivalents excluding LULUCF has decreased by 6.2 % from 1990 to 2012 and decreased 6.1% including LULUCF. Comments on the overall trends etc. seen in Figure 16.2.1 and Figure 16.2.2 are given in the sections below on the individual greenhouse gases.

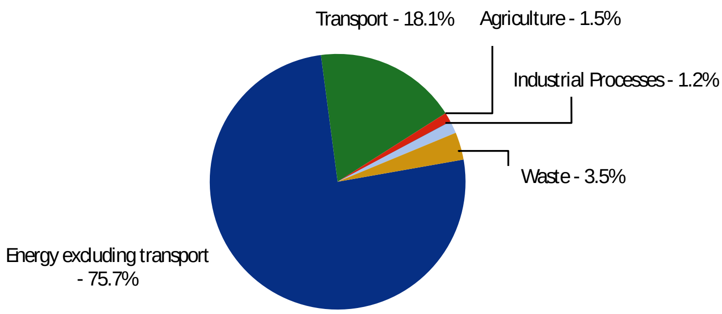


Figure 16.2.2 Greenhouse gas emission in CO_2 equivalents distributed on main sectors for 2012.

16.2.2 Description and interpretation of emission trends by gas

Carbon Dioxide

Emission of CO_2 accounted for 93.8 % of the total GHG emission in 2012. The largest source to the emission of CO_2 is the energy sector comprising Fuel Combustion (Sectoral Approach) and Fugitive Emissions from Fuels. In 2012 the energy sector contributed to 99.4 % of the total CO_2 emission.

In Figure 16.2.3 and Figure 16.2.4 CO_2 emissions are split into several subcategories i.e. Energy Industries, Manufacturing Industries and Construction, Transport, Commercial and Institutional, Residential, Agriculture and Fishing all subcategories from the energy sector. All remaining sectors are included in the subcategory Other including Waste incineration, Solvents and Other Product Use and Industrial Processes.

The largest source to the emission of CO_2; the energy sector includes combustion of fossil fuels like gas oil, gasoline, jet kerosene etc. From this sector Agriculture and Fishing (AFF) contributes with 23.2 % making AFF the largest contributor in 2012 followed by Residental with 19.6 % and Energy Industries and Transport both sharing 19.1 % of the total CO_2 emission in 2012.

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 emissions in the Energy Industries to rise to the highest point ever. In 2012 oil exploration activities came to a standstill, which send energy combustion in Energy Industries to the lowest level ever in the time series since 1990.

Commercial and Institutions contributes with 9.4 % of the total CO_2 emission and Manufacturing Industries and Construction with 6.3 %. The category *Other* contributed with 3.3 % of the CO_2 emissions in 2012.

CO_2 emissions excluding LULUCF decreased by 20.2 % from 2011 to 2012. The main reason for this decrease was a standstill in the oil explorations in 2012. In 2012, the actual CO_2 emission was 7.2 % lower than the emission in 1990 excluding LULUCF.

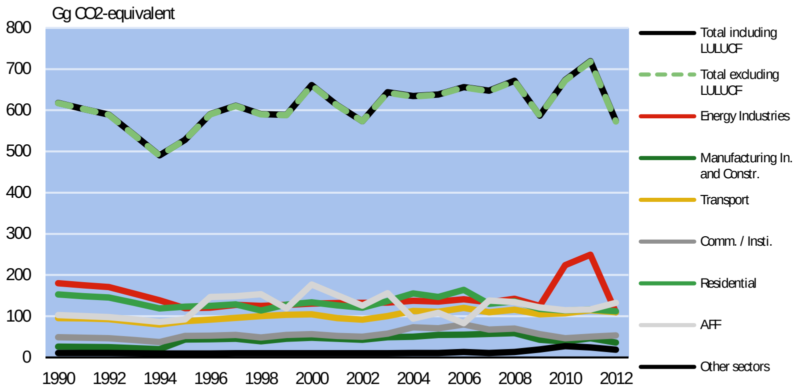


Figure 16.2.3 CO_2 emissions, time series for 1990-2012.

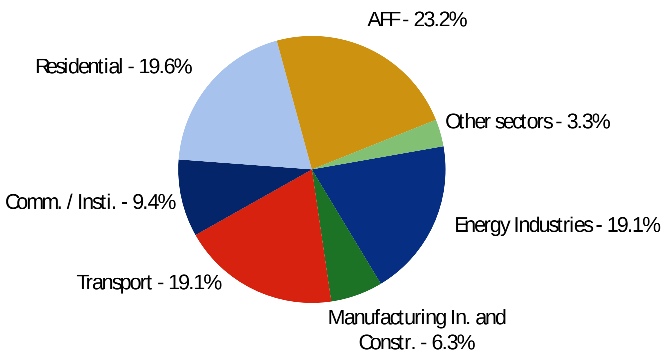


Figure 16.2.4 CO_2 emissions, distribution according to the main sectors for 2012.

Nitrous oxide

Waste, particularly waste water handling is the most important N_2O emission source in 2012 contributing 68.5 % to the total N_2O emissions, see Figure 16.2.6. Agricultural activities contributed 20.8 % to the total N_2O emissions in 2012. Fuel combustion including transport contributed 10.7 %. Since 1990 total emission of N_2O has decreased by 10.1 %.

The N_2O emission from agriculture decreased during the early nineties due to a decrease in reindeer livestock from 1990 to 1994. Since 1995 the emission of N_2O has increased and decreased for shorter periods depending on changes in the livestock and the use of fertiliser. In 2008, the actual N_2O emission was double the emission in 1990, see Figure 16.2.5. The cause of this was a significant increase in the use of fertilisers in 2008.

Besides from a temporary increase in 2011 total N_2O emission was reduced in 2009-2010 and 2012 by 18.4 %, 2.1 %, and 7.6 % due to a fall in the amount of waste water handling from industrial fishing plants and reduced use of synthetic fertilisers in agricultural activities, see Figure 16.2.5.

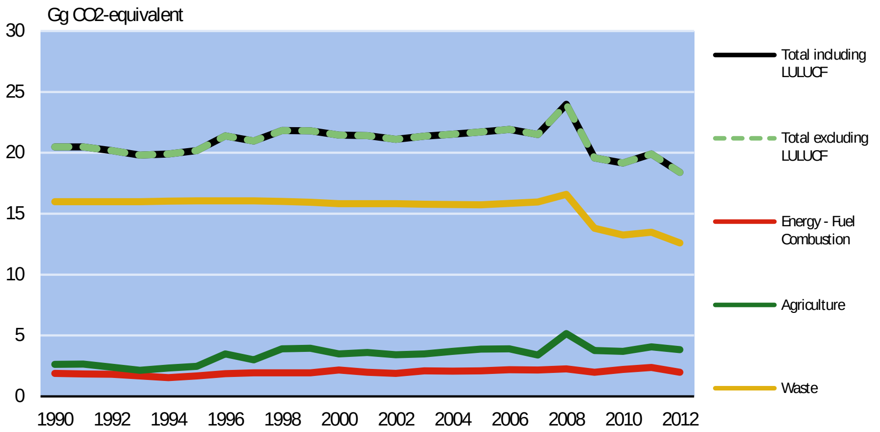


Figure 16.2.5 N_2O emissions, time series for 1990-2012.

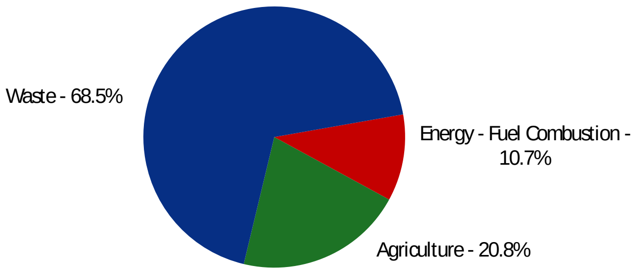


Figure 16.2.6 N_2O emissions, distribution according to the main sectors in 2012.

Methane

The largest sources of anthropogenic CH_4 emissions are agricultural activities contributing with 45.6 % of total CH_4 emission in 2012; see Figure 16.2.8. Waste handling contributes to 45.5 % of total emission and the energy sector to 9.0 % of total CH_4 emission in 2012. The emission from agriculture derives from enteric fermentation (97.7 %) and management of animal manure (2.3 %).

Since 1990 the overall number of sheep has increased, while the overall number of reindeer has decreased. From 1990 to 2012 the emission of CH_4 from agricultural activities has decreased by 10.5 %.

The emission of CH_4 from waste derives from solid waste disposal (70.9 %) and waste incineration (29.1 %). From 1990 to 2012 the emission of CH_4 from solid waste disposal has increased by 7.2 %, while emissions from waste incineration have decreased by 29.4 %. Overall emission of CH_4 from waste handling has decreased by 6.8 % from 1990 to 2012.

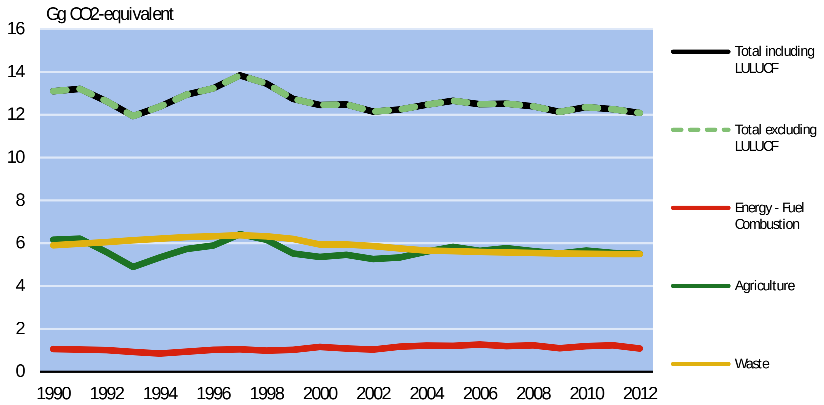


Figure 16.2.7 CH_4 emissions, time series for 1990-2012.

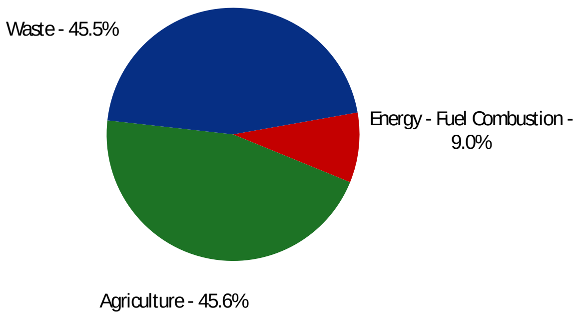


Figure 16.2.8 CH_4 emissions, distribution according to the main sectors in 2012.

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. From 1995 to 2012 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 16.2.9. This increase is caused by and simultaneous with an increase in the emission of HFCs. For the time series 2004-2012 the increase is lower than for the years 1995 to 2004. The increase from 1995 to 2004 is 8,892 %. From 2004 to 2012 total emission increased by 32.4 %. SF_6 contributed to the F-gas sum in 1995 with 59.4 %. Environmental awareness and regulation of this gas under Danish law has reduced its use considerably since 1995. In 2012 the contribution from SF_6 to the emission of F-gases was only 0.04 %.

The use of HFCs has increased to a great extent. Today HFCs are by far the dominant F-gas, comprising 40.6 % in 1995, but 99.96 % in 2012. HFCs are mainly used as a refrigerant.

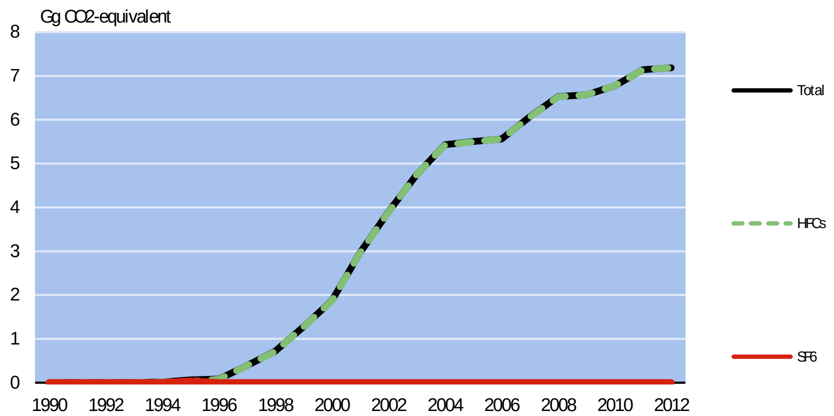


Figure 16.2.9 F-gas emissions, time series for 1990-2012.

16.2.3 Description and interpretation of emission trends by category

Energy

The emission of CO_2 from energy has decreased by 7.4 % from 1990 to 2012. 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. In 2010 and 2011 emissions increased significantly due to a significant increase in fuel conbustion due to the initation of oil exploration, which caused CO_2 emission from energy to rise by 14.6 % in 2010 and by 6.9 % in 2011. However, in 2012 oil exploration activities came to a standstill, while Greenlands fifth hydro power plant went into operation. This caused CO_2 emissions from energy to decrease by 20.3 % in 2012.

Emission of CH_4 has increased by 3.0 % from 1990 to 2012 primarily due to an increase in the use of fuel for transportation as well as in the energy recovery from waste. The CH_4 emission from the transport sector has increased by 54.4 % from 1990 to 2012, mainly due to increasing domestic aviation.

Emission of N_2O has increased by 5.3 % from 1990 to 2012.

Industrial processes

Emissions from industrial processes (consumption of halocarbons and SF_6) other than fuel combustion amount to 1.2 % of the total emission in CO_2 equivalents excluding LULUCF in 2012. The main source is consumptions of HFCs. Emission of F-gases have increased considerable since 1990.

Agriculture

The agricultural sector contributes with 1.6 % of the total GHG emissions excluding LULUCF in 2012, 45.8 % of the total CH_4 emission and 22.1 % of the total N_2O emission. The total emission from the sector has increased by 6.4 % from 1990 to 2012. This increase is due to a rise in the use of synthetic fertilisers. The number of reindeer has decreased from 6,000 heads in 1990 to 3,000 heads in 2012. The number of sheep has increased from 19,929 heads in 1990 to 20,107 heads in 2012. The CH_4 emission has decreased by 10.5 % from 1990 to 2012 primarily due to the fall in the number of reindeers. In the same period N_2O emission has increased by 46.2 % due to a significantly increase in the use of fertilisers.

LULUCF

Emissions from the LULUCF sector amount to just 0.2 % of the total emission in CO_2 equivalents in 2012. Forests are assumed to be a sink for the whole period increasing from approximately zero in 1990 to 42.3 tonnes CO_2 in 2012. The emission from cropland is estimated to zero in 1990 as there were no cropland in Greenland in 1990 and a net source in 2012 of 48.1 tonnes CO_2. The emission from grassland has been estimated to 214 tonnes CO_2 in 1990 increasing to 1,316 tonnes CO_2 in 2012.

Waste

The waste sector contributes with 3.5 % of the total greenhouse gas emissions in 2012, 45.5 % of the total CH_4 emission and 73.2 % of the total N_2O emission. The total emission from the sector has decreased by 13.1 % from 1990 to 2012. This decrease is caused by a drop in the CH_4 emission from waste incineration by 29.4 %, and a decrease in N_2O emission from waste water handling by 20.8 %.

Total GHG emission from waste incineration without energy recovery has decreased by 6.3 % from 1990 to 2012 due to an increasing amount of waste incineration with energy recovery and a decrease in waste water handling from industrial fishing plants in 2012. Emission from incinerated waste used for heat production is included in the 1A1 IPCC category Energy Industries.

16.2.4 Description and interpretation of emission trends for indirect greenhouse gases and SO_2

NO_X

The largest sources to emission of NOx 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 2012, 50.8 % of the Greenlandic emission of NO_X came from AFF-related activities.

The emission of NO_X from AFF varies from year to year. In recent years emission of NO_X from AFF has been relatively stabile with a slightly decreasing tendency since 2000.

The emissions from transport obtain 26.5 % of total emissions in 2012. From 1990 to 2012 emission of NO_X from AFF has increased by 28.9 %, while emissions from transport have increased by 17.3 %. In the same period total emission of NO_X has increased by 15.6 %.

The emissions from energy industries obtain 6.9 % of total emission in 2012. The emission from energy industries have decreased by 39.3 % from 1990 to 2012. The decrease is due to a continuous substitution of fossil fuels with hydro power.

Emission of NO_X from waste handling obtains 0.9 % of total emission, see Figure 16.2.10.

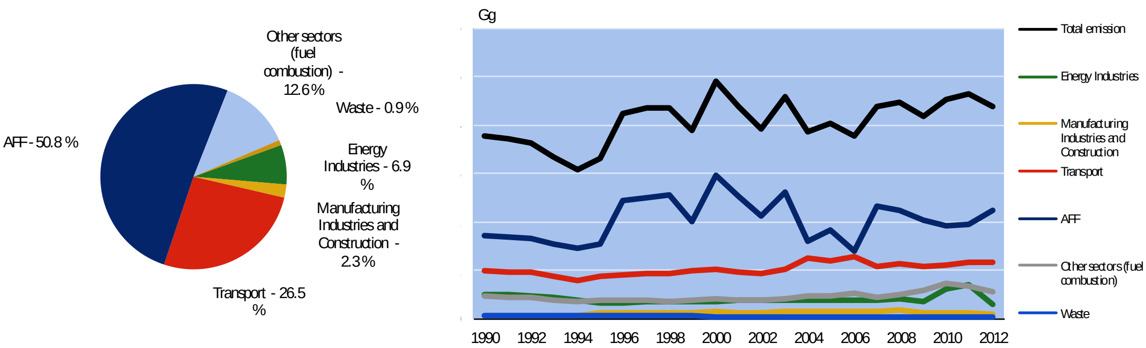


Figure 16.2.10 NO_X emissions. Distribution according to the main sectors (2012), and time series (1990-2012).

CO

Mobile sources like transport and AFF (agriculture, forestry and fisheries) contribute significantly to the total emission of this pollutant. Transport is the largest contributor to the total CO emission, see Figure 16.2.11.

Total CO emission has increased by 43.8 % from 1990 to 2012, largely due to increasing emissions from road transportation and civil aviation. Emissions from energy industries have more than doubled from 1990 to 2012, while emissions from transport have nearly doubled since 1990.

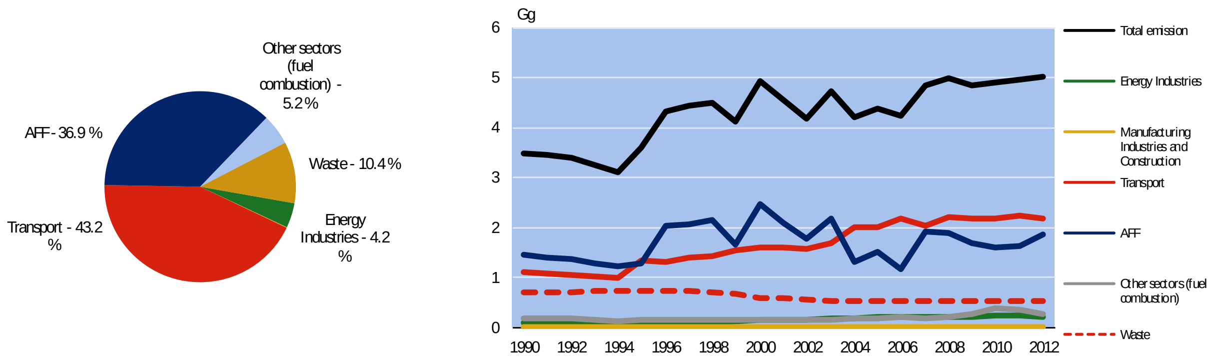


Figure 16.2.11 CO emissions. Distribution according to the main sectors (2012), and time series (1990-2012).

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 37.4 % of the total NMVOC emission in 2012. Fishing vessels are included under AFF (agriculture, forestry and fisheries), which obtain 31.8 % of total NMVOC emission in 2012, see Figure 16.2.12.

The evaporative emissions mainly originate from the use of solvents and the extraction, handling and storage of oil. Emissions from solvents and other product use have decreased by 12.5 % from 1990 to 2012.

The total anthropogenic emissions have increased by 24.6 % from 1990 to 2012, largely due to the increase in road transportation and AFF activities.

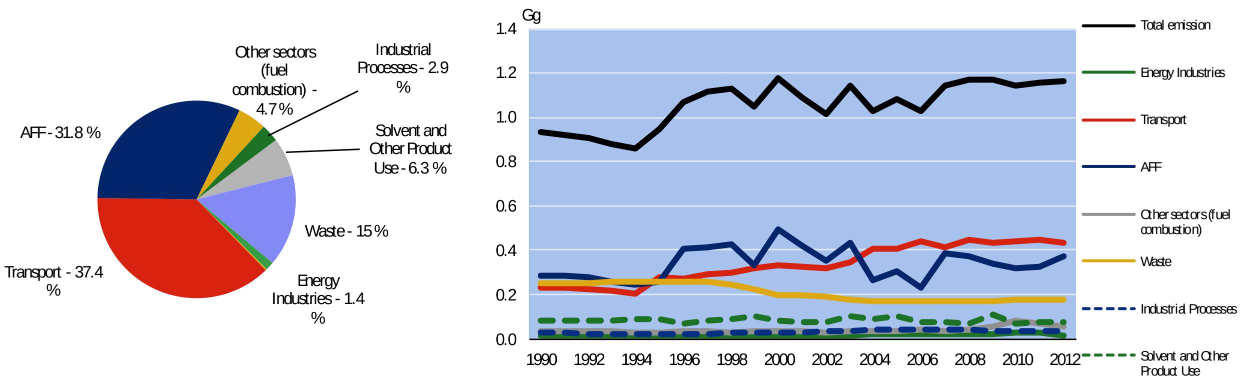


Figure 16.2.12 NMVOC emissions. Distribution according to the main sectors (2012), and time series (1990-2012).

SO_2

The main part of the SO_2 emission originates from the combustion of fossil fuels mainly gas oil in public power and district heating plants. From 1990 to 2012, total emission of SO_2 decreased by 10.7 %.

Emissions from AFF (Agriculture, Forestry and Fisheries) obtain 34.5 % of total SO_2 emission in 2012 followed by Energy Industries obtaining 23.6 % in 2012. Also emissions from other industrial combustion plants, non-industrial combustion plants and mobile sources are important. Transport contributed with 13.6 % of total SO_2 emission in 2012.

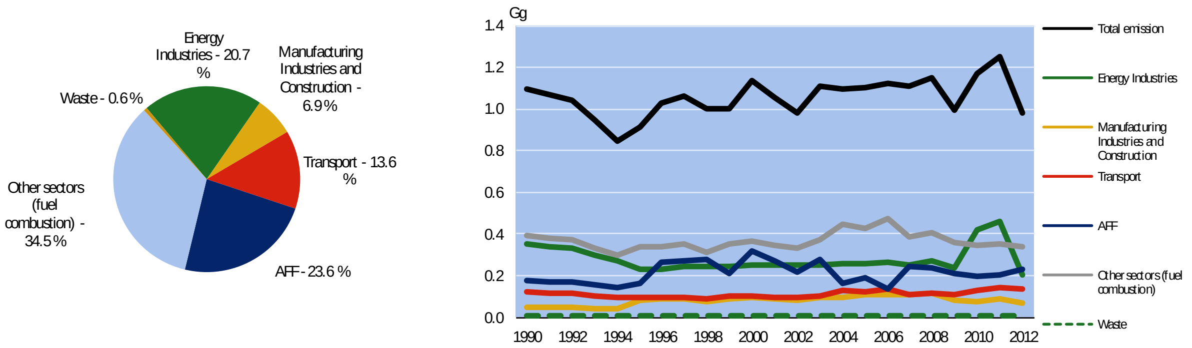


Figure 16.2.13 SO_2 emissions. Distribution according to the main sectors (2012), and time series (1990-2012).

16.3 Energy (CRF sector 1)

16.3.1 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. The emissions 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 below.

Table 16.3.1 CO_2 emission from the energy sector.

Greenhouse gas source and sink categories	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
						Gg					
1. Energy	614.6	600.0	586.0	536.6	487.1	525.1	587.0	607.4	586.4	584.4	657.0
A. Fuel Combustion (Sectoral Approach)	614.6	600.0	586.0	536.6	487.1	525.1	587.0	607.4	586.4	584.4	657.0
1 . Energy Industries	180.4	175.2	171.1	154.8	138.5	119.6	120.4	127.3	125.3	127.4	130.8
2 . Manufacturing Industries and Construction	26.0	25.2	24.6	22.2	19.8	43.2	43.8	45.5	39.4	45.2	47.5
3 . Transport	95.1	94.6	92.6	86.3	80.0	87.9	91.8	95.7	100.1	103.5	104.8
4 . Other Sectors	305.0	297.1	290.0	266.3	242.6	267.8	324.3	332.3	315.0	301.8	367.2
5 . Other	8.1	7.9	7.7	7.0	6.2	6.5	6.5	6.5	6.6	6.6	6.6
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	608.0	570.1	639.4	630.1	634.2	652.3	643.3	667.6	583.6	668.7	714.7
A. Fuel Combustion (Sectoral Approach)	608.0	570.1	639.4	630.1	634.2	652.3	643.3	667.6	583.6	668.7	714.7
1 . Energy Industries	131.9	132.6	133.2	137.1	135.8	141.0	133.8	142.6	124.8	224.3	249.3
2 . Manufacturing Industries and Construction	45.1	42.6	49.2	50.2	54.5	55.1	56.8	58.8	42.7	38.3	46.8
3 . Transport	95.1	91.5	100.3	112.4	110.8	120.0	109.3	116.0	104.9	107.4	114.4
4 . Other Sectors	329.2	296.8	350.2	322.9	325.8	326.7	335.8	340.4	295.3	274.6	283.1
5 . Other	6.6	6.6	6.6	7.4	7.2	9.6	7.6	9.9	15.8	24.1	21.1
B . Fugitive Emissions from Fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	0.02	0.03
continued	2012										
1. Energy	569.3										
A. Fuel Combustion (Sectoral Approach)	569.3										
1 . Energy Industries	109.6										
2 . Manufacturing Industries and Construction	36.2										
3 . Transport	109.6										
4 . Other Sectors	298.4										
5 . Other	15.5										
B . Fugitive Emissions from Fuels	NO										

Table 16.3.2 CH_4 emission 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	0.05
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	0.05
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	0.00	0.00	0.01	0.01	0.01	0.00
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	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06
A. Fuel Combustion (Sectoral Approach)	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	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	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	0.01	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	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.04	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	0.002	0.001
continued	2012										
1. Energy	0.05										
A. Fuel Combustion (Sectoral Approach)	0.05										
1 . Energy Industries	0.01										
2 . Manufacturing Industries and Construction	0.00										
3 . Transport	0.01										
4 . Other Sectors	0.03										
5 . Other	0.00										
B . Fugitive Emissions from Fuels	NO										

Table 16.3.3 N_2O emission 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	0.00	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	0.00	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	0.00	0.00
continued	2012										
1. Energy	0.01										
A. Fuel Combustion (Sectoral Approach)	0.01										
1 . Energy Industries	0.00										
2 . Manufacturing Industries and Construction	0.00										
3 . Transport	0.00										
4 . Other Sectors	0.00										
5 . Other	0.00										
B . Fugitive Emissions from Fuels	NO										

16.3.2 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 annual statistics on energy published by Statistics Greenland and information on waste incineration with energy recovery. The annual statistics on energy is divided into sectors according to the Greenlandic Business Register (GB2000). The register comprises 577 business categories. The official statistics on energy is published by aggregation into 34 categories.

In the Greenlandic emission database, all activity rates and emissions are based on the official statistics on energy. However, in order to fit the CRF format fuel consumption from the official statistics on energy is further aggregated into 15 sectors increased to 16 sectors in 2010 with the energy sebsector "Manufacture of Solid Fuels and Other Energy Industries" that contains emissions from oil exploration.

Fuel combustion

In 2012, total fuel combustion was 8,014 TJ of which 7.826 TJ was liquid fossil fuels.

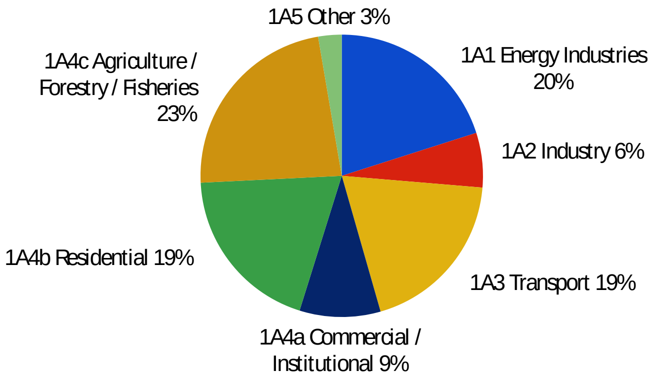
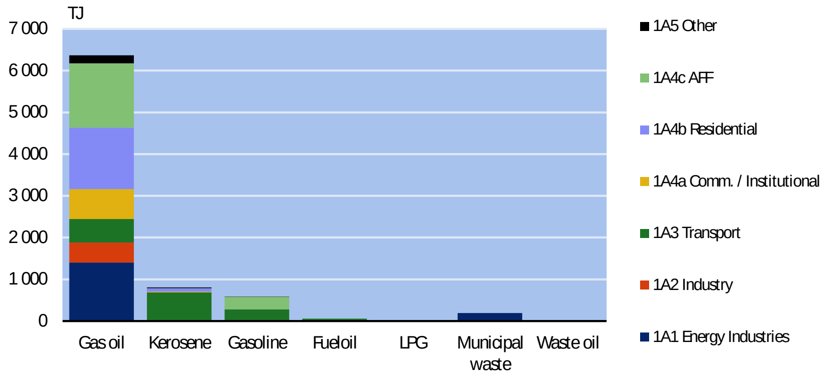


Figure 16.3.1 Fuel combustion rates, fossil fuels 2012 (Statistics Greenland).

In Greenland gas oil, kerosene and gasoline are used in fuel combustion. From 2010 fuel oil is also being imported and combusted in ships. Gas oil and kerosene are the most utilised fuels. Gas oil 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 gas oil increased significantly due to oil explorations. Due to a standstill in oil explorations total fuel combustion decreased significantly in 2012.

Kerosene is primarily used in aviation, but also for heating in smaller settlements.

A time series on the consumption of Liquid Petrol Gas (LPG) was introduced for the first time in the 2013 inventory submission. However, the consumption of LPG amount to less than 1 % of the total fuel combustion, see Figure 16.3.2. It has been possible to contruct a time series on LPG consumption running from 2004 and onwards.



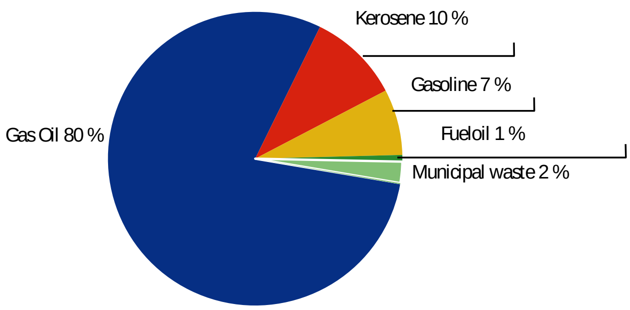
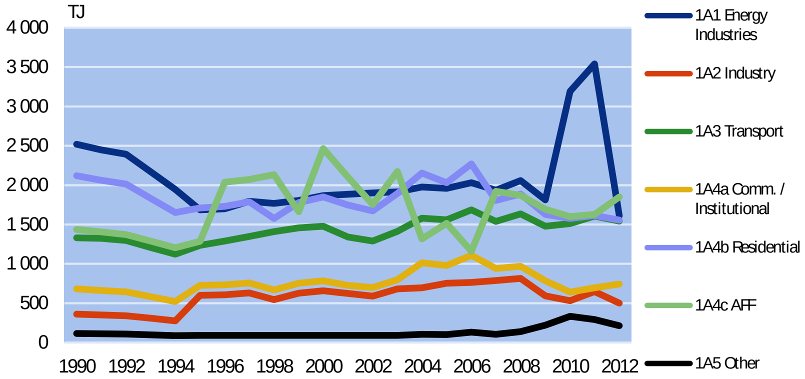


Figure 16.3.2 Fuel combustion, 2012 (Statistics Greenland).

Time series on fuel consumption are presented in Figure 16.3.3. Total fuel consumption has decreased by 6.4 % from 1990 to 2012. This overall decrease in fuel consumption is entirely caused by a drop in the consumption of liquid fossil by 8.1 %. Consumption of renewable waste-energy has increased continuously with a total increase of more than 300 % from 1990 to 2012.



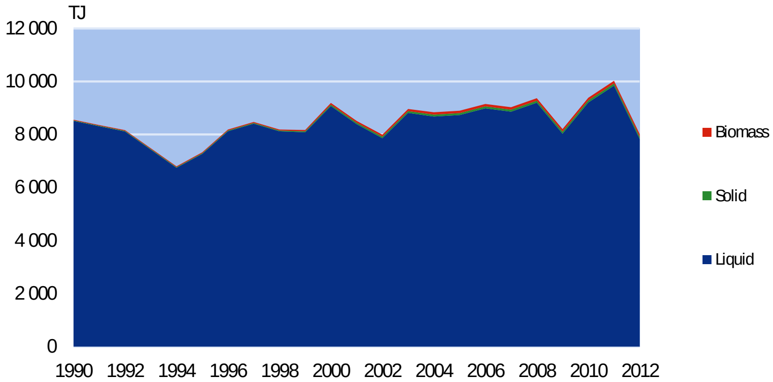


Figure 16.3.3 Fuel consumption time series 1990-2012 (Statistics Greenland).

Fuel consumption is dominated by liquid fuels e.g. gas oil, kerosene and gasoline. In 2012 total fuel consumption consists of 98 % liquid fuels, 1 % solid fuels and 1 % biomass.

In 2012 Energy Industries accounted for 20 % of total fuel consumption. From 1990 to 1995 fuel consumption in Energy Industries decreased significantly due to the introduction of the first hydro power plant in 1993, and the introduction of burning waste to produce heat for district heating networks in 1989. Dependence on gas oil conversion decreased immediately. Nevertheless, from 1995 an onwards consumption of gas oil once again increased due to the general economic development. In 2007 fuel consumption in Energy Industries decreased due to a relatively warm winter. Contrary to this, the winter in 2008 was relatively colder, which increased fuel consumption to produce heat. In 2009 hydro power productions increased further when a fourth plant was opened. Together with a relatively warm 2009 winter fuel consumption in Energy Industries decreased additionally. In 2010 and 2011 fuel consumption increased significantly due to oil explorations along the westcoast of Greenland. In 2012, most recently fuel consumption decreased significantly due to a standstill in the oil exploration and the opening of the fifth hydro power plant.

Fuel consumption in Agriculture, Forestry and Fisheries accounted for 23 % of total fuel consumption in 2012. Fuel consumption in this sector has increased since 2010. Before 2004, annual 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.

Residential fuel consumption also accounted for 19 % of total fuel consumption in 2012. 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.

For 2004-2012 Statistics Greenland has conducted statistics on energy including detailed information on fuel consumption divided into 33 business categories and private households; see Section 16.3.3.1. 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 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 scotish company initiated a search for oil along the westcoast of Greenland. Three wells were drilled and tested in 2010. Five wells in 2011. The oil company reported a total fugitive emission of 44 tonnes CO_2-eqv methan from all three wells in 2010. This information has been recognised as the total fugitive emission of CH_4 from fuels in 2010. The calculation of fugitive emission of CO_2 and N_2O, and total fugitive emissions in 2011 has been based on IPCC Guideline emission factors (IPCC 2000 GPG, Table 2.16).

All oil exploration activities ere put on halt in 2012. No wells were drilled and tested in 2012. Hence, no fugitive emissions occurred in 2012.

Furthermore, 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 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 Civil aviation.

International Marine 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 and 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 other sectors of the Greenlandic inventory (Industrial Processes (CRF sector 2) and Solvent and Other Product Use (CRF sector 3)).

16.3.3 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, Statoil and Malik Supply A/S. Polaroil imports and distributes fuel in all parts of Greenland. Statoil 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 then 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, company tax accountings, municipal accountings and Greenland Government accountings, and by estimation.

Since 2008 Statistics Greenland has conducted an annual survey among larger companies. By completing a questionnaire each company returned detailed information on the consumption of specific types of fuel in 2004-2012. The survey covered 53.2 % of total GHG emission from energy combustion in 2012, see Table 16.3.4. The decreased coverage by the survey is due to a drop in fuel combustion in companies that are covered by the survey primarily companies in Energy Industries.

By using detailed information on sales from Polaroil and local fuel distributors it is possible to determine fuel combustion in private companies and public offices with an automatic deal on supply. The sales data covered 11.8 % of total GHG emission from energy combustion in 2012, see Table 16.3.4.

Tax accountings in DKK are used to determine annual consumption of fuel in private companies, 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 13.1 % of total GHG emission from energy combustion in 2012, see Table 16.3.4.

The remaining amount of total inland fuel combustion is divided into sectors and private households by estimation. This work is carried out by involving statistical material on population, housing, public finances, fisheries and hunting, and national accountings. The Greenlandic Business Register (GER) 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 GER-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 i.e. 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 2008-2013. 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), Royal Arctic Bygdeservice A/S (freight/passengers), and Arctic Umiaq Line A/S (passengers) and the liquidated Assartuivik A/S (passengers).

Table 16.3.4 shows the part of total CO_2 emission divided into sources - survey, specific sales data, tax accountings, and estimation.

Table 16.3.4 CO_2 emission from fuel combustion by sources to sectoral division (2004-2012).

	2004	2005	2006	2007	2008	2009	2010	2011	2012
					pct.				
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Survey	48.8	48.4	47.9	49.6	50.3	52.8	63.0	61.3	53.2
Sales data from Polaroil	2.7	3.4	3.7	3.6	3.4	3.0	4.2	5.0	5.7
Sales data from local fuel distributors	0.0	0.0	3.2	5.1	6.6	6.5	5.0	5.6	6.1
Accountings	12.7	12.1	12.9	12.8	12.2	12.7	10.8	11.0	13.1
Estimation	35.8	36.1	32.3	29.0	27.5	25.0	17.0	17.0	21.8

The procedure described above is used to divide total fuel combustion into sectors and private households during the period 2004-2012. 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 16.3.5 shows the activity data on fuel combustion for the period 1990-2012.

Table 16.3.5 Activity data on fuel combustion (SINK categories).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
						TJ					
Total	8 559	8 358	8 166	7 484	6 801	7 331	8 190	8 475	8 189	8 172	8 559
Energy industries	2 519	2 447	2 393	2 169	1 944	1 685	1 698	1 794	1 766	1 805	2 519
Manufacturing and construction	360	349	340	307	274	598	607	630	546	626	360
Domestic aviation	541	556	547	524	500	581	636	660	775	748	541
Road transport	501	488	476	437	397	370	369	387	361	401	501
National navigation	288	280	273	248	224	285	285	299	275	308	288
Commercial/Institutional	682	662	645	583	520	724	733	757	667	753	682
Residential	2 120	2 062	2 014	1 832	1 651	1 710	1 731	1 787	1 576	1 777	2 120
AFF	1 436	1 405	1 372	1 288	1 205	1 287	2 039	2 070	2 134	1 663	1 436
Other	113	110	107	97	86	91	91	91	91	91	113
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total	8 514	7 995	8 964	8 840	8 898	9 153	9 031	9 371	8 207	9 387	10 026
Energy industries	1 885	1 900	1 915	1 976	1 959	2 032	1 934	2 057	1 813	3 192	3 542
Manufacturing and construction	624	590	680	696	755	763	787	814	592	531	649
Domestic aviation	632	603	646	608	633	691	701	753	635	654	723
Road transport	399	388	433	508	505	575	505	535	493	478	479
National navigation	308	297	334	464	420	421	334	347	350	378	405
Commercial/Institutional	725	699	796	1 014	979	1 107	939	969	784	641	694
Residential	1 748	1 670	1 895	2 155	2 032	2 271	1 804	1 888	1 628	1 577	1 615
AFF	2 101	1 755	2 174	1 317	1 516	1 161	1 921	1 871	1 691	1 600	1 628
Other	91	91	91	103	100	132	105	138	219	335	292
Continued	2012										
Total	8 014										
Energy industries	1 609										
Manufacturing and construction	501										
Domestic aviation	660										
Road transport	469										
National navigation	413										
Commercial/Institutional	742										
Residential	1 554										
AFF	1 851										
Other	215										

Sources: Statistics Greenland. Notes: Data on fuel combustion in 1993 are interpolated from 1992 and 1994, since no data is available for 1993.

Emission factors

For each fuel and source category a set of general area source emission factors has been determined. The emission factors are either nationally referenced or based on the IPCC Reference Manual (IPCC, 1997).

CO_2

The CO_2 emission factors applied are presented in Table 16.3.6. For municipal waste and all other fuels the same emission factor is applied for 1990-2012.

In 2013 a technical analysis has been conducted on the arctic gas oil 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 gas oil, see Table 16.3.6 and Section 16.3.7 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 (75.1 + 37.0 kg pr GJ) is divided into two parts: the emission from combustion of the plastic 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*. The emission factors on municipal waste were revised in the 2012 inventory submission. Greenland uses the Danish emission factors on municipal waste, which have been revised recently due to new information.

Table 16.3.6 CO_2 emission factors 1990-2012.

Fuel	Emission factor	Unit	Reference type	IPCC fuel Category
Gas oil	72.237	kg pr GJ	Country specific	Liquid
Kerosene	71.148	kg pr GJ	IPCC reference manual	Liquid
Jet-Kerosene	70.785	kg pr GJ	IPCC reference manual	Liquid
Gasoline	68.607	kg pr GJ	IPCC reference manual	Liquid
Fueloil	76.593	kg pr GJ	IPCC reference manual	Liquid
LPG	63.100	kg pr GJ	IPCC reference manual	Liquid
Waste oil	76.593	kg pr GJ	IPCC reference manual	Liquid
Municipal waste – biomass	75.100	kg pr GJ	Country specific	Biomass
Municipal waste – fossil fuel	37.000	kg pr GJ	Country specific	Other fuels

The CO_2 emission has been calculated by using the same methodology as described in the IPCC Guidelines (IPCC, 1997). 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

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), se Table 16.3.7 – Table 16.3.9 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 1990-2012 are presented in Table 16.3.7. 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, 1997).

Table 16.3.7 CH_4 emission factors 1990-2012.

Fuel group	Fuel	CRF sector		Emission factor, g pr GJ	Reference
Liquid	Gas oil	1A1	Energy Industries	3	IPCC, 1997
		1A2	Manufacturing Industries and Constructions	2	IPCC, 1997
		1A3a	Transport – Civil aviation	0.5	IPCC, 1997
		1A3b	Transport – Road transportation	5	IPCC, 1997
		1A3d	Transport – Navigation	5	IPCC, 1997
		1A4a	Other sectors – Commercial / Institutional	10	IPCC, 1997
		1A4b	Other sectors – Residential	10	IPCC, 1997
		1A4c	Other sectors – AFF stationary	10	IPCC, 1997
		1A4c	Other sectors – AFF mobile	5	IPCC, 1997
		1A5b	Other – Military mobile	5	IPCC, 1997
	Kerosene	1A1	Energy Industries	3	IPCC, 1997
		1A2	Manufacturing Industries and Constructions	2	IPCC, 1997
		1A3a	Transport – Civil aviation	0.5	IPCC, 1997
		1A3b	Transport – Road transportation	20	IPCC, 1997
		1A3d	Transport – Navigation	5	IPCC, 1997
		1A4a	Other sectors – Commercial / Institutional	10	IPCC, 1997
		1A4b	Other sectors – Residential	10	IPCC, 1997
		1A4c	Other sectors – AFF stationary	10	IPCC, 1997
		1A4c	Other sectors – AFF mobile	5	IPCC, 1997
		1A5b	Other – Military mobile	5	IPCC, 1997
	Gasoline	1A1	Energy Industries	3	IPCC, 1997
		1A2	Manufacturing Industries and Constructions	2	IPCC, 1997
		1A3a	Transport – Civil aviation	0.5	IPCC, 1997
		1A3b	Transport – Road transportation	20	IPCC, 1997
		1A3d	Transport – Navigation	5	IPCC, 1997
		1A4a	Other sectors – Commercial / Institutional	10	IPCC, 1997
		1A4b	Other sectors – Residential	10	IPCC, 1997
		1A4c	Other sectors – AFF stationary	10	IPCC, 1997
		1A4c	Other sectors – AFF mobile	5	IPCC, 1997
		1A5b	Other – Military mobile	5	IPCC, 1997
	Fueloil	1A1	Energy Industries	3	IPCC, 1997
		1A2	Manufacturing Industries and Constructions	2	IPCC, 1997
		1A3a	Transport – Civil aviation	0.5	IPCC, 1997
		1A3b	Transport – Road transportation	5	IPCC, 1997
		1A3d	Transport – Navigation	5	IPCC, 1997
		1A4a	Other sectors – Commercial / Institutional	10	IPCC, 1997
		1A4b	Other sectors – Residential	10	IPCC, 1997
		1A4c	Other sectors – AFF stationary	10	IPCC, 1997
		1A4c	Other sectors – AFF mobile	5	IPCC, 1997
		1A5b	Other – Military mobile	5	IPCC, 1997
	LPG	1A1	Energy Industries	1	IPCC, 1997
		1A2	Manufacturing Industries and Constructions	5	IPCC, 1997
		1A3a	Transport – Civil aviation	-	IPCC, 1997
		1A3b	Transport – Road transportation	50	IPCC, 1997
		1A3d	Transport – Navigation	-	IPCC, 1997
		1A4a	Other sectors – Commercial / Institutional	5	IPCC, 1997
		1A4b	Other sectors – Residential	5	IPCC, 1997
		1A4c	Other sectors – AFF stationary	5	IPCC, 1997
		1A4c	Other sectors – AFF mobile	5	IPCC, 1997
		1A5b	Other – Military mobile	-	IPCC, 1997
	Waste oil	1A1	Energy Industries	3	IPCC, 1997
Biomass	Municipal waste	1A1	Energy Industries	30	Nielsen et al., 2010
Other fuel	Municipal waste	1A1	Energy Industries	30	Nielsen et al., 2010

N_2O

The N_2O emission factors applied for 1990-2012 are presented in Table 16.3.8. 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, 1997).

Table 16.3.8 N_2O emission factors 1990-2012.

Fuel group	Fuel	CRF sector		Emission factor g pr GJ	Reference
Liquid	Gas oil	1A1	Energy Industries	0.6	IPCC, 1997
		1A2	Manufacturing Industries and Constructions	0.6	IPCC, 1997
		1A3a	Transport – Civil aviation	2	IPCC, 1997
		1A3b	Transport – Road transportation	0.6	IPCC, 1997
		1A3d	Transport – Navigation	0.6	IPCC, 1997
		1A4	Other sectors	0.6	IPCC, 1997
		1A5b	Other – Military mobile	0.6	IPCC, 1997
	Kerosene	1A1	Energy Industries	0.6	IPCC, 1997
		1A2	Manufacturing Industries and Constructions	0.6	IPCC, 1997
		1A3a	Transport – Civil aviation	2	IPCC, 1997
		1A3b	Transport – Road transportation	0.6	IPCC, 1997
		1A3d	Transport – Navigation	0.6	IPCC, 1997
		1A4	Other sectors	0.6	IPCC, 1997
		1A5b	Other – Military mobile	0.6	IPCC, 1997
	Gasoline	1A1	Energy Industries	0.6	IPCC, 1997
		1A2	Manufacturing Industries and Constructions	0.6	IPCC, 1997
		1A3a	Transport – Civil aviation	2	IPCC, 1997
		1A3b	Transport – Road transportation	0.6	IPCC, 1997
		1A3d	Transport – Navigation	0.6	IPCC, 1997
		1A4	Other sectors	0.6	IPCC, 1997
		1A5b	Other – Military mobile	0.6	IPCC, 1997
	Fueloil	1A1	Energy Industries	0.6	IPCC, 1997
		1A2	Manufacturing Industries and Constructions	0.6	IPCC, 1997
		1A3a	Transport – Civil aviation	2	IPCC, 1997
		1A3b	Transport – Road transportation	0.6	IPCC, 1997
		1A3d	Transport – Navigation	0.6	IPCC, 1997
		1A4	Other sectors	0.6	IPCC, 1997
		1A5b	Other – Military mobile	0.6	IPCC, 1997
	LPG	1A1	Energy Industries	0.1	IPCC, 1997
		1A2	Manufacturing Industries and Constructions	0.1	IPCC, 1997
		1A3a	Transport – Civil aviation	-	IPCC, 1997
		1A3b	Transport – Road transportation	0.1	IPCC, 1997
		1A3d	Transport – Navigation	-	IPCC, 1997
		1A4	Other sectors	0.1	IPCC, 1997
		1A5b	Other – Military mobile	0.1	IPCC, 1997
	Waste oil	1A1	Energy Industries	0.6	IPCC, 1997
Biomass	Municipal waste	1A1	Energy Industries	4	Nielsen et al., 2010
Other fuel	Municipal waste	1A1	Energy Industries	4	Nielsen et al., 2010

SO_2, NO_X, NMVOC and CO

Emission factors for SO_2, NO_X, NMVOC and CO are listed in Table 16.3.9. The same emission factors have been applied in the period 1990-2012.

Table 16.3.9 SO_2, NO_X, NMVOC and CO emission factors 1990-2012 (g pr GJ).

Fuel group	Fuel	CRF sector		NO_X	CO	NMVOC	SO_2	Ref
Liquid	Gas oil	1A1	Energy Industries	200	15	5	141	1
		1A2	Manufacturing Industries and Constructions	200	10	5	141	1
		1A3a	Transport – Civil aviation	300	100	50	141	1
		1A3b	Transport – Road transportation	800	1 000	200	141	1
		1A3d	Transport – 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 Constructions	200	10	5	23	1
		1A3a	Transport – Civil aviation	300	100	50	23	1
		1A3b	Transport – Road transportation	600	8 000	1 500	23	1
		1A3d	Transport – 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 Constructions	200	10	5	46	1
		1A3a	Transport – Civil aviation	300	100	50	46	1
		1A3b	Transport – Road transportation	600	8 000	1 500	46	1
		1A3d	Transport – 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 Constructions	200	10	5	492	1
		1A3a	Transport – Civil aviation	300	100	50	492	1
		1A3b	Transport – Road transportation	600	8 000	1 500	492	1
		1A3d	Transport – 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 Constructions	150	30	5	0.13	1
		1A3a	Transport – Civil aviation	-	-	-	-	1
		1A3b	Transport – Road transportation	600	400	5	0.13	1
		1A3d	Transport – 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
	Waste oil	1A1	Energy Industries	200	15	5	477	1
Biomass	Municipal waste	1A1	Energy Industries	100	1 000	50	6	2
Other fuel	Municipal waste	1A1	Energy Industries	100	1 000	50	6	2

Sources: 1) IPCC Guidelines (IPCC, 1997). 2) Nielsen et al., 2010.

16.3.4 Emissions

The greenhouse gas (GHG) emissions are listed in Table 16.3.10. The total emission of greenhouse gases from energy (fuel combustion and fugitive emissions) accounts for 93.6 % of total Greenlandic GHG emission in 2012.

The CO_2 emission from energy accounts for 99.4 % 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 9.0 % of the Greenlandic emission and the N_2O emission from fuel combustion accounts for 10.7 % of the Greenlandic N_2O emission, see Table 16.3.10.

Table 16.3.10 Greenhouse gas emission for the year 2012.

		CO_2	CH_4	N_2O
		Gg CO_2 equivalent		
1A1	Fuel consumption, Energy Industries	109.6	0.2	0.5
1A2	Fuel consumption, Manufacturing Industries and Construction	36.2	0.0	0.1
1A3	Fuel consumption, Transport	109.6	0.2	0.6
1A4	Fuel consumption, Other sectors	313.9	0.7	0.8
1B2	Fugitive emissions from fuel, Oil and natural gas	NO	NO	NO
Total emission from energy		569.3	1.1	2.0
Greenlandic emission (excluding net emission from LULUCF)		572.7	12.1	18.4
			%	
Emission share for energy		99.4	9.0	10.7

CO_2 is the most important GHG pollutant and accounts for 99.5 % of the GHG emission in CO_2 equivalents from energy, see Figure 16.3.4.

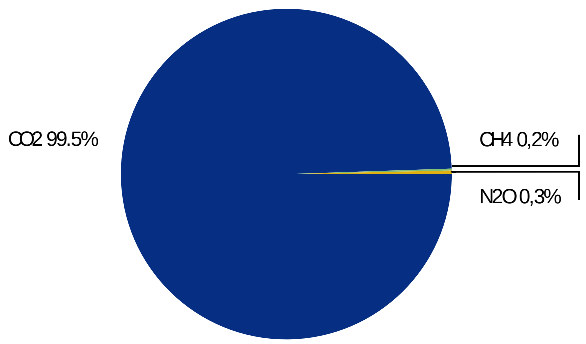


Figure 16.3.4 GHG emissions (CO_2 equivalent) from stationary combustion plants.

Figure 16.3.5 depicts the time series of GHG emission in CO_2 equivalents from energy. 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 7.3 % and 7.4 % lower in 2012 compared to 1990.

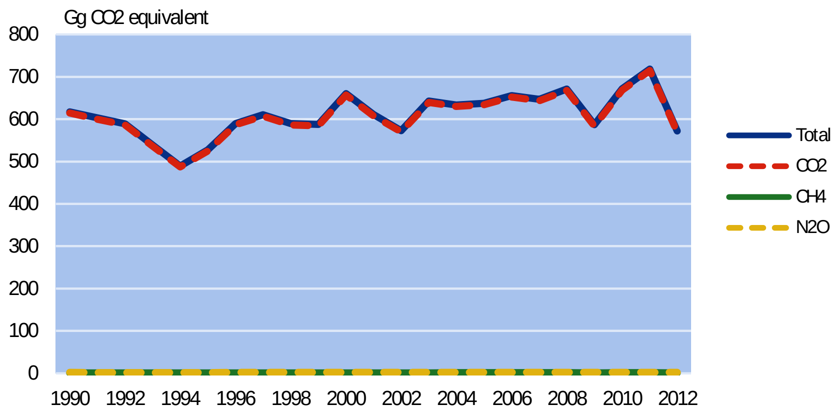


Figure 16.3.5 GHG emission time series for energy.

From 1990 to 1994 total GHG emission was reduced by 21 %. This was primarily due to the introduction of the first hydropower plant in 1993 but also to the introduction of burning waste to produce heat for district heating network in 1989. Dependence on gas oil conversion decreased immediately. Nevertheless, from 1995 an onwards consumption of gas oil once again increased due to the general economic development

In 2001-2002 total GHG emission decreased due to a minor recession in the economy. However since 1994 GHG emissions have increased in general with some fluctuations from year to year. The fluctuations are largely a result of outdoor temperature variations from year to year i.e. in 2008 the winter was relatively colder than in 2007. As a result fuel consumption increased in 2008 increasing GHG emission from fuel combustion. In 2009 GHG emission decreased by 13 % due to a significantly substitution in Energy Industries from fuel consumption to hydro power production together with a relatively warmer winter. However, in 2010 and 2011 GHG emission increased by 15 % and 7 % due to the initiation of oil exploration. In the most recent year, 2012 GHG emission decreased by 7.3 % due to the standstill in the oil exploration activities and a drop in fuel combustion in Energy Industries due to the opening of Greenlands fifth hydro power plant.

CO_2

CO_2 emission from energy accounts for 99.4 % of the total Greenlandic CO_2 emission. Table 16.3.11 lists the CO_2 emission inventory for the energy sector in 2012 as well as the relative percentage for each category under the sectoral approach.

The table reveals that Agriculture, Forestry and Fisheries (AFF) accounts for 23.3 % of the CO_2 emission. Other large CO_2 emission sources are Residental, Transportation and Energy Industries. These are sectors, which also account for a considerable share of fuel consumption.

Table 16.3.11 CO_2 emission from energy 2012.

		2012	
		Gg	%
1A1	Energy Industries	109.6	19.3
1A2	Manufacturing Industries	36.2	6.4
1A3	Transport	109.6	19.3
1A4a	Commercial / Institutional	53.6	9.4
1A4b	Residential	112.2	19.7
1A4c	Agriculture / Forestry / Fisheries	132.6	23.3
1A5	Other	15.5	2.7
1B2	Fugitive emissions from fuel, oil and natural gas	NO	NO
Total		569.3	100.0

The 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 2012, the CO_2 emission from biomass combustion was 14.1 Gg.

Time series for CO_2 emissions are provided in Figure 16.3.6. 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 "Manufacture of Solid Fuels and Other Energy Industries. Due to a stand-still in oil exploration fuel combustion in (and emissions from) Energy Industries dropped in 2012.

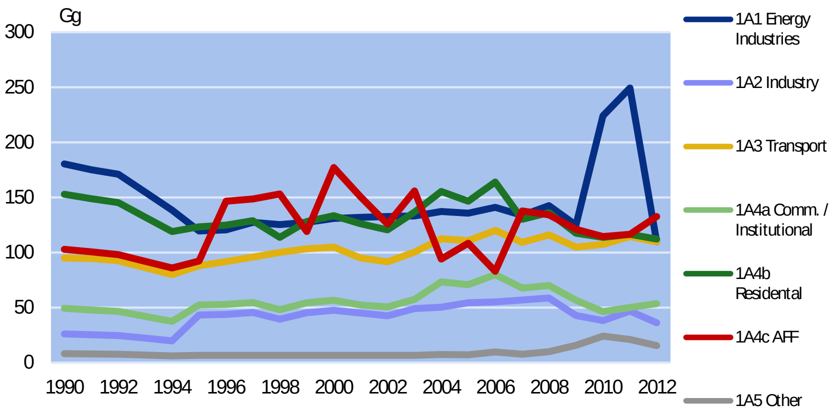


Figure 16.3.6 CO_2 emission time series for fuel combustion (Sectoral Approach).

Detailed trend discussion on CRF category level is available in Section 16.2.

CH_4

CH_4 emission from energy accounts for 9.0 % of the Greenlandic CH_4 emission. Table 16.3.12 lists the CH_4 emission inventory for energy in 2012. The table reveals that Residental plants accounted for 30.1 % of the CH_4 emission from energy in 2012. Energy Industries accounted for 19.27 % of the emission in 2012.

Table 16.3.12 CH_4 emission from fuel combustion 2012.

		2012	
		Mg	%
1A1	Energy Industries	9.9	19.2
1A2	Industry	1.0	2.0
1A3	Transport	7.4	14.3
1A4a	Commercial / Institutional	7.4	14.4
1A4b	Residential	15.5	30.1
1A4c	Agriculture / Forestry / Fisheries	9.3	18.0
1A5	Other	1.1	2.1
1B2	Fugitive emissions from fuel, Oil and natural gas	NO	NO
Total		51.5	100.0

The CH_4 emission from energy has increased by 3.0 % since 1990. You may notice that CH_4 emission has decreased from 1990 to 2012 while CO_2 emission from energy has fallen in the same period. The reason for this is that the amount of recovered energy from waste has increased, while the consumption of liquid fossil fuel has decreased from 1990 to 2012. And in view of the fact that CH_4 emission from energy recovered waste by far exceeds the overall CH_4 emission from liquid fossil fuel, total CH_4 emission from energy has from 1990 to 2012, while CO_2 emissions dropped.

Time series for CH_4 emissions are provided in Figure 16.3.7. 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. The increase of CH_4 emission in 2010 and 2011 was caused by the initation of activities concerning oil exploration, while the decrease of CH_4 emission in 2012 is due to a standstill in oil explorations in 2012.

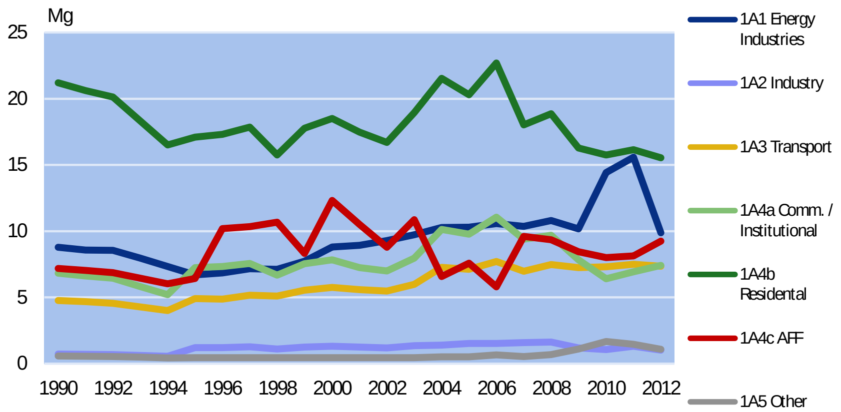


Figure 16.3.7 CH_4 emission time series for energy.

Detailed trend discussion on CRF category level is available in Section 16.2.

N_2O

The N_2O emission from energy accounts for 10.7 % of the Greenlandic N_2O emission. Table 16.3.13 lists the N_2O emission inventory for energy in 2012. The table reveals that Transportations accounted fro 29.0 % of the N_2O emission from energy. Energy Industries accounted for 25.2 % of the emissions in 2012.

Table 16.3.13 N_2O emission from energy 2012.

		2012	
		Mg	%
1A1	Energy Industries	1.6	25.2
1A2	Industry	0.3	4.7
1A3	Transport	1.8	29.0
1A4a	Commercial / Institutional	0.4	7.0
1A4b	Residential	0.9	14.6
1A4c	Agriculture / Forestry / Fisheries	1.1	17.4
1A5	Other	0.1	2.0
1B2	Fugitive emissions from fuel, oil and natural gas	NO	NO
Total		6.4	100.0

Figure 16.3.8 shows the time series for the N_2O emission from energy. The N_2O emission has increased by 5.3 % from 1990 to 2012. Similar to the increase in CH_4 emissions, N_2O emissions have increased from 1990 to 2012 due to an increase in the use of recovered energy from waste simultaneously to a decrease in the consumption of liquid fuels.

Once again, the 2010 and 2011 increases in N_2O emission from Energy Industries are predominantly caused by the startup of oil explorative activities, while the decrease of N_2O emission in 2012 is due to a standstill in oil explorations in 2012.

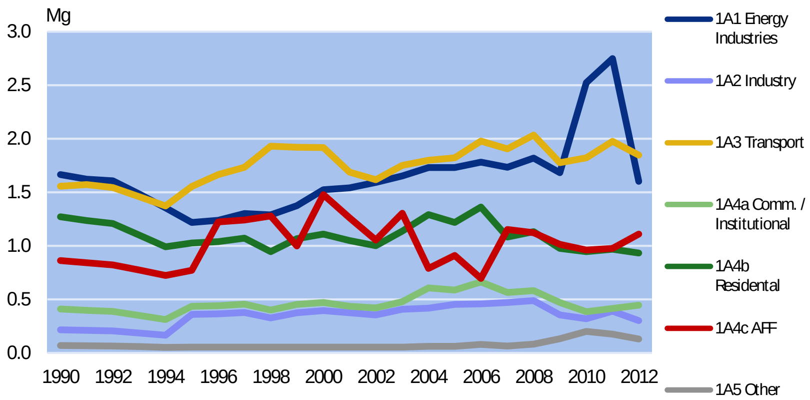


Figure 16.3.8 N_2O emission time series for energy.

Detailed trend discussion on CRF category level is available in Section 16.2.

SO_2, NO_X, NMVOC and CO

The emissions of SO_2, NO_X, NMVOC and CO from energy in 2012 are presented in Table 16.3.14. SO_2 from energy accounts for 99.4 % of the Greenlandic SO_2 emission. NO_X, CO and NMVOC account for 99.1, 89.6 % and 75.5 % respectively, of the Greenlandic emissions for these substances.

Table 16.3.14 SO_2, NO_X, NMVOC and CO emission from energy 2012.

	NO_X	CO	NMVOC	SO_2
	Gg	Gg	Gg	Gg
1A1 Fuel consumption, Energy Industries	0.3	0.2	0.0	0.2
1A2 Fuel consumption, Manuf. Industries and Constr.	0.1	0.0	0.0	0.1
1A3 Fuel consumption, Transport	1.2	2.2	0.4	0.1
1A4 Fuel consumption, Other sectors	2.8	2.1	0.4	0.6
1B2 Fugitive emissions from fuel, Oil and natura gas	NO	NO	NE	NO
Total emission from fuel consumption and fugitive emissions from fuel	4.3	4.5	0.9	1.0
Greenlandic emission	4.4	5.0	1.2	1.0
		%		
Emission share for fuel consumption	99.1	89.6	75.5	99.4

16.3.5 Uncertainties

A tier 1 uncertainty assessment has been carried out in accordance with the IPCC GPG (IPCC, 2000). 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 16.3.15.

Table 16.3.15 Uncertainties for activity data and emission factors for the energy sector.

Subsector	Pollutant	Activity data uncertainty	Emission factor uncertainty
1A Liquid fuels	CO_2	2	2
1A Municipal waste	CO_2	2	25
1B2 Oil exploration	CO_2	2	1 000
1A Liquid fuels	CH_4	2	100
1A Municipal waste	CH_4	2	100
1A Biomass	CH_4	2	100
1B2 Oil exploration	CH_4	2	1 000
1A Liquid fuels	N_2O	2	500
1A Municipal waste	N_2O	2	500
1A Biomass	N_2O	2	200
1B2 Oil exploration	N_2O	2	1 000

The activity data comes from the official Greenlandic energy statistics, which is considered to be of high quality, therefore the uncertainty of the activity data have been set to 2 %.

Regarding the emission factor uncertainty, the CO_2 emission factors are considered the most certain. In previous submissions the emission factor uncertainty for liquid fuels was set to 5 %. Due to a technical analysis a country specific emission factor is now available on the Greenlandic gas oil; the dominating liquid fuel comprising 79 % in 2012. Consequently, in this 2014 submission the CO_2 emission factor uncertainty has been revised from 5 % to 2 % for liquid fuels.

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 GPG (IPCC, 2000). For N_2O the emission factor uncertainties have been estimated to 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 in 2012. Regarding fugitive emissions from oil exploration emission factor uncertainty has been set to 1,000 % for CO_2, CH_4 and N_2O. In 2011 fugitive emission of CO_2, CH_4 and N_2O is calculated based on standard IPCC emission factors for drilling and testing. In 2010 the emission factor uncertainty for CH_4 was set to 200 % due to the fact that the amount of fugitive emission of CH_4 in 2010 was obtained directly from the scotish oil company and the uncertainty concerning CH_4 was therefore considered to be mush lower than for CO_2 and N_2O.

The resulting uncertainties for the individual greenhouse gases and the total uncertainty on the greenhouse gas emission are shown in Table 16.3.16.

Table 16.3.16 Uncertainties for the emission estimates.

	Uncertainty %	Trend 1990-2012 %	Trend uncertainty %
GHG	± 3.2	-7.3	± 2.6
CO_2	± 2.8	-7.4	± 2.6
CH_4	± 89	3.0	± 10.6
N_2O	± 442	5.3	± 51

16.3.6 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 gas oil, 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 XML-files 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, 1997). 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 for 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, 1997). 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 2012 the fuel consumption rates in the two approaches differ by 0.0 % and the CO_2 emission differs by 0.9 %. In the period 1990-2012 both the fuel consumption and the CO_2 emission differ by 1 % or less at all times. The differences in energy consumption are below 1 % for all years. The difference in CO_2 emission is 1 % from 1990 to 1994, and below 1 % since 1995. 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 16.3.9.

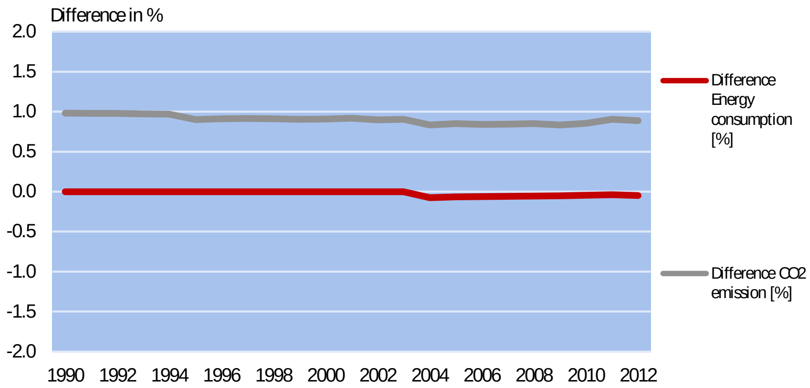


Figure 16.3.9 Comparison of the reference approach and the national approach.

16.3.7 Source specific recalculations and improvements

Improvements and recalculations since the 2013 emission inventory submission include:

- A technical analysis has been conducted on a sample of the Greenlandic gas oil. Due to the technical analysis, conducted by the Danish Technical Institute, a country specific emission factor is now available on the Greenlandic gas oil; the most dominant liquid fuel in Greenland with a percentage of 79 % of all liquid fuels used in 2012. The result of the technical analysis is found in Annex 8 (Section 16.19).
- Update of fuel rates according to the latest energy statistics. The update includes the years 2004-2011.
- And a further update of gas oil rates according to a new (country specific) calorific value on gas oil, see Annex 8 (Section 16.19). The update includes the years 2004-2011.
- Adjustment of municipal waste with energy recovery according to improvements in population statistics, which is used in the estimation of municipal waste.

Table 6.3.17 shows recalculations in the energy sector compared with the 2013 submission.

Table 16.3.17 Changes in GHG emission in the energy sector compared with the 2013 submission.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Previous inventory, Gg CO_2 eqv.	625.7	610.8	596.6	546.2	495.7	534.4	597.5	618.2	596.7	594.7	668.7
Recalculated, Gg CO_2 eqv.	617.5	602.9	588.9	539.2	489.5	527.7	589.9	610.4	589.3	587.4	660.3
Change in Gg CO_2 eqv.	-8.2	-7.9	-7.7	-7.0	-6.2	-6.7	-7.6	-7.8	-7.4	-7.3	-8.4
Change in pct.	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.2	-1.2	-1.3
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Previous inventory, Gg CO_2 eqv.	618.8	580.2	650.9	639.0	643.1	661.4	652.2	676.9	591.7	677.9	724.4
Recalculated, Gg CO_2 eqv.	611.0	573.0	642.7	633.4	637.5	655.7	646.6	671.1	586.7	672.2	718.3
Change in Gg CO_2 eqv.	-7.8	-7.2	-8.2	-5.6	-5.6	-5.7	-5.6	-5.8	-5.0	-5.8	-6.1
Change in pct.	-1.3	-1.2	-1.3	-0.9	-0.9	-0.9	-0.9	-0.9	-0.8	-0.8	-0.8
continued	2012										
Previous inventory, Gg CO_2 eqv.	-										
Recalculated, Gg CO_2 eqv.	572.4										
Change in Gg CO_2 eqv.	-										
Change in pct.	-										

16.3.8 Source specific planned improvements

Some planned improvements to the emission inventories are discussed below.

1) 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.

2) 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.

3) 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.

4) Country specific emission factors

Statistics Greenland has acquired a technical analysis on the gas oil 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 gas oil. The goal was to implement the new country specific emission factors in the 2015 submission, but with the technical results all ready in hand it was managed to implement the new country specific emission factor on gas oil in this 2014 submission. The arctic gas oil stands for 79 % of all liquid fuels in 2012.

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 gas oil.

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16.4 Industrial processes (CRF sector 2)

16.4.1 Overview of sector

In this chapter industrial emissions of greenhouse gases, not related to generation of energy, are presented.

The emission of greenhouse gases from industrial processes includes CO_2, HFCs and SF_6. The emissions are reported in CRF Tables 2(I), 2(I).A, 2(II), 2(II).C, 2(II).E and 2(II).F. 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).

An overview of sources identified is presented in Table 16.4.1 with an indication of the contribution to the industrial part of the emission of greenhouse gases in 2012. Emissions are extracted from the CRF tables.

Table 16.4.1 Overview of greenhouse gas sources 2012.

Process	IPCC Code	Substance	Emission tonnes CO_2 eqv.	%
Mineral Products				
Limestone and Dolomite Use	2A	CO_2	19.57	0.272
Asphalt Roofing	2A	CO_2	0.23	0.003
Road Paving with Asphalt	2A	CO_2	0.10	0.001
Consumption of Halocarbons and SF_6				
Refrigeration and Air Conditioning Equipment	2F	HFCs	7 185	99.684
Electrical Equipment	2F	SF_6	2.90	0.040
Total emission			7 208	100

The subsectors *Mineral Products* (2A) constitutes 0.276 % and *Consumption of Halocarbons and* SF_6 (2F) constitutes 99.724 % of the industrial emission of greenhouse gases. The total emission of greenhouse gases (excl. LULUCF) in Greenland is estimated to 610.4 Gg CO_2 equivalent, of which industrial processes contribute with 7.208 Gg CO_2 equivalent (1.2 %). The emission of greenhouse gases from industrial processes from 1990-2012 are presented in Figure 16.4.1.

Greenland has no chemical industry, metal production or production of halocarbons or SF_6. Greenland has no consumption of PFCs.

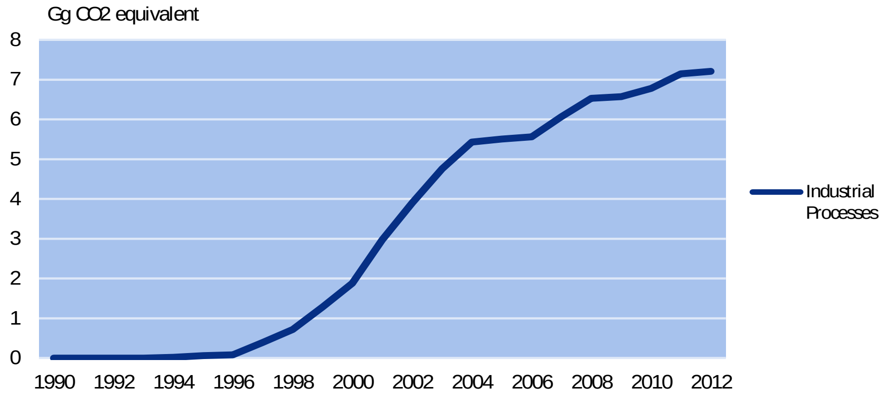

Figure 16.4.1 Emission of greenhouse gases from industrial processes 1990-2012.

The key category in the industrial sector *Consumption of Halocarbons and SF*$_6$ constitutes 1.2 % of the total emission of greenhouse gases. The trends in greenhouse gases from the industrial sector/subsectors are presented in Table 16.4.2. The emissions are extracted from the CRF tables.

Table 16.4.2 Emission of greenhouse gases from industrial processes in different subsectors from 1990-2012.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
CO_2 (tonnes CO_2)											
A. Mineral Products	0.11	0.11	0.11	0.11	0.10	0.11	0.10	0.13	0.12	0.13	4.09
CH_4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
N_2O	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
HFCs (tonnes CO_2 eqv.)											
F. Consumption of Halocarbons and SF_6	NE	NE	NE	NE	16	25	77	390	713	1 279	1 871
PFCs (tonnes CO_2 eqv.)											
F. Consumption of Halocarbons and SF_6	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
SF_6 (tonnes CO_2 eqv.)											
F. Consumption of Halocarbons and SF_6	NE	NE	NE	NE	NE	35.9	3.4	3.4	3.3	3.3	3.3
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
CO_2 (tonnes CO_2)											
A. Mineral Products	2.94	1.46	3.05	2.06	0.52	0.20	1.71	3.24	0.20	5.08	0.30
CH_4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
N_2O	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
HFCs (tonnes CO_2 eqv.)											
F. Consumption of Halocarbons and SF_6	2 964	3 898	4 750	5 425	5 499	5 558	6 065	6 527	6 568	6 771	7 144
PFCs (tonnes CO_2 eqv.)											
F. Consumption of Halocarbons and SF_6	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
SF_6 (tonnes CO_2 eqv.)											
F. Consumption of Halocarbons and SF_6	3.2	3.2	3.2	3.1	3.1	3.1	3.0	3.0	3.0	3.0	2.9
continued	2012										
CO_2 (tonnes CO_2)											
A. Mineral Products	19.90										
CH_4	NO										
N_2O	NO										
HFCs (tonnes CO_2 eqv.)											
F. Consumption of Halocarbons and SF_6	7 185										
PFCs (tonnes CO_2 eqv.)											
F. Consumption of Halocarbons and SF_6	NO										
SF_6 (tonnes CO_2 eqv.)											
F. Consumption of Halocarbons and SF_6	2.9										

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 has reported use of SF_6 in 1995. The emission of SF_6 was 35.9 tonnes CO_2 equivalents in 1995. The annual emission from 1996 and onwards 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 period 1996-2012.

Energy consumption associated with industrial processes and emissions thereof are included in the Energy sector of the inventory.

16.4.2 Source category description

Mineral products

The subsector *Mineral products* (2A) cover the following processes:

- Limestone and dolomite use.
- Roof covering with asphalt materials.
- Road paving with asphalt.

The time series for the emission of CO_2 from Mineral products (2A) are presented in Table 16.4.3. The emissions are extracted from the CRF tables and the values are rounded.

Table 16.4.3 Time series for emission of CO_2 (tonnes) from Mineral products (2A).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
3. Limestone and dolomite use	-	-	-	-	-	-	-	-	-	-	3.96
5. Asphalt roofing	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.01
6. Road paving	0.10	0.10	0.10	0.10	0.10	0.10	0.09	0.11	0.11	0.13	0.12
Total	0.11	0.11	0.11	0.11	0.10	0.11	0.10	0.13	0.12	0.13	4.09
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
3. Limestone and dolomite use	2.77	1.32	2.64	1.80	0.11	0.03	1.51	2.96	0.03	4.94	0.00
5. Asphalt roofing	0.00	0.02	0.04	0.07	0.03	0.05	0.05	0.08	0.06	0.06	0.04
6. Road paving	0.17	0.12	0.37	0.19	0.38	0.12	0.15	0.20	0.11	0.07	0.26
Total	2.94	1.46	3.05	2.06	0.52	0.20	1.71	3.24	0.20	5.08	0.30
continued	2012										
3. Limestone and dolomite use	19.57										
5. Asphalt roofing	0.23										
6. Road paving	0.10										
Total	19.90										

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.

In 2012 the most significant CO_2 emission came from the use of limestone and dolomite, which constituted 98.3 % of the total CO_2 emission from mineral products in 2012. According to Table 16.4.3 the emission of CO_2 from the use of limestone and dolomite exploded from nearly nothing in 2011 to 19.57 tonnes CO_2 in 2012. However, this increase in CO_2 emission from limestone and dolomite is merely an expression of the fact that imports of limestone and dolomite increased substantial in 2012.

The relative increase in CO_2 emission is most significant for the use of asphalt roofing. From 1990 to 2012, CO_2 emissions increased from 0.01 to 0.23 tonnes CO_2; an increase of 2 441 %. The increase in CO_2 from asphalt roofing has primarily taken place from 2002 and onwards.

The CO_2 emission from subsectors under mineral products fluctuates a great deal from year to year. This is caused by fluctuations in building activities and road paving. However fluctuations in CO_2 are also caused by the fact that activity data for mineral products are based on import data, which do not allow distinction of imported amount into consumption and stockpiling.

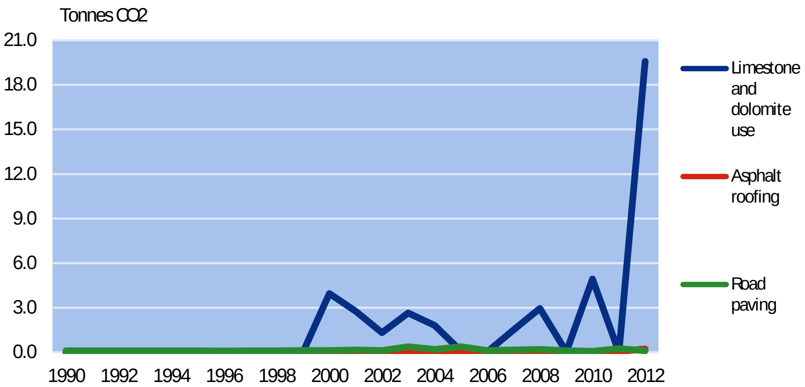

Figure 16.4.2 Emission of CO_2 from mineral products.

Consumption of Halocarbons and SF_6

The subsector *Consumption of Halocarbons and SF_6* (2F) includes the following source categories and the following F-gases of relevance for Greenlandic emissions:

- 2F1: Refrigeration: HFC32, 125, 134a, 143a, unspecified HFCs.
- 2F8: Electrical equipment: SF_6.

A quantitative overview is given below for each of these source categories and each F-gas, showing their emissions in tonnes through the time series. 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 1990-1993 (1994) might not cover emissions of these gases in full. The chosen base-year for these gases is 1995 for Greenland.

Table 16.4.4 Emission of HFCs from refrigeration (t).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
HFC32	NE	NE	NE	NE	NE	NA	0.00	0.00	0.00	0.00	0.00
HFC125	NE	NE	NE	NE	NE	NA	0.01	0.04	0.08	0.15	0.22
HFC134a	NE	NE	NE	NE	0.01	0.02	0.03	0.06	0.10	0.17	0.24
HFC143a	NE	NE	NE	NE	NE	NA	0.01	0.05	0.09	0.16	0.24
Unspecified HFCs	NE	NE	NE	NE	NE	NA	0.00	0.00	0.00	0.00	0.00
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
HFC32	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
HFC125	0.35	0.46	0.56	0.64	0.64	0.65	0.71	0.76	0.77	0.80	0.84
HFC134a	0.35	0.45	0.55	0.63	0.65	0.65	0.68	0.67	0.64	0.62	0.63
HFC143a	0.39	0.51	0.63	0.71	0.72	0.72	0.79	0.86	0.88	0.91	0.97
Unspecified HFCs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
continued	2012										
HFC32	0.01										
HFC125	0.85										
HFC134a	0.59										
HFC143a	0.98										
Unspecified HFCs	0.00										

Table 16.4.5 Emission of SF_6 from electrical equipment (kg).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
SF_6	NE	NE	NE	NE	NE	1.50	0.14	0.14	0.14	0.14	0.14
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
SF_6	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.12	0.12
continued	2012										
SF_6	0.12										

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 2012 the emission of SF_6 was 0.12 kg.

HFCs are used in various types of refrigeration in industry, retail, buildings and onboard ships. In 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 rapidly since 1995.

Table 16.4.6 and Figure 16.4.3 and Figure 16.4.4 quantify an overview of the emissions of the gases in CO_2 eqv. The reference is the trend table as included in the CRF table for year 2012.

Table 16.4.6 Time series for emission of HFCs and SF_6 (tonnes CO_2 eqv.).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
HFCs	NE	NE	NE	NE	16	25	77	390	713	1 279	1 871
SF_6	NE	NE	NE	NE	NE	35.9	3.4	3.4	3.3	3.3	3.3
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
HFCs	2 964	3 898	4 750	5 425	5 499	5 558	6 065	6 527	6 568	6 771	7 144
SF_6	3.2	3.2	3.2	3.1	3.1	3.1	3.0	3.0	3.0	3.0	2.9
continued	2012										
HFCs	7 185										
SF_6	2.9										

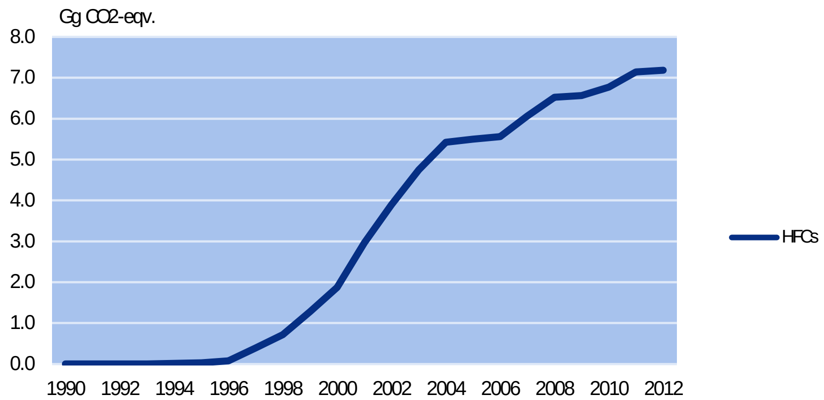

Figure 16.4.3 Emission of HFCs (from refrigeration).

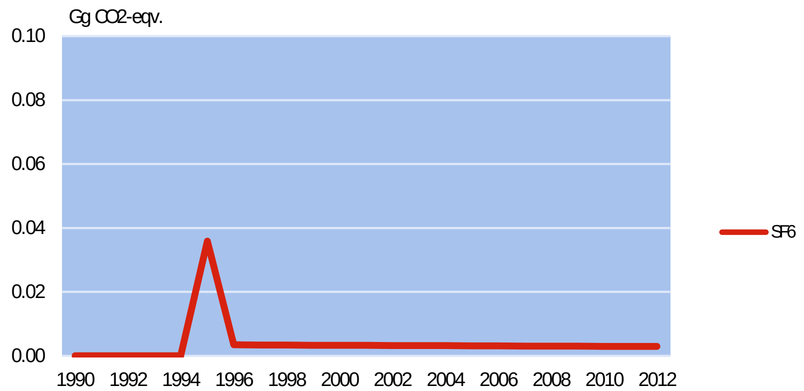

Figure 16.4.4 Emission of SF_6 (from electrical equipment).

HFCs is by far the most dominant group. HFCs constitute a key category both with regard to the key category level and the trend analysis.

16.4.3 Methodological issues

General

The CO_2 emission from the use of limestone and dolomite, 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 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.

Activity data

Activity data for subsectors *Mineral Products* (2A) and *Other Production* (2D) are presented in Table 16.4.7. Activity data under subsector *Other Production* (2D) are used for calculation of emission of non-methane volatile organic compounds (NMVOC).

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 of mineral products. 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 (2012b).

Production of beer including a fermentation process has taken place at the brewery "Godthåb Bryghus" since 2005 (Godthåb Bryghus, 2013). 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 16.4.7 Time series for activity data for Mineral Products and Other Production (Godthåb Bryghus, 2013, Statistics Greenland, 2013b).

		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Mineral Products													
2A3	Limestone and dolomite use (t)	-	-	-	-	-	-	-	-	-	-	9	6
2A5	Asphalt materials used for roofing (t)	37	35	39	39	13	56	29	59	39	7	26	11
2A6	Asphalt used for road paving (t)	591	581	595	604	597	577	532	664	649	752	694	988
Other Production													
2D2	Food and Drink - Beans roasted to produce coffee (t)	0	0	0	0	-	0	-	-	0	0	0	1
2D2	Food and Drink - Production of bread (t)	356	346	339	358	501	244	415	500	847	689	687	566
2D2	Food and Drink - Landings of fish and seafood (t)	81 768	72 395	65 553	59 423	64 479	67 786	60 662	62 244	67 247	63 750	74 105	66 929
2D2	Food and Drink - Production of beer (hl)	-	-	-	-	-	-	-	-	-	-		
continued		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Source	Source
Mineral Products													
2A3	Limestone and dolomite use (t)	3	6	4	0	0	3	7	0	11	0	45	1
2A5	Asphalt materials used for roofing (t)	81	149	263	114	193	209	321	241	256	173	929	1
2A6	Asphalt used for road paving (t)	705	2 218	1 127	2 258	698	912	1 206	629	443	1 529	583	1
Other Production													
2D2	Food and Drink - Beans roasted to produce coffee (t)	-	0	0	0	0	1	0	0	0	0	1	2
2D2	Food and Drink - Production of bread (t)	1 020	1 048	1 338	1 014	1 134	859	931	587	790	584	563	2
2D2	Food and Drink - Landings of fish and seafood (t)	85 970	80 667	102 570	103 642	111 351	118 260	109 420	102 393	99 829	104 020	97 532	3
2D2	Food and Drink - Production of beer (hl)	-	-	-	1 000	2 000	2 000	1 850	1 650	2 010	2 115	2 080	4

Sources:

1) Statistics on imports are used to estimate annual consumption of mineral products.

2) Statistics on imports of whole coffee beans and yeast for baking are used to estimate annual production of coffee and bread.

3) Statistics on landings of fish and seafood to domestic plants are used to determine domestic processing of fish and seafood.

4) Data from the brewery "Godthåb Bryghus" are used to determine annual production of beer.

The data for emission of HFCs and SF_6 has been obtained in continuation on the work on inventories for previous years. The determination 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 (1997), vol. 3, p. 2.43ff), as well as the relevant decision trees from the IPCC Good Practice Guidance (IPCC (2000) p. 3.53ff).

The following sources of information have been used (Statistics Greenland, 2013a):

- 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 16.4.8 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 16.4.8 have been used.

Activity data for the consumption of F-gases is shown in Table 16.4.9. The activity data are rounded and given in kg.

Table 16.4.9 Time series for activity data for the consumption of F-gases by trade-names (Statistics Greenland, 2013a).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
						Kg					
HFC-134											
Domestic	NE	NE	NE	264	139	91	187	134	453	319	289
Commercial and Industry	NE	NE	NE	-	-	-	123	123	247	247	493
Transport	NE	NE	NE	-	-	-	64	64	128	128	256
HFC-404a											
Commercial and Industry	NE	NE	NE	-	-	-	488	488	976	976	1 952
Transport	NE	NE	NE	-	-	-	82	82	164	164	328
HFC-407c											
Commercial and Industry	NE	NE	NE	-	-	-	34	34	68	68	135
HFC-507a											
Transport	NE	NE	NE	-	-	-	113	113	225	225	450
Unspecified HFCs											
Commercial and Industry	NE	NE	NE	-	-	-	45	45	90	90	180
SF_6											
Electrical Equipment	NE	NE	NE	-	-	30	-	-	-	-	-

continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
HFC-134											
Domestic	492	774	635	635	-	-	-	-	-	-	-
Commercial and Industry	493	493	493	260	208	680	329	312	195	484	340
Transport	256	256	256	120	120	30	30	-	-	-	-
HFC-404a											
Commercial and Industry	1 952	1 952	1 952	1 324	1 041	2 033	2 069	1 950	2 089	2 993	2 687
Transport	328	328	328	154	222	369	413	384	241	205	205
HFC-407c											
Commercial and Industry	135	135	135	68	83	31	4	112	90	-	90
HFC-507a											
Transport	450	450	450	-	-	120	180	-	120	-	180
Unspecified HFCs											
Commercial and Industry	180	180	180	326	314	556	698	309	400	576	600
SF_6											
Electrical Equipment	-	-	-	-	-	-	-	-	-	-	-

continued	2012
HFC-134	
Domestic	-
Commercial and Industry	225
Transport	-
HFC-404a	
Commercial and Industry	2 760
Transport	205
HFC-407c	
Commercial and Industry	45
HFC-507a	
Transport	180
Unspecified HFCs	
Commercial and Industry	35
SF_6	
Electrical Equipment	-

Emission factors

The CO_2 emission factors applied for mineral products in 2012 are presented in Table 16.4.10. The same emission factor has been applied for 1990-2012.

Table 16.4.10 CO_2 emission factors 2012.

Product	Emission factor	Unit	Reference	IPCC Category
Limestone and dolomite use	440	kg pr tonne	IPCC, 1997	2A3
Asphalt materials used for roofing	0.25	kg pr tonne	Nielsen et al., 2011	2A5
Asphalt used for road paving	0.168	kg pr tonne	Nielsen et al., 2011	2A6

The CO emission factors applied for the consumption of asphalt products under mineral products in 2012 are presented in Table 16.4.11. The same emission factor has been applied for 1990-2012.

Table 16.4.11 CO emission factors 2012.

Product	Emission factor	Unit	Reference	IPCC Category
Asphalt materials used for roofing	0.01	kg pr tonnes	Nielsen et al., 2011	2A5
Asphalt used for road paving	0.075	kg pr tonnes	Nielsen et al., 2011	2A6

The NMVOC emission factors applied for the consumption of asphalt products under mineral products and products used in the production of food and drink in 2012 are presented in Table 16.4.12. The same emission factor has been applied for 1990-2012.

Table 16.4.12 NMVOC emission factors 2012.

Product	Emission factor	Unit	Reference	IPCC Category
Asphalt materials used for roofing	0.08	kg pr tonnes	Nielsen et al., 2011	2A5
Asphalt used for road paving	0.015	kg pr tonnes	Nielsen et al., 2011	2A6
Food and Drink - Beans roasted to produce coffee	0.55	kg pr tonnes	IPCC, 1997	2D2
Food and Drink - Production of bread	8	kg pr tonnes	IPCC, 1997	2D2
Food and Drink - Landings of fish and seafood	0.3	kg pr tonnes	IPCC, 1997	2D2
Food and Drink - Production of beer	0.0625	kg pr hl	Nielsen et al., 2011	2D2

16.4.4 Emissions

The greenhouse gas (GHG) emissions are listed in Table 16.4.13. The emission from industrial processes accounts for 1.2 % of the Greenlandic GHG emission.

The CO_2 emission from industrial processes accounts for just 0.00348 % 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 accounts for 100 % of the Greenlandic emission and the SF_6 emission accounts for 100 % of the Greenlandic SF_6 emission.

Table 16.4.13 Greenhouse gas emission for the year 2012.

		CO_2	HFC	SF_6
		Tonne CO_2 equivalent		
2A3	Limestone and Dolomite Use	19.57	NA	NA
2A5	Asphalt Roofing	0.23	NA	NA
2A6	Road Paving with Asphalt	0.10	NA	NA
2F1	Refrigeration	NA	7 185	NA
2F8	Electrical Equipment	NA	NA	2.9
Total emission from industrial processes		19.90	7 185	2.9
Greenlandic emission (excluding net emission from LULUCF)		572 699	7 185	2.9
			%	
Emission share for industrial processes		0.00348	100	100

HFC is the most important GHG pollutant and accounts for 99.7 % of the GHG emission in CO_2 equivalents from industrial processes. 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 16.4.5 depicts the time series of CO_2 emission from industrial processes. As shown by the blue curve total CO_2 emission follows the CO_2 emission from use of limestone and dolomite closely. Limestone and dolomite was not imported to Greenland before 2000. Thus emission of CO_2 from the use of mineral products increased significantly in 2000. The emission of CO_2 has increased by a factor 184 from 1990 to 2012 primarily due to the introduction of limestone and dolomite import in 2000. In 2012 limestone and dolomite imports increased significantly causing emissions from mineral products to increase as well. Data on imports are used to estimate the annual use of limestone and dolomite. This causes a great deal of fluctuations from year to year. Hence, in years with none or low import of limestone and dolomite, i.e. 2009 and 2011, CO_2 emission from the use of limestone and dolomite are also low.

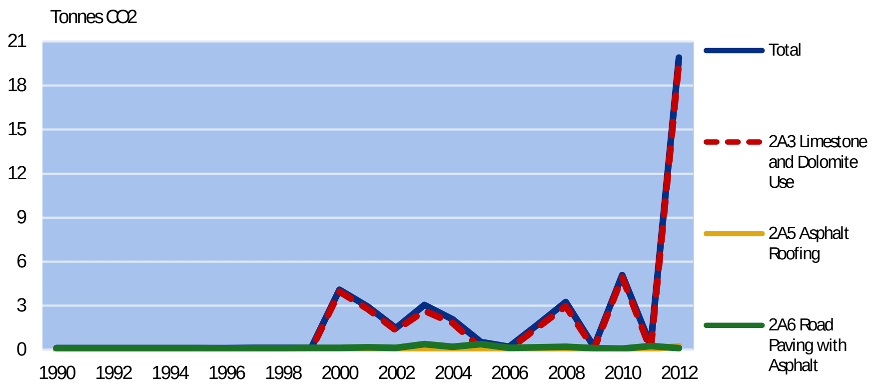

Figure 16.4.5 Emission of CO_2 from industrial processes.

Emission of HFCs and SF_6 are illustrated in Figure 16.4.3 and Figure 16.4.4.

NMVOC and CO

The emissions of NMVOC and CO from industrial processes in 2012 are presented in Table 16.4.14. NMVOC and CO account for 2.92 % and 0.001 % respectively, of the Greenlandic emissions for these substances.

Table 16.4.14 NMVOC and CO emission from industrial processes 2012.

		NMVOC	CO
		Tonnes	
2A5	Asphalt Roofing	0.07	0.01
2A6	Road Paving with Asphalt	0.01	0.04
2D2	Food and Drink	33.90	NA
Total emission from industrial processes		33.98	0.05
Greenlandic emission		1 163.8	5 011.3
		%	
Emission share for industrial processes		2.92	0.001

16.4.5 Uncertainties

A tier 1 uncertainty assessment has been carried out in accordance with the IPCC GPG (IPCC, 2000). 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 16.4.15.

Table 16.4.15 Uncertainties for activity data and emission factors for industrial processes.

Subsector	Pollutant	Activity data uncertainty	Emission factor uncertainty
2A3 Limestone and dolomite use	CO_2	5	5
2A5 Asphalt roofing	CO_2	5	25
2A6 Road paving with asphalt	CO_2	10	50
2F Consumption of HFC	HFC	10	50
2F Consumption of SF6	SF_6	10	50

The activity data comes from the import statistics, which is considered to be of high quality, therefore the uncertainty of the activity data has been set to 5 % for limestone and dolomite use and asphalt roofing, while it is assumed to be 10 % for road paving and consumption of HFCs and SF_6.

Regarding the emission factor 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 asphalt roofing and road paving are expert judgements. 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, Greenlandic statistics have been developed over a number of 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 16.4.16.

Table 16.4.16 Uncertainties for the emission estimates.

	Uncertainty %	Trend 1990-2012[1] %	Trend uncertainty %
GHG	± 36	16 856	± 4 679
CO_2	± 7	18 258	± 4 440
HFC	± 51	29 210	± 4 145
SF_6	± 51	-92	± 1.1

[1] For f-gases the base year of 1995 is used.

16.4.6 Source specific QA/QC

The elaboration of a formal QA/QC plan is to be completed.

However, the official Greenland import statistics has gone through a great deal of quality work with regard to accuracy, comparability and completeness. Statistics Greenland is responsible for the official Greenlandic import statistics, and as such responsible for the completeness of data.

Statistics on imports is reported by Statistics Greenland in form of a spreadsheet. Annual import of limestone and dolomite, asphalt materials used for roof covering and road paving, 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. In other words, no information is typed manually into the CRF Reporter. Instead, all information is imported to the CRF Reporter through XML-files to ensure maximum accuracy and completeness.

16.4.7 Source specific recalculations and improvements

The sectors *Mineral Products* (2A) and *Other Production* (2D) were included in the inventory for the first time in the 2010 submission. During implementation the following improvements were made:

Introduction of new activity data on non-energy use of limestone and dolomite, products containing bitumen used for asphalt roofing, and road paving with asphalt.

Introduction of new activity data on consumption of products used in the production of food and drink i.e. raw coffee beans, yeast used for baking, landings of fish, shellfish, seals and whales, and production of beer. Use of these products caused no CO_2 emission only non-methane volatile organic compounds (NMVOC).

Improved data on use of F-gases. Activity data on F-gases are now divided into domestic, commercial and industry, transport, and electrical equipment. Further more the substances, which are accounted according to their trade names, are now transferred into "pure" substances.

In the 2014 emission inventory submission there have been no further improvements or recalculations compared to the 2013 submission. Therefore Table 16.4.17 shows no changes in recalculations relating to industrial processes compared with the 2013 submission.

Table 16.4.17 Changes in GHG emission in the industrial processes sector compared with the 2013 submission.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Previous inventory, Gg CO_2 eqv.	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.4	0.7	1.3	1.9
Recalculated, Gg CO_2 eqv.	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.4	0.7	1.3	1.9
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-	-
Change in pct.	-	-	-	-	-	-	-	-	-	-	-
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Previous inventory, Gg CO_2 eqv.	3.0	3.9	4.8	5.4	5.5	5.6	6.1	6.5	6.6	6.8	7.1
Recalculated, Gg CO_2 eqv.	3.0	3.9	4.8	5.4	5.5	5.6	6.1	6.5	6.6	6.8	7.1
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-	-
Change in pct.	-	-	-	-	-	-	-	-	-	-	-
continued	2012										
Previous inventory, Gg CO_2 eqv.	-										
Recalculated, Gg CO_2 eqv.	7.2										
Change in Gg CO_2 eqv.	-										
Change in pct.	-										

16.4.8 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.

16.4.9 References

Godthåb Bryghus (Brewery in Nuuk), 2013: Data on production of beer 2006-2013. Not published.

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http://www.ipcc-nggip.iges.or.jp/public/gl/invs6.htm (15-04-2007).

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Nielsen, O.-K., Plejdrup, M.S., Winther, M., Nielsen, M., Gyldenkærne, S., Mikkelsen, M.H., Albrektsen, R., Thomsen, M., Hjelgaard, K., Hoffmann, L., Fauser, P., Bruun, H.G., Johannsen, V.K., Nord-Larsen, T., Vesterdal, L., Møller, I.S., Caspersen, O.H., Rasmussen, E., Petersen, S.B., Baunbæk, L., Hansen, M.G., 2013: Denmark's National Inventory Report 2013 – Emission Inventories 1990-2012 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. National Environmental Research Institute, University of Aarhus. 1,203 pp. – Scientific Report from DCE – Danish Center for Environment and Energy no. 56. Available at:
http://www2.dmu.dk/Pub/SR56.pdf

Statistics Greenland, 2013a: Annual survey among importers, suppliers and consumers of F-gases in Greenland in 2012. Not published.

Statistics Greenland, 2013b: Foreign Trade, Import and Export. Available at: http://www.stat.gl/dialog/main.asp?lang=da&sc=IE&version=201301 as "Grønlands udenrigshandel 2012" (27-03-2013). Data more detailed than the published version of the foreign trade statistics are used in order to access imports at the most detailed level.

16.5 Solvent and other product use (CRF sector 3)

16.5.1 Overview of sector

This section presents the methodology used for calculating CO_2 and NMVOC emissions from use of solvents in industrial processes and households that are related to the source categories Paint application (CRF sector 3A), Degreasing and dry cleaning (CRF sector 3B), Chemical products, manufacture and processing (CRF sector 3C) and Other (CRF sector 3D).

Solvents are chemical compounds that are used on a global scale in industrial processes and as constituents in final products to dissolve e.g. paint, cosmetics, adhesives, ink, rubber, plastic, pesticides, aerosols or are used for cleaning purposes, i.e. 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 solvent 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 – 2012 are summarised. The method is based on the detailed approach described in EMEP/CORINAIR (2004) and emissions are calculated for the CRF sectors mentioned above.

16.5.2 Source category description

Table 16.5.1 and Figure 16.5.1 show the emissions of chemicals from 1990 to 2012, where the used amounts of single chemicals have been assigned to specific products and CRF categories.

Table 16.5.2 shows the used amounts of chemicals for the same period. Table 16.5.1 is derived from Table 16.5.2 by applying emission factors relevant to individual chemicals and production or use activities. Table 16.5.3 shows the used amounts of products from 1990 to 2012.

The default NMVOC-CO_2 conversion factor of 0.85 * 3.667 = 3.11 is used.

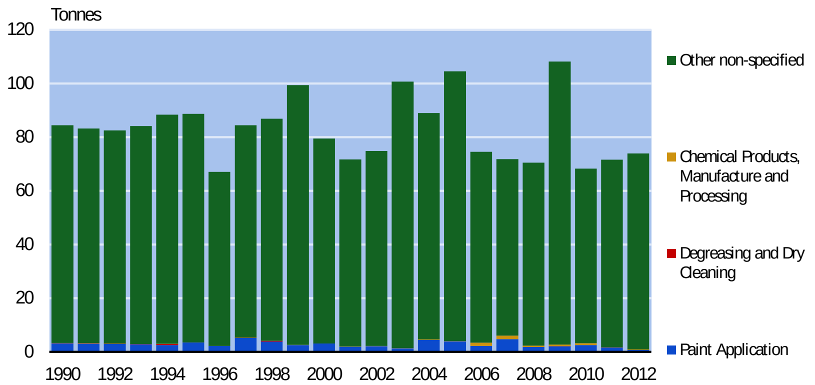

Figure 16.5.1 Emission of NMVOC from solvent and other product use. The methodological approach for finding emissions is described in the text. Figures can be seen in Table 16.5.1.

Table 16.5.1 Emission of chemicals in tonnes per year.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Paint application (3A)	3.1	3.0	2.9	2.8	2.5	3.4	2.1	5.2	3.8	2.5	3.1
Degreasing and dry cleaning (3B)	0.1	0.1	0.1	0.1	0.4	NO	NO	0.1	0.2	NO	NO
Chemical products, manufacturing and processing (3C)	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0
Other (3D)	81.2	80.1	79.4	81.2	85.4	85.2	64.9	79.2	82.8	96.8	76.4
Total NMVOC	84.4	83.3	82.5	84.1	88.3	88.7	67.1	84.4	86.9	99.4	79.5
Total CO_2	263.4	259.7	257.4	262.5	275.6	276.7	209.3	263.4	271.0	310.1	247.9
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Paint application (3A)	1.9	2.1	1.3	4.4	3.9	2.2	4.7	1.8	2.0	2.5	1.6
Degreasing and dry cleaning (3B)	NO	NO	NO	NO	NO	NO	NO	0.0	0.0	NO	NO
Chemical products, manufacturing and processing (3C)	0.0	0.1	0.0	0.2	0.1	1.2	1.3	0.4	0.6	0.7	0.0
Other (3D)	69.8	72.7	99.3	84.3	100.5	71.1	65.8	68.3	105.5	65.1	69.9
Total NMVOC	71.7	74.8	100.7	88.9	104.5	74.5	71.8	70.5	108.2	68.3	71.5
Total CO_2	223.6	233.5	314.0	277.5	326.1	232.5	224.0	219.9	337.5	213.0	223.1
continued	2012										
Paint application (3A)	0.6										
Degreasing and dry cleaning (3B)	0.0										
Chemical products, manufacturing and processing (3C)	0.2										
Other (3D)	73.0										
Total NMVOC	73.9										
Total CO_2	230.5										

Table 16.5.2 Used amounts of chemicals in tonnes per year.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Paint application (3A)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Degreasing and dry cleaning (3B)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Chemical products, manufacturing and processing (3C)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other (3D)	37.0	36.6	35.1	34.8	59.6	43.5	45.4	32.8	27.1	36.5	18.6
Total NMVOC	37.0	36.6	35.1	34.8	59.6	43.5	45.4	32.8	27.1	36.5	18.6
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Paint application (3A)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Degreasing and dry cleaning (3B)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Chemical products, manufacturing and processing (3C)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other (3D)	33.0	20.0	31.9	27.5	27.4	30.4	24.2	26.2	68.2	36.7	23.9
Total NMVOC	33.0	20.0	31.9	27.5	27.4	30.4	24.2	26.2	68.2	36.7	23.9
continued	2012										
Paint application (3A)	NO										
Degreasing and dry cleaning (3B)	NO										
Chemical products, manufacturing and processing (3C)	NO										
Other (3D)	25.3										
Total NMVOC	25.3										

Table 16.5.3 Used amounts of products in tonnes per year.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Paint application (3A)	3.9	3.8	3.7	3.5	3.1	4.3	2.7	6.5	4.8	3.1	3.8
Degreasing and dry cleaning (3B)	0.2	0.2	0.1	0.1	0.8	NO	NO	0.1	0.4	NO	NO
Chemical products, manufacturing and processing (3C)	0.3	0.2	0.2	0.2	0.5	0.1	0.1	0.1	0.1	0.8	0.0
Other (3D)	84.6	83.5	83.5	85.8	84.9	84.5	61.8	81.8	90.9	105.7	83.8
Total products	89.0	87.7	87.5	89.7	89.4	89.0	64.6	88.6	96.1	109.5	87.6
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Paint application (3A)	2.4	2.6	1.6	5.5	4.8	2.8	5.8	2.3	2.6	3.1	2.0
Degreasing and dry cleaning (3B)	NO	NO	NO	NO	NO	NO	NO	0.0	0.0	NO	NO
Chemical products, manufacturing and processing (3C)	0.1	0.4	0.2	0.5	0.3	11.5	13.9	4.4	6.1	5.7	0.3
Other (3D)	72.2	83.3	109.5	96.2	107.2	77.8	69.8	71.6	97.5	66.9	75.9
Total products	74.6	86.2	111.4	102.2	112.3	92.1	89.5	78.2	106.2	75.6	78.2
continued	2012										
Paint application (3A)	0.8										
Degreasing and dry cleaning (3B)	0.0										
Chemical products, manufacturing and processing (3C)	2.7										
Other (3D)	88.4										
Total products	91.9										

16.5.3 Methodological issues

Emission modelling of solvents can basically be done in two ways: 1) By estimating the amount of (pure) solvents consumed, or 2) By estimating the amount of solvent containing products consumed, taking account of their solvent content (EMEP/CORINAIR, 2004).

In 1) all relevant solvents must be estimated, or at least those together representing more than 90 % of the total NMVOC emission, and in 2) all relevant source categories must be inventoried or at least those together contributing more than 90 % of the total NMVOC emission. A simple approach is to use a pr capita emission for each category, whereas a detailed approach is to get all relevant consumption data (EMEP/CO-RINAIR, 2004).

The detailed method 1) is used in the emission inventory for solvent use, thus representing a chemicals approach, where 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.

Activity data

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".

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.

Emission factors

For some chemicals the emission factors are precise but for others they are rough estimates. In the Danish inventory emission factors are divided into four categories: 1) chemical industry (lowest EF), 2) other industry, 3) non-industrial activities, 4) domestic and other diffuse use (highest EF). This implies that high emission factors are applicable for use of solvent containing products and lower emission factors are applicable for use in industrial processes

The emission factors used in the Greenlandic inventory are the same as developed for the Danish inventory (please refer to Chapter 5). For the chemicals assumed to be used for industrial purposes the mean value of category 1 and 2 above is used.

16.5.4 Emissions

Table 16.5.1 and Figure 16.5.1 show the emissions of chemicals from 1994 to 2012, where the used amounts of single chemicals have been assigned to specific products and CRF categories. Table 16.5.2 shows the used amounts of chemicals for the same period. Table 16.5.1 is derived from Table 16.5.2 by applying emission factors relevant to individual chemicals and production or use activities. Table 16.5.3 showing the used amount of products is derived from Table 16.5.2, by assessing the amount of chemicals that is comprised within products belonging to each of the four source categories. The default NMVOC-CO_2 conversion factor of 0.85 * 3.667 = 3.11 is used.

16.5.5 Uncertainties

A tier 1 uncertainty assessment has been carried out in accordance with the IPCC GPG (IPCC, 2000). The uncertainty has been estimated for all sources included in the reporting for solvent and other product use. The uncertainties for the activity data and emission factors are shown in Table 16.5.4.

Table 16.5.4 Uncertainties for activity data and emission factors for solvents.

Subsector	Pollutant	Activity data uncertainty	Emission factor uncertainty
3A Paint application	CO_2	10	15
3B Degreasing and dry cleaning	CO_2	10	15
3C Chemical products, manufacturing and processing	CO_2	10	15
3D5 Other	CO_2	10	20

The activity data comes from the import statistics, which is considered to be of high quality, therefore the uncertainty of the activity data has been set to 10 %.

Regarding the emission factor uncertainties, the uncertainty comprises of both the uncertainty of the NMVOC emission factor, and the uncertainty of the conversion factor of NMVOC to CO_2.

The resulting uncertainty for CO_2 is shown in Table 16.5.5.

Table 16.5.5 Uncertainties for the emission estimates.

	Uncertainty %	Trend 1990-2012 %	Trend uncertainty %
CO_2	± 22.1	-12.5	± 12.2

16.5.6 Source specific QA/QC

Time series of activity data and emissions are analysed. Large inter annual variations is investigated further to ensure the accuracy of the estimates.

16.5.7 Source specific recalculations and improvements

Emissions from solvent and other product use were included in the Greenlandic emission inventory for the first time in the 2010 submission.

There have been no improvements in the 2014 emission inventory submission.

Priorily the notation key NE has been used regarding N_2O from fire extinguishers. However, a 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 has been changed from NE to NO concerning every year in the time series 1990-2011. The changed happened in the 2013 submission. With regard to aerosol cans, we are aware that N_2O is found in the products. Since we can not find any activity data on aerosol cans, we continue to report the notation key NE for N_2O in aerosol cans.

Table 16.5.6 Changes in GHG emission in the industrial processes sector compared with the 2013 submission.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Previous inventory, Gg CO_2 eqv.	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.2
Recalculated, Gg CO_2 eqv.	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.2
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-	-
Change in pct.	-	-	-	-	-	-	-	-	-	-	-
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Previous inventory, Gg CO_2 eqv.	0.2	0.2	0.3	0.3	0.3	0.2	0.2	0.2	0.3	0.2	0.2
Recalculated, Gg CO_2 eqv.	0.2	0.2	0.3	0.3	0.3	0.2	0.2	0.2	0.3	0.2	0.2
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-	-
Change in pct.	-	-	-	-	-	-	-	-	-	-	-
continued	2012										
Previous inventory, Gg CO_2 eqv.	-										
Recalculated, Gg CO_2 eqv.	0.2										
Change in Gg CO_2 eqv.	-										
Change in pct.	-										

16.5.8 Source specific planned improvements

It will be investigated whether use of N_2O is occurring in Greenland.

16.5.9 References

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Convention on Climate Change and the Kyoto Protocol. National Environmental Research Institute, University of Aarhus. 1,203 pp. – Scientific Report from DCE – Danish Center for Environment and Energy no. 56. Available at:
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Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations, Brüssel, 1999.

Statistics Greenland, 2013b: Foreign Trade, Import and Export. Available at: http://www.stat.gl/dialog/main.asp?lang=da&sc=IE&version=201301 as "Grønlands udenrigshandel 2012" (27-03-2013). Data more detailed than the published version of the foreign trade statistics are used in order to access imports at the most detailed level.

16.6 Agriculture (CRF sector 4)

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 4.A, 4.B and 4.D.

Emission from rice production, burning of agricultural crop residue and burning of savannas does not occur in Greenland and the CRF Tables 4.F, 4.C and 4.E have, consequently, not been completed.

Emission of non-methane volatile organic compounds (NMVOC) from agricultural activities has not been estimated.

16.6.1 Overview of sector

In CO_2 equivalents, the agricultural sector (without LULUCF) contributes with 1.5 % of the overall greenhouse gas emission (GHG) in 2012. From 1990 to 2012 emissions increased from 8.78 Gg CO_2 equivalents to 9.34 Gg CO_2 equivalents, which correspond to an increase of 6.4 %, see Table 16.6.1. This emission increase is primarily caused by an growing use of synthetic fertiliser.

Table 16.6.1 Emission of GHG in the agricultural sector 1990-2012 in Gg CO_2 equivalents

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
CH_4	6.16	6.21	5.58	4.89	5.33	5.72	5.89	6.42	6.16	5.52	5.36
N_2O	2.62	2.64	2.40	2.15	2.33	2.47	3.48	2.99	3.89	3.94	3.48
Total	8.78	8.85	7.98	7.03	7.66	8.19	9.37	9.41	10.05	9.46	8.84
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
CH_4	5.46	5.26	5.33	5.60	5.82	5.64	5.77	5.63	5.52	5.66	5.54
N_2O	3.60	3.41	3.47	3.70	3.87	3.90	3.39	5.16	3.77	3.69	4.06
Total	9.06	8.67	8.80	9.30	9.70	9.54	9.16	10.79	9.29	9.35	9.60
continued	2012										
CH_4	5.51										
N_2O	3.83										
Total	9.34										

As showed in Figure 16.6.1, CH_4 emission contributed with 59.0 % of the total GHG emission from the agricultural sector in 2012 and N_2O contributed with the remaining 41.0 % given in CO_2 equivalents. 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 synthetic fertiliser, nitrogen leaching from leaching and run-off and emission from grassing animals.

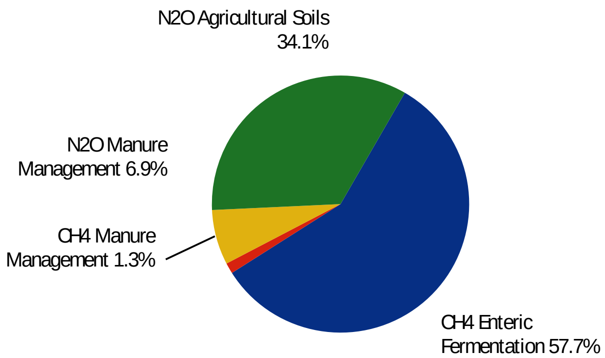

Figure 16.6.1 Emission of greenhouse gases from agriculture in 2012.

16.6.2 Source category description

The calculations of the emissions are based on methods described in the IPCC Reference Manual (IPCC, 1997) 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 16.6.2 List of institutes involved in the emission inventory for the agricultural sector.

References	Link	Abbreviation	Data/information
Statistics Greenland	*www.stat.gl*	GST	- reporting - data collecting - no. of animal - feed import - use of synthetic 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

16.6.3 CH_4 emission from Enteric Fermentation (CRF sector 4A)

Description

The major part of the agricultural CH_4 emission originates from digestive processes. In 2012, this source accounts for 57.7 % of the total GHG emission from agricultural activities. The emission is primarily related to ruminants, which in Greenland is sheep. In 2012 sheep contributed with 87 % and the remaining 13 % 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 %.

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 16.6.3 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	0.06	11.2
Reindeer	27.5	0.06	10.7

The default CH_4 emission factor for sheep Tier 1 methodology is estimated to 8 kg CH_4 per animal per year. 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 27.5 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 16.6.4 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 16.6.4 Number of animals from 1990-2012 (CRF Table 4.A. 4.B (a) and 4.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										
Sheep	20 107										
Reindeer	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. Therefore the same IEF is used for all years.

Time series consistency

The emission from enteric fermentation is given in Table 16.6.5. From 1990 to 2012, the emission has decreased by 10.5 % due to a fall in number of reindeer.

Table 16.6.5 Emission of CH_4 from Enteric Fermentation 1990–2012, tonnes CH_4.

CRF 4.A	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Sheep	222	225	200	181	199	217	225	258	222	234	228
Reindeer	64	64	60	46	49	49	49	41	64	23	21
Total, tonnes CH_4	287	289	260	227	248	266	274	299	287	257	250
Total, tonnes CO_2 eqv.	6 018	6 066	5 452	4 775	5 208	5 594	5 758	6 275	6 018	5 396	5 240
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Sheep	228	212	215	227	238	238	242	235	225	231	226
Reindeer	27	33	33	33	33	25	26	27	32	32	32
Total, tonnes CH_4	254	245	248	261	271	262	268	262	257	263	258
Total, tonnes CO_2 eqv.	5 336	5 141	5 209	5 473	5 692	5 510	5 635	5 502	5 393	5 532	5 415
continued	2012										
Sheep	224										
Reindeer	32										
Total, tonnes CH_4	256										
Total, tonnes CO_2 eqv.	5 386										

16.6.4 CH_4 and N_2O emission from Manure Management (CRF sector 4B)

Description

The emissions of CH_4 and N_2O from manure management are given in CRF Table 4.B (a) and 4.B (b). This source contributes with 8.3 % of the total emission from the agricultural sector in 2012. The major part of the emission originates from the production of sheep.

Methodological issues

CH_4 emission

The IPCC Tier 2/CS methodology has been used for the estimation of the CH_4 emission from manure management. Calculation of volatile solids, VS is based on national value of gross energy intake (GE). Default values is used for the maximum methane producing capacity (B_0), digestibility (DE), the ash content and the methane conversion factor (MCF).

For reindeer no default values exists. 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 16.6.6 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
Ash content (ASH)	Percent	8	8	IPCC default
Volatile solids (VS)	Kg VS pr head pr day	0.57	0.54	National
Max. methane producing capacity (B_0)	M^3 pr kg VS	0.19	0.19	IPCC default
CH_4 conversion factor (MCF), solid storage and pasture	Percent	1	1	IPCC default
Emission factor	Kg CH_4 pr head pr yr	0.26	0.25	Tier 2

There are no changes in stable conditions or feed intake during the years 1990 to 2012. The implied emission factor is therefore the same for all years.

The default emission factor for sheep is 0.19 kg CH_4 per head per year. The higher national value is due to a higher estimate for gross energy intake.

Table 16.6.7 shows a decrease in the CH_4 emission from manure management from 1990 to 2012 by 11.2 %, which primarily is related to the fall in the production of reindeer.

Table 16.6.7 Emission of CH_4 from Manure Management 1990-2012, tonnes CH_4.

CRF 4.A	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Sheep	5.2	5.2	4.7	4.2	4.6	5.1	5.2	6.0	5.2	5.5	5.3
Reindeer	1.5	1.5	1.4	1.1	1.2	1.2	1.2	1.0	1.5	0.5	0.5
Total, tonnes CH_4	6.7	6.7	6.1	5.3	5.8	6.2	6.4	7.0	6.7	6.0	5.8
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Sheep	5.3	4.9	5.0	5.3	5.5	5.5	5.6	5.5	5.2	5.4	5.3
Reindeer	0.6	0.8	0.8	0.8	0.8	0.6	0.6	0.6	0.8	0.8	0.8
Total, tonnes CH_4	5.9	5.7	5.8	6.1	6.3	6.1	6.3	6.1	6.0	6.1	6.0
continued	2012										
Sheep	5.2										
Reindeer	0.8										
Total, tonnes CH_4	6.0										

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 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.

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 increased by 0.9 % from 1990 to 2012 (Table 16.6.8) due to an increase in the number of sheep.

Table 16.6.8 Total nitrogen excretion for sheep, 1990-2012, tonnes N.

CRF table 4.B(b)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Livestock category											
N-excreted, tonnes in total	120	121	107	98	107	117	121	139	120	126	123
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
Livestock category											
N-excreted, tonnes in total	122	114	116	122	128	128	130	126	121	124	121
N-excretion, tonnes in stable	67	63	64	67	70	70	72	70	66	68	67
continued	2012										
Livestock category											
N-excreted, tonnes in total	121										
N-excretion, tonnes in stable	66										

Time series consistency

As shown in Table 16.6.9 total emission from manure management from 1990 to 2012 in CO_2 equivalents has decreased by 1.2 % due to a decrease in the number of reindeer.

Table 16.6.9 Emissions of N_2O and CH_4 from Manure Management 1990-2012.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
N_2O emission, tonnes CO_2 eqv.	641	647	576	523	573	626	648	744	641	675	657
CH_4 emission, tonnes CO_2 eqv.	140	141	127	111	121	130	134	146	140	126	122
Total, tonnes CO_2 eqv.	781	789	703	634	694	756	783	890	781	801	779
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
N_2O emission, tonnes CO_2 eqv.	656	610	619	655	685	684	698	678	647	666	650
CH_4 emission, tonnes CO_2 eqv.	124	120	121	128	133	128	131	128	126	129	126
Total, tonnes CO_2 eqv.	780	730	741	783	818	813	829	806	773	795	777
continued	2012										
N_2O emission, tonnes CO_2 eqv.	646										
CH_4 emission, tonnes CO_2 eqv.	126										
Total, tonnes CO_2 eqv.	772										

16.6.5 N_2O emission from Agricultural Soils (CRF sector 4D)

Description

The N_2O emissions from agricultural soils CRF Table 4.D contributed in 2012 with 34.0 % of the total emission from the agricultural sector. Figure 16.6.2 shows the overall development from 1990 to 2012 and the distribution on different sources. Since 1990 N_2O emissions increased suddenly in 1996, when farmers increased their use of synthetic fertiliser significantly. From 1997 to 2007 the emission of N_2O varied with an increasing trend. In 2008 the emission of N_2O increased considerably due to a considerable increase in the use of synthetic fertiliser caused by a periodical drought in the agricultural part of Greenland. In 2009 the use of synthetic fertiliser returned back to a more normal level, thus the emission of N_2O dropped as well. In 2012 the use of synthetic fertiliser decreased by of 13.7 % compared to 2011.

Emission from synthetic fertiliser and nitrogen leaching is an essential part of the total emission from agricultural soils and contributes totally with 58.7 %. Of the remaining sources the greatest part of the emission, by 20.4 %, origins from pasture, range and paddocks. Emissions from all sources have increased from 1990 to 2012 except from grassing animal where a fall in number of reindeer has taken place.

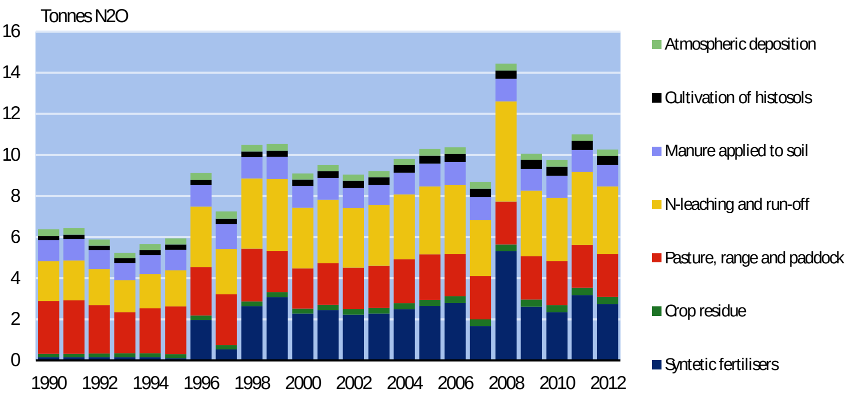

Figure 16.6.2 N_2O emissions from agricultural soils 1990-2012.

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 crops residue. Emissions of N_2O are closely related to the nitrogen balance. Data concerning the N-excretion, evaporation of ammonia from synthetic fertiliser and grassing animal are based on national values.

The NH_3 and N_2O emission factor survey is presented in Table 16.6.10 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 16.6.10 Emissions factor - N_2O emission from the Agricultural Soils 1990-2012.

Agricultural soils – emission sources CRF Table 4.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
1. Direct Soil Emissions			
Synthetic Fertiliser Applied to Soils	0.01 (CS)		0.0125
Animal Wastes Applied to Soils	0.20 (IPCC default)		0.0125
N-fixing Crops			0.0125
Crop Residue			0.0125
Cultivation of Histosols		1.06*	
2. Animal Production	0.07 (CS)		0.02
3. Indirect Soil Emissions			
Atmospheric Deposition			0.01
Nitrogen Leaching and Runoff			0.025

CS = country specific value.

* Include both emission from cropland and improved grassland. For further details see Section 16.7.

Direct emissions

Synthetic fertiliser

The calculation of nitrogen (N) applied to soil from use of synthetic fertiliser is based on data on imports from the 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 16.6.11 shows the consumption of each type of fertiliser. Furthermore, the ammonia emission factor for each fertiliser is given, based on the values given in EMEP/EEA emission inventory guide book 2009 (Table 3-2). The emission factors are depending on the mean spring temperature estimated to seven degrees in Greenland. The spring temperature has to reflect the time where the fertilisers are applied, which in Greenland normally is June.

Table 16.6.11 Synthetic fertiliser consumption 2012 and the NH_3 emission factors.

Synthetic fertiliser	Calculation of ammonia emission factor[1]	NH_3 emission factor[1] kg NH_3-N pr kg N	Consumption[2] t N
Fertiliser type			
Ammonium sulphate	=0.0107+0.0006*ts	1.49	NO
Ammonium nitrate	=0.008+0.0001*ts	0.87	7
Calcium ammonium nitrate	=0.008+0.0001*ts	0.87	0
Anhydrous ammonia	=0.0127+0.0012*ts	2.11	NO
Urea	=0.1067+0.0035*ts	13.12	0
Nitrogen solutions	=0.0481+0.0025*ts	6.56	NO
Ammonium phosphates	=0.0107+0.0006*ts	1.49	NO
Other NK and NPK	=0.008+0.0001*ts	0.87	133
Total consumption of N in synthetic fertiliser			141
National emission of NH_3-N, tonnes	1.2		
Average NH_3-N emission (FracGASF)	0.01		

*ts= means spring temperature=7 degree.

[1]) EMEP/EEA (2009).

[2]) Statistics Greenland and the Danish Plant Directorate.

The Greenlandic value for the FracGASF is estimated to less than 0.01 in 2012, which is considerably lower than the recommended default value in IPCC, i.e. 0.10. The major part of the fertiliser types used in Greenland is related to ammonia nitrate and NPK fertiliser where the emission factor is quite low, i.e. 0.0087 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 0.10-0.13.

Table 16.6.12 FracGASF, 1990-2012.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
FracGASM	0.13	0.13	0.13	0.13	0.13	0.10	0.02	0.03	0.01	0.01	0.01
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
FracGASM	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
Continued	2012										
FracGASM	0.01										

Table 16.6.13 shows an increase in use of fertiliser and a particularly high increase in 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. Hence, it is possible that farmers have tended to increase the use of fertilisers in 2008 to produce more feed. The use of fertiliser returned to a more normal level in 2009 and 2010. In 2011 the use of synthetic fertilisers increased 35.6 %. Most recently the use of synthetic fertilisers decreased 13.7 % in 2012.

Table 16.6.13 Nitrogen applied as fertiliser to agricultural soils 1990-2012.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
N content in synthetic fertiliser, tonnes N	9	9	9	9	9	6	102	28	135	158	117
NH_3-N emission, tonnes	1	1	1	1	1	1	2	1	1	1	1
N in fertiliser applied on soil, tonnes N	8	8	8	8	8	6	100	27	134	157	116
N_2O emission, tonnes	0.16	0.16	0.16	0.16	0.16	0.11	1.97	0.53	2.63	3.08	2.28
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
N content in synthetic fertiliser, tonnes N	126	114	117	128	136	144	86	273	134	120	163
NH_3-N emission, tonnes	1	1	1	1	1	1	1	2	1	1	1
N in fertiliser applied on soil, tonnes N	125	113	116	127	135	142	85	271	133	119	162
N_2O emission, tonnes	2.45	2.22	2.27	2.49	2.65	2.80	1.67	5.32	2.61	2.34	3.17
Continued	2012										
N content in synthetic fertiliser, tonnes N	141										
NH_3-N emission, tonnes	1										
N in fertiliser applied on soil, tonnes N	139										
N_2O emission, tonnes	2.74										

Manure applied to soil

The amount of nitrogen applied to soil from sheep on 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 IPCC default is used. However, the FracGASM default at 0.20 (IPCC 1997. Table 4-19) match the Danish emission ammonia from sheep, which are estimated to 24 % in 1990 reduced to 19 % in 2008. A lower ammonia emission in Greenland is expected due to the cold climate, but on the other hand no ammonia reducing measures are implemented as in Denmark. The FracGASM at 0.20 are therefore considered as reliable.

Table 16.6.14 shows the development in nitrogen excretion in stables, the estimated amount of N applied on soil and the N_2O emission.

Table 16.6.14 Nitrogen applied as manure to agricultural soils 1990-2012.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
N-excretion in stable, tonnes N	66	66	59	54	59	64	67	76	66	69	67
NH_3-N emission, tonnes N	13	13	12	11	12	13	13	15	13	14	13
N in manure applied on soil, tonnes N	53	53	47	43	47	51	53	61	53	55	54
N_2O emission, tonnes N_2O	1.03	1.04	0.93	0.84	0.92	1.01	1.05	1.20	1.03	1.09	1.06
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
N-excretion in stable, tonnes N	67	63	64	67	70	70	72	70	66	68	67
NH_3-N emission, tonnes N	13	13	13	13	14	14	14	14	13	14	13
N in manure applied on soil, tonnes N	54	50	51	54	56	56	57	56	53	55	53
N_2O emission, tonnes N_2O	1.06	0.98	1.00	1.06	1.11	1.10	1.13	1.09	1.04	1.07	1.05
Continued	2012										
N-excretion in stable, tonnes N	66										
NH_3-N emission, tonnes N	13										
N in manure applied on soil, tonnes N	53										
N_2O emission, tonnes N_2O	1.04										

Crop residue

The cultivated area is approximately 1,070 ha with the main part as grass fields, only 10.5 ha are used for potato production. The cultivated area has decreased compared to 2009 due to the shutdown of four farms. To estimate the emission from crop residue, IPCC Tier 1b has been applied. N_2O emissions from crop residues are calculated based on the total aboveground N-content in crop residue returned to soil, which in Greenland includes residue of leafs from grass fields and the top from potatoes.

National values for nitrogen content used are provided by the Faculty of Agricultural Sciences, Aarhus University (Djurhuus and Hansen 2003). Values are calculated based on relatively few observations related to Danish conditions, but are at present the best available data.

Table 16.6.15 N-content in crops residue 2012.

	Stubble	Husks	Top	Leafs	Frequency of ploughing	Nitrogen content in crop residue	
Crop type	kg N pr ha	kg N pr ha	kg N pr ha	kg N pr ha	No. of year before ploughing	kg N pr ha pr yr	kg N pr yr
Potatoes (top), non-harvest	-	-	48.7	-	1	48.7	17 441
Grass- and clover field in rotation	32.3		-	10.0	5	16.5	511
Total N from crop residue – 2012, kg							17 952

Reference: Djurhuus and Hansen 2003

To calculate the N_2O emission the IPCC standard emission factor 1.25 % is used. The national emission from crop residues has more than doubled from 1990 to 2012 (Table 16.6.16) as a result of increasing agricultural area.

Table 16.6.16 Emissions from crop residue 1990-2012.

Crop residue	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Grass stub/leaves, kg N	8 071	8 498	8 925	9 352	9 778	10 205	10 632	11 059	11 486	11 912	12 339
Potato tops, kg N	-	-	-	-	-	-	-	-	-	-	-
Crop residue total, kg N	8 071	8 498	8 925	9 352	9 778	10 205	10 632	11 059	11 486	11 912	12 339
N_2O emission, kg	159	167	175	184	192	200	209	217	226	234	242
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Grass stub/leaves, kg N	12 766	14 005	14 384	14 614	15 176	15 823	16 018	16 378	17 925	17 546	17 624
Potato tops, kg N	244	244	244	244	244	244	244	244	317	317	511
Crop residue total, kg N	13 010	14 249	14 628	14 857	15 420	16 066	16 262	16 621	18 241	17 863	18 135
N_2O emission, kg	256	280	287	292	303	316	319	326	358	351	356
Continued	2012										
Grass stub/leaves, kg N	17 441										
Potato tops, kg N	511										
Crop residue total, kg N	17 952										
N_2O emission, kg	353										

Frac vaules

There is no cultivation of nitrogen fixing crops, why the Fraction value $Frac_{NCRBF}$ is not relevant. Until national data is available, the default value of $Frac_{NCRO}$ by 0.015 is used. The default value of $Frac_R$ is not current for the Greenlandic conditions, where the main part of the aboveground biomass is harvest and used for ensilage. Until national data is available, the $Frac_R$ is registered as "Not Estimated".

Cultivation of histosols

N_2O emissions from histosols are based on the area with organic soils multiplied by the emission factor of 1.06 kg N_2O-N pr. kg N in 2012. See Section 16.7 on LULUCF for further description on cultivation of histosols.

Table 16.6.17 shows an increase in the N_2O emission from 1990 to 2012 due to extend of the agricultural area.

Table 16.6.17 Activity data and emission from cultivation of histosols 1990-2012.

CRF – Table 4.D	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Cultivated histosols, ha	123	129	136	142	149	155	161	168	174	181	187
N_2O emission, kg	201	211	222	232	243	254	264	275	285	296	307
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Cultivated histosols, ha	195	214	220	223	232	242	245	250	274	268	270
N_2O emission, kg	325	356	366	371	385	401	406	415	456	447	455
Continued	2012										
Cultivated histosols, ha	268										
N_2O emission, kg	451										

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 2009 use a similar emission factor at 6 % for grassing dairy cattle (calculated from 4B, Appendix B).

Table 16.6.18 shows the estimated values of N-excretion from grassing animals, ammonia emission, the N_2O emission and the FracGRAZ value. As a consequence of an overall drop in number of reindeer, both the N_2O emission and the FracGRAZ value have decreased from 1990 to 2012.

Table 16.6.18 Emission from grassing animals 1990-2012.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
N-excretion on grass, tonnes N	88	89	81	69	75	79	81	84	88	69	67
NH_3-N emission, tonnes	6	6	6	5	5	6	6	6	6	5	5
N deposited on grass, tonnes N	82	83	75	64	69	73	75	78	82	64	62
N_2O emission, tonnes	2.58	2.60	2.35	2.01	2.18	2.31	2.36	2.46	2.58	2.01	1.95
FracGRAZ	0.57	0.57	0.58	0.56	0.56	0.55	0.55	0.52	0.57	0.50	0.50
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
N-excretion on grass, tonnes N	69	69	70	73	75	71	73	71	72	73	72
NH_3-N emission, tonnes	5	5	5	5	5	5	5	5	5	5	5
N deposited on grass, tonnes N	64	64	65	68	70	66	68	66	67	68	67
N_2O emission, tonnes	2.03	2.02	2.04	2.13	2.20	2.07	2.12	2.08	2.09	2.14	2.10
FracGRAZ	0.51	0.52	0.52	0.52	0.52	0.50	0.50	0.51	0.52	0.52	0.52
Continued	2012										
N-excretion on grass, tonnes N	72										
NH_3-N emission, tonnes	5										
N deposited on grass, tonnes N	67										
N_2O emission, tonnes	2.09										
FracGRAZ	0.52										

Indirect emissions

Atmospheric deposition

Atmospheric deposition includes ammonia emission from manure management, use of synthetic fertiliser and from grassing animals.

The N_2O emission from atmospheric deposition is nearly unaltered from 1990 to 2012. The fall in the reindeer production compensate for an increase in the number of sheep and a rise in use of synthetic fertiliser.

Table 16.6.19 Emission from atmospheric deposition 1990-2012.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
NH_3-N manure management, tonnes	13	13	12	11	12	13	13	15	13	14	13
NH_3-N synthetic fertliser, tonnes	1	1	1	1	1	1	2	1	1	1	1
NH_3-N pasture, tonnes	6	6	6	5	5	6	6	6	6	5	5
NH_3-N total, tonnes	21	21	19	17	18	19	21	22	21	20	19
N_2O emission, tonnes	0.32	0.33	0.29	0.26	0.29	0.30	0.33	0.34	0.32	0.32	0.30
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
NH_3-N manure management, tonnes	13	13	13	13	14	14	14	14	13	14	13
NH_3-N synthetic fertliser, tonnes	1	1	1	1	1	1	1	2	1	1	1
NH_3-N pasture, tonnes	5	5	5	5	5	5	5	5	5	5	5
NH_3-N total, tonnes	19	18	19	20	21	20	21	21	19	20	20
N_2O emission, tonnes	0.30	0.29	0.29	0.31	0.32	0.32	0.33	0.33	0.31	0.31	0.31
Continued	2012										
NH_3-N manure management, tonnes	13										
NH_3-N synthetic fertliser, tonnes	1										
NH_3-N pasture, tonnes	5										
NH_3-N total, tonnes	20										
N_2O emission, tonnes	0.31										

Nitrogen leaching and Run-off

The amount of nitrogen lost by leaching and run-off is calculated by using the IPCC default FracLEACH at 0.3 (IPCC 1997, Table 4-24).

The N_2O emission from N-leaching and runoff more than doubled from 1990 to 2008. However, lately in 2009-2010 and 2012 total N_2O emission has decreased each year. In 2012 the N_2O emission from N-leaching and runoff amounted to 3.28 tonnes, which is 70.5 % more than in 1990.

From 1990 ton 2012 total nitrogen content in manure has decreased due to a fall in the reindeer production. However, in the same period the use of synthetic fertilisers has increased significantly causing the overall N_2O emission from N-leaching and runoff to increase.

Table 16.6.20 Emission from N-leaching and runoff 1990-2012.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
N-excretion total, tonnes N	154	155	140	122	133	143	147	161	154	138	134
N in synthetic fertiliser, tonnes	9	9	9	9	9	6	102	28	135	158	117
N_2O emission, tonnes	1.92	1.94	1.75	1.55	1.68	1.76	2.94	2.22	3.41	3.50	2.96
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
N-excretion total, tonnes N	137	132	133	140	146	141	144	141	138	142	139
N in synthetic fertiliser, tonnes	126	114	117	128	136	144	86	273	134	120	163
N_2O emission, tonnes	3.09	2.89	2.95	3.16	3.32	3.36	2.72	4.88	3.20	3.09	3.55
Continued	2012										
N-excretion total, tonnes N	138										
N in synthetic fertiliser, tonnes	141										
N_2O emission, tonnes	3.28										

Activity data

Table 16.6.21 provides an overview on activity data from 1990 to 2012 used to 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 16.6.21 Activity data - agricultural soils 1990-2012, tonnes N (cultivation of histosols = ha).

CRF – Table 4.D	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1. Direct Emissions											
Synthetic Fertiliser	8	8	8	8	8	6	100	27	134	157	116
Animal Manure Applied to Soils	53	53	47	43	47	51	53	61	53	55	54
Crop Residue	8	8	9	9	10	10	11	11	11	12	12
Cultivation of histosols	123	129	136	142	149	155	161	168	174	181	187
2. Pasture, Range and Paddock Manure	82	83	75	64	69	73	75	78	82	64	62
3. Indirect Emissions											
Atmospheric Deposition	21	21	19	17	18	19	21	22	21	20	19
Nitrogen Leaching and Run-off	49	49	45	39	43	45	75	56	87	89	75
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1. Direct Emissions											
Synthetic Fertiliser	125	113	116	127	135	142	85	271	133	119	162
Animal Manure Applied to Soils	54	50	51	54	56	56	57	56	53	55	53
Crop Residue	13	14	15	15	15	16	16	17	18	18	18
Cultivation of histosols	195	214	220	223	232	242	245	250	274	268	270
2. Pasture, Range and Paddock Manure	64	64	65	68	70	66	68	66	67	68	67
3. Indirect Emissions											
Atmospheric Deposition	19	18	19	20	21	20	21	21	19	20	20
Nitrogen Leaching and Run-off	79	74	75	80	85	85	69	124	82	79	90
Continued	2012										
1. Direct Emissions											
Synthetic Fertiliser	139										
Animal Manure Applied to Soils	53										
Crop Residue	18										
Cultivation of histosols	268										
2. Pasture, Range and Paddock Manure	67										
3. Indirect Emissions											
Atmospheric Deposition	20										
Nitrogen Leaching and Run-off	84										

Time series consistency

The N_2O emissions from agricultural soils have increased from 6.4 tonnes N_2O in 1990 to 14.5 tonnes N_2O in 2008. The more than doubled emission is a consequence of a significant increase in use of nitrogen in synthetic fertiliser. In 2012 N_2O emissions from agricultural soils decreased primarily due to a fall in the use of synthetic fertiliser.

Table 16.6.22 Emissions of N_2O from Agricultural Soils 1990–2012, tonnes N_2O.

CRF – Table 4.D	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total N_2O emission	6.4	6.4	5.9	5.2	5.7	5.9	9.1	7.2	10.5	10.5	9.1
1. Direct Emissions											
Synthetic Fertiliser	0.2	0.2	0.2	0.2	0.2	0.1	2.0	0.5	2.6	3.1	2.3
Animal Manure Applied on Soil	1.0	1.0	0.9	0.8	0.9	1.0	1.0	1.2	1.0	1.1	1.1
Crop Residue	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cultivation of Histosols	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3
2. Pasture, Range and Paddock Manure	2.6	2.6	2.4	2.0	2.2	2.3	2.4	2.5	2.6	2.0	1.9
3. Indirect Emissions											
Atmospheric Deposition	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Nitrogen Leaching and Run-off	1.9	1.9	1.8	1.5	1.7	1.8	2.9	2.2	3.4	3.5	3.0
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total N_2O emission	9.5	9.0	9.2	9.8	10.3	10.4	8.7	14.5	10.1	9.7	11.0
1. Direct Emissions											
Synthetic Fertiliser	2.4	2.2	2.3	2.5	2.6	2.8	1.7	5.3	2.6	2.3	3.2
Animal Manure Applied on Soil	1.1	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.0	1.1	1.0
Crop Residue	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4
Cultivation of Histosols	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.5
2. Pasture, Range and Paddock Manure	2.0	2.0	2.0	2.1	2.2	2.1	2.1	2.1	2.1	2.1	2.1
3. Indirect Emissions											
Atmospheric Deposition	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Nitrogen Leaching and Run-off	3.1	2.9	2.9	3.2	3.3	3.4	2.7	4.9	3.2	3.1	3.6
Continued	2012										
Total N_2O emission	10.3										
1. Direct Emissions											
Synthetic Fertiliser	2.7										
Animal Manure Applied on Soil	1.0										
Crop Residue	0.4										
Cultivation of Histosols	0.5										
2. Pasture, Range and Paddock Manure	2.1										
3. Indirect Emissions											
Atmospheric Deposition	0.3										
Nitrogen Leaching and Run-off	3.3										

16.6.6 Uncertainties

A tier 1 uncertainty assessment has been carried out in accordance with the IPCC GPG (IPCC, 2000). 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 16.6.23.

Table 16.6.23 Uncertainties for activity data and emission factors for agriculture.

Subsector	Pollutant	Activity data uncertainty	Emission factor uncertainty
4A Enteric Fermentation	CH_4	10	100
4B Manure Management	CH_4	10	100
4B Manure Management	N_2O	10	100
4D1 Direct N_2O emissions from agricultural soils	N_2O	20	50
4D2 Pasture range and paddock	N_2O	20	25
4D3 Indirect N_2O emissions from agricultural soils	N_2O	20	50

The resulting uncertainties for the individual greenhouse gases and the total uncertainty on the greenhouse gas emission are shown in Table 16.6.24.

Table 16.6.24 Uncertainties for the emission estimates.

	Uncertainty %	Trend 1990-2012 %	Trend uncertainty %
GHG	± 59	6.4	± 17
CH_4	± 98	-10.5	± 12
N_2O	± 31	46.2	± 28

16.6.7 Source specific QA/QC

The elaboration of a formal QA/QC plan is to be completed.

However, data on livestock, land-use categories, synthetic fertilisers and cultivation of histosols 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 livestock, land-use categories, synthetic 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. In other words, no information is typed manually into the CRF Reporter. Instead, all information is imported to the CRF Reporter through XML-files to ensure maximum accuracy and completeness.

16.6.8 Source specific recalculations and improvements

Table 16.6.25 shows recalculations in the agricultural sector compared with the 2013 submission. In this 2012 submission the use of synthetic fertilisers in 2011 has been changed compared to the 2013 submission. Therefore Table 16.6.25 shows a change in the recalcalculations with regard to the emissions in 2011.

Table 16.6.25 Changes in GHG emission in the agricultural sector compared with the 2013 submission.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Previous inventory, Gg CO_2 eqv.	8.8	8.9	8.0	7.0	7.7	8.2	9.4	9.4	10.1	9.5	8.8
Recalculated, Gg CO_2 eqv.	8.8	8.9	8.0	7.0	7.7	8.2	9.4	9.4	10.1	9.5	8.8
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-	-
Change in pct.	-	-	-	-	-	-	-	-	-	-	-
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Previous inventory, Gg CO_2 eqv.	9.1	8.7	8.8	9.3	9.7	9.5	9.2	10.8	9.3	9.3	8.7
Recalculated, Gg CO_2 eqv.	9.1	8.7	8.8	9.3	9.7	9.5	9.2	10.8	9.3	9.3	9.6
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-	0.9
Change in pct.	-	-	-	-	-	-	-	-	-	-	10.3
Continued	2012										
Previous inventory, Gg CO_2 eqv.	-										
Recalculated, Gg CO_2 eqv.	9.3										
Change in Gg CO_2 eqv.	-										
Change in pct.	-										

16.6.9 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.

16.6.10 References

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16.7 LULUCF (CRF sector 5)

16.7.1 Overview of LULUCF

This LULUCF chapter covers only the territory of Greenland. Greenland is part of the Danish Kingdom.

Figure 16.7.1 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, -8.6°, Kangerlussuaq, -17.0° and Ilulissat -9.6° (2007) and for July: Nuuk 7.7°, Kangerlussuaq 11.5° and Ilulissat 9.6° (2007).

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. The total population in January 2012 was 56 749 inhabitants.

Due to the cold climate and the small constant 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 1060 hectares and unimproved Grassland covering 241 000 hectares. Wetlands consist of man made water reservoirs – in total 1076 hectares. Settlements cover 5655 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 with forest established after 1990 under Article 3.3.
R:	Reforestation, areas which have temporarily been unstocked for less than 10 years - included under Article 3.4.
D:	Deforestation, areas where forests are permanently removed to allow for other land use, included under Article 3.3.
FF:	Forest remaining Forest, areas remaining forest after 1990.
FL:	Forest Land meeting the definition of forests.
CL:	Cropland.
GL:	Grassland.
SE:	Settlements.
OL:	Other land, unclassified land.
FM:	Forest Management, areas managed under Article 3.4.
CM:	Cropland Management, areas managed under Article 3.4.
GM:	Grazing land Management, areas managed under Article 3.4.

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 1.32 Gg CO_2 equivalents in 2012 equivalent to 0.2 % of the total Greenlandic emission.

The overall land use change from 1990 to 2012 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 new CRF format under IPCC categories 5A (Forestry), 5B (Cropland), 5C (Grassland), 5D (Wetlands) and 5E (Settlements) and 5F (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 16.7.1 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 2010. GL has been estimated to be a small net source in 2010 due a decrease in the improved area with grassland compared to 2009, which has decreased the amount of living biomass in GL.

Table 16.7.1 Overall emission (Gg CO_2) from the LULUCF sector in Greenland, 1990-2010.

Greenhouse gas source and sink categories	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012
5. Land Use, Land-Use Change and Forestry, CO_2	0,21	0,39	0,53	0,64	0,96	0,86	0,15	1,42	1,21	1,32
A. Forest Land	NA	-0,02	-0,03	-0,05	-0,05	-0,06	-0,03	-0,04	-0,04	-0.04
B. Cropland	IE,NA,NO	IE,NA,NO	IE,NA,NO	0,02	0,02	0,02	0,03	0,03	0,05	0.05
C. Grassland	0,21	0,41	0,56	0,66	0,98	0,89	0,16	1,43	1,20	1.32
D. Wetlands	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO
E. Settlements	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO	NA,NO
F. Other Land	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

16.7.2 Forest remaining forest (5.A.1)

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. In an attempt 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 16.7.2 and Table 16.7.2. Information about the Greenlandic Arboret can be found at:

http://ign.ku.dk/english/about/arboreta/arboretum-greenland/

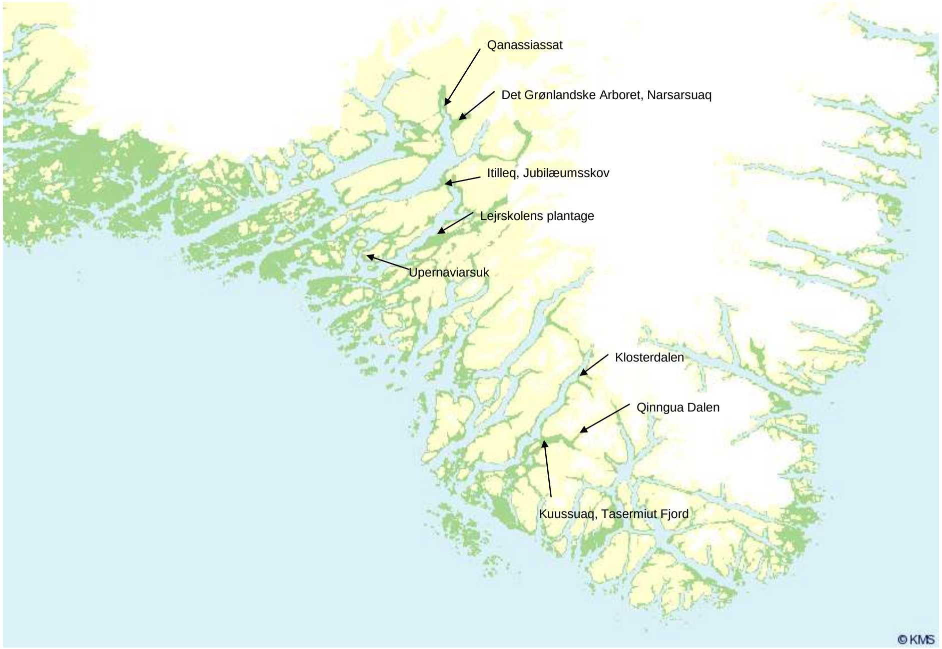

Figure 16.7.2 The position of the Greenlandic forests (Courtesy to Rasmus Enoksen Christensen).

Table 16.7.2 Forests in Greenland 1990 and 2012.

Location	Established	Dominant tree	Area,ha	1990 average tree height (m)	2012 average tree height	Density 1990 (trees pr ha)	Density 2009
Qinngua Valley	Natural	Birch and mountain ash	45	n.a	6	100	100
Qanassiassat Forest	1953-63	Conifer	1	5	11.5	1500	1000
Kuussuaq Forest	1962-64 -1982	Conifer	5	3	10.8	1300	900
Kuussuaq Forest	2008	Conifer	3	***	< 1	***	3500
Greenland Arboretum	(1976-1980)	Conifer	3	4	7	300	300
Greenland Arboretum	1980 -	Conifer	150	2	3	1500	1700
Itilleq	2004-2005	Conifer	6	***	< 1	***	3500
Upernaviarsuk	1954	Conifer	0,5	1,5	3	200	200
Lejrskolen	1999-2005	Conifer	4	***	1	***	2500
Klosterdalen	2000	Conifer	1	***	1	***	2000
Total			232.5				

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 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, 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 16.7.3 shows a picture of the best developed forest in Greenland.

Figure 16.7.3 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 (Pers. Comm. 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 16.7.4 Kuussuaq, Tasermiut fjor. Photo: Rasmus 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 16.7.2.

Table 16.7.2 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 16.7.3.

Table 16.7.3 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 16.7.3). 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 takes 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 at the moment 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.

16.7.3 Land converted to forests

Forest area

See Section 16.2.1 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation.

Forest definition

See Section 16.2.1 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 16.2.1.

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

See Section 16.2.1. For uncertainties, please se Chapter 16.7.13.

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.

16.7.4 Cropland – 5B

Cropland and cropland management – 5B1

In 1990 there were no cropland occurring in Greenland. Due to the 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 – 5B2

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 16.7.5 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 CL.

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.

Uncertainties and time series consistency

The time series are complete. For uncertainties, please see Chapter 16.7.13.

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.

16.7.5 Grassland – 5C

Grassland remaining grassland – 5C1
Grassland in Greenland is dominated by unimproved grassland where the sheep is grazing. The total area with GL has been estimated to 242 000 hectares. Of these only approximately 1 000 hectare is improved where stones have been removed combined with sowing of more high yielding species, see Figure 16.7.5.

Since 1990 the area with improved grassland has been extended from 460 hectares to 1060 hectares.

Methodological issues for grassland
Grassland is divided into improved and unmanaged Grassland.

Change in carbon stock in living biomass
As more GL becomes improved the amount of living biomass at peak is increased. To estimate the amount of living biomass in improved GL 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 1 700 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.

Uncertainties and time series consistency
The time series is complete. For uncertainties, please se Chapter 16.7.13.

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.

16.7.6 Wetlands – 5D

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 has been made yet.

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.

16.7.7 Settlements – 5E

In total there are approximately 56 000 inhabitants in Greenland with about one quarter of the population in the capital, Nuuk.

Table 7.4 Inhabitants and the area occupied with houses, hectares.

	1990	2000	2010	2012
Cities, inhabitants	44,427	45,734	47,641	48,232
Small villages, inhabitants	11,131	10,373	8,811	8,517
City area, ha	2,964	3,051	3,355	3,830
Villages, ha	1,825	1,825	1,825	1,825
Settlements, total, ha	4,789	4,876	5,1805	5,655

The cities are build on the rocky coastline where almost none vegetation occurs. As a consequence 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 by the use of NunaGIS, which is a digital internet atlas displaying maps over villages and settlements in Greenland. NunaGIS is available at www.nunagis.gl.

16.7.8 Other land

The far 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 given in 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".

16.7.9 Direct N_2O emissions from N fertilization of Forest Land and Other land use – 5(I)

Not occurring.

16.7.10 Non-CO_2 emissions from drainage of forest soils and wetlands – 5(II)

Not occurring.

16.7.11 N_2O emissions from disturbance associated with land-use conversion to cropland – 5(III)

Not occurring.

16.7.12 CO_2 emissions from agricultural lime application – 5(IV)

As part of the agricultural practice liming is taking place on acidic agricultural soils (Kenneth Høeg, personal communation). The total amount of lime consumed in 2009, based on import statistics, is 5 tonnes lime and 5 tonnes dolomite. This figure is used for the period 2009-2012.

The amount of C is calculated according to the guidelines with a 90 % purity of lime and 95 % purity for dolomite. It is assumed that all C disappear as CO_2 the same year as the lime is applied.

Planned Improvements

None.

16.7.13 Biomass burning – 5(V)

No biomass burning takes place in Greenland, and wildfires rarely occur due to the moist climate.

16.7.14 Uncertainties

A tier 1 uncertainty assessment has been carried out in accordance with the IPCC GPG (IPCC, 2000). 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 16.7.4.

Table 16.7.4 Uncertainties for activity data and emission factors for LULUCF.

Subsector	Pollutant	Activity data uncertainty	Emission factor uncertainty
5A Forest	CO_2	5	50
5B Cropland	CO_2	5	50
5C Grassland	CO_2	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 16.7.5.

Table 16.7.5 Uncertainties for the emission estimates.

		1990	2012					2012
		Emission/sink, Gg CO_2 eqv.	Emission/sink, Gg CO_2 eqv.	Activity data, %	Emission factor, %	Combined uncertainty	Total	Uncertainty 95 %, Gg CO_2 eqv.
5. LULUCF		-0,7	-1.2				50,0	
5.A Forests		-0,7	1.32				46.9	
Forests	CO_2	0	-0.04				50.2	0.620
5.B Cropland		NA	-0.04				50.2	
Cropland	CO_2	0,0	0.05	5	50	50.2	50.2	0.021
5.C.Grassland		NA	0.05				50.2	
Grassland	CO_2	-0,8	1.32	5	50	50.2	50.2	0.024
5(IV) Liming	CO_2	0.21	1.32				50.2	
	CO_2	0,0	0.004	5	50	50.2	50.2	0.661

16.7.15 References

Christensen, R.E. 2010: Information on Greenlandic forests. Not published.

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. & Tanabe, K. (eds). Published: IGES, Japan. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

Vanclay, J.K. 2009: Tree diameter, height and stocking in even-aged forests, Ann. For. Sci. 66. 702 Available online at: EDP Sciences, 2009. Available at: www.afs-journal.org DOI: 10.1051/forest/2009063.

16.8 Waste (CRF sector 6)

16.8.1 Overview of sector

The waste sector consists of the CRF source category 6.A. Solid Waste Disposal on Land, 6.B. Wastewater Handling, 6.C. Waste Incineration and 6.D. Other.

In CO_2 equivalents, the waste sector (without LULUCF) contributes with 3.5 % of the overall greenhouse gas emission (GHG) in 2012. This corresponds to an emission of 21.2 Gg CO_2 equivalents.

The Greenlandic inventory includes CH_4 emissions from solid waste disposal on land, CH_4 and N_2O from wastewater handling and CO_2, CH_4, N_2O, NO_x, CO, NMVOC and SO_2 from waste incineration. 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.

Table 16.8.1 shows the greenhouse gas emissions from the waste sector. The emissions are taken from the CRF tables and are presented as rounded figures.

Table 16.8.1 Emissions for the waste sector, Gg CO_2 equivalents.

		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
6 A. Solid Waste Disposal on Land	CH_4	3.6	3.7	3.8	3.8	3.9	3.9	4.0	4.1	4.1	4.1	4.2
6 B. Wastewater Handling	N_2O	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
6 C. Waste incineration	CO_2	2.6	2.6	2.6	2.6	2.7	2.7	2.9	3.1	3.5	3.4	3.2
6 C. Waste incineration	CH_4	2.3	2.3	2.3	2.3	2.3	2.4	2.3	2.3	2.2	2.1	1.8
6 C. Waste incineration	N_2O	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0	0.9
6. Waste total		24.4	24.5	24.6	24.7	24.9	25.1	25.3	25.5	25.8	25.6	25.0
Continued		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
6 A. Solid Waste Disposal on Land	CH_4	4.1	4.1	4.1	4.1	4.1	4.0	4.0	4.0	3.9	3.9	3.9
6 B. Wastewater Handling	N_2O	14.9	14.9	14.9	15.0	14.9	15.0	15.2	15.8	13.0	12.4	12.7
6 C. Waste incineration	CO_2	3.3	3.2	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
6 C. Waste incineration	CH_4	1.8	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
6 C. Waste incineration	N_2O	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
6. Waste total		25.1	24.9	24.7	24.5	24.5	24.5	24.6	25.2	22.4	21.9	22.1
Continued		2012										
6 A. Solid Waste Disposal on Land	CH_4	3.9										
6 B. Wastewater Handling	N_2O	11.8										
6 C. Waste incineration	CO_2	3.1										
6 C. Waste incineration	CH_4	1.6										
6 C. Waste incineration	N_2O	0.8										
6. Waste total		21.2										

The largest source of greenhouse gas emission in 2012 from the waste sector is N_2O emission from wastewater handling (56 %), more specifically from industrial effluents. Other large sources are CH_4 from solid waste disposal on land (18 %) and CO_2 from waste incineration (15 %).

The total greenhouse gas emission from the waste sector has decreased by 13.1 % from 1990 to 2012. In 2012 emissions from all sources except wastewater handling were more or less unchanged. However, N_2O from wastewater handling decreased by 6.9 %.

16.8.2 Solid waste management

Activity data for waste amounts for solid waste management are shown in Table 16.8.2.

Table 16.8.2 Waste amounts for solid waste management, tonnes.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
6 A1. Managed Waste Disposal	6 056	6 124	6 168	6 232	6 334	6 428	6 410	6 416	6 145	5 697	4 876
6 A2. Unmanaged Waste Disposal	1 362	1 359	1 358	1 360	1 341	1 289	1 217	1 160	1 060	988	910
6 C. Waste incin., energy recovery	5 519	5 578	5 618	5 733	5 918	6 072	6 178	6 275	6 398	8 200	11 279
6 C. Waste incin., without energy rec.	16 566	16 713	16 808	16 955	17 195	17 460	17 828	18 162	18 756	17 827	16 068
6. Waste total	29 503	29 775	29 952	30 280	30 788	31 249	31 633	32 014	32 360	32 712	33 132
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
6 A1. Managed Waste Disposal	4 943	4 746	4 451	4 215	4 246	4 264	4 293	4 312	4 346	4 413	4 476
6 A2. Unmanaged Waste Disposal	868	843	835	828	826	818	791	763	746	722	692
6 C. Waste incin., energy recovery	11 526	12 658	14 084	15 312	15 572	15 788	16 056	16 366	16 686	17 077	17 500
6 C. Waste incin., without energy rec.	16 285	15 874	15 220	14 700	14 790	14 836	14 823	14 778	14 837	14 955	15 028
6. Waste total	33 623	34 121	34 589	35 055	35 435	35 705	35 964	36 220	36 614	37 168	37 695
continued	2012										
6 A1. Managed Waste Disposal	4 503										
6 A2. Unmanaged Waste Disposal	658										
6 C. Waste incin., energy recovery	17 854										
6 C. Waste incin., without energy rec.	15 027										
6. Waste total	38 043										

The 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 villages, 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 villages 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 of waste on land.

Methodological issues, activity data, emission factors and emissions

In Table 16.8.3 the composition of the waste according to the survey mentioned is shown.

Table 16.8.3 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	26.40
Other combustible	17.50[1]	16.00	17.02	3.40	11.00
Glass	7.50[1]	3.00[1]	6.06	6.06	19.60
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 16.8.2 are estimated back to 1960 (not shown) based on the methodology described in connection to Table 16.8.2. Combining these activity data and the composition data in Table 16.8.3 time series for 1960-2012 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 16.8.2 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 GL and GPG for managed disposals, Table 16.8.4 and unmanaged disposal, Table 16.8.5.

Table 16.8.4 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	0.40	0.20	0.00	0.20	0.20	0.00	0.00	0.00	0.00
Emission factor kg CH_4/tonnes[1]	133.3	66.7	0.0	66.7	66.7	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 16.8.5 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	0.40	0.20	0.00	0.20	0.20	0.00	0.00	0.00	0.00
Emission factor kg CH_4/tonnes[1]	53.3	26.7	0.0	26.7	26.7	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 16.8.6 and 16.8.7 selected data and results are shown for 1990-2012 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 16.8.6 Managed disposal. AD for the FOD model (amounts of waste in fractions), the potential emission of CH_4, the oxidized CH_4 and the annual CH_4 emission for 1990-2012.

	Paper /cardboard dry	Paper /cardboard wet	Plastics	Organic waste	Other combustible	Glass	Metal	Other, non combustible	Hazardous waste	Waste total	Potential emission	Annual generated 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	446	388	6 056	232.7	174.8	17.5	157.3
1991	469	358	303	1 616	674	1 200	661	451	392	6 124	236.4	177.8	17.8	160.0
1992	472	361	305	1 627	679	1 209	666	455	395	6 168	239.0	180.7	18.1	162.6
1993	477	364	308	1 644	686	1 221	673	459	399	6 232	240.8	183.6	18.4	165.3
1994	485	370	313	1 671	697	1 241	684	467	405	6 334	243.3	186.5	18.6	167.8
1995	492	376	318	1 696	708	1 260	694	474	412	6 428	247.2	189.4	18.9	170.5
1996	491	375	317	1 691	705	1 256	692	473	410	6 410	250.9	192.4	19.2	173.2
1997	491	375	317	1 693	706	1 257	693	473	411	6 416	250.2	195.2	19.5	175.7
1998	471	359	304	1 621	676	1 204	664	453	393	6 145	250.5	197.9	19.8	178.1
1999	436	333	281	1 503	627	1 116	615	420	365	5 697	239.9	199.9	20.0	179.9
2000	373	285	241	1 286	537	955	527	359	312	4 876	222.4	201.0	20.1	180.9
2001	378	289	244	1 304	544	969	534	364	316	4 943	190.3	200.5	20.0	180.4
2002	363	277	234	1 252	522	930	513	350	304	4 746	193.0	200.1	20.0	180.1
2003	341	260	220	1 174	490	872	481	328	285	4 451	185.3	199.4	19.9	179.4
2004	323	246	208	1 112	464	826	455	311	270	4 215	173.7	198.1	19.8	178.3
2005	325	248	210	1 120	467	832	459	313	272	4 246	164.5	196.5	19.7	176.9
2006	326	249	211	1 125	469	836	460	314	273	4 264	165.7	195.0	19.5	175.5
2007	329	251	212	1 133	473	841	464	316	275	4 293	166.4	193.6	19.4	174.3
2008	330	252	213	1 138	475	845	466	318	276	4 312	167.6	192.4	19.2	173.2
2009	333	254	215	1 147	478	852	469	320	278	4 346	168.3	191.2	19.1	172.1
2010	338	258	218	1 164	486	865	477	325	283	4 413	169.6	190.2	19.0	171.2
2011	343	262	221	1 181	493	877	483	330	287	4 476	172.3	189.3	18.9	170.4
2012	345	263	222	1 188	496	882	486	332	288	4 503	174.7	188.6	18.9	169.8

Table 16.8.7 Unmanaged disposal. AD for the FOD model (amounts of waste in fractions), the potential emission of CH_4, the oxidized CH_4 and the annual CH_4 emission for 1990-2012.

	Paper /cardboard dry	Paper /cardboard wet	Plastics	Organic waste	Other combustible	Glass	Metal	Other, non combustible	Hazardous waste	Waste total	Potential emission	Annual generated 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	1 362	21	15.8	0.0	15.8
1991	104	79	67	359	150	266	147	100	87	1 359	21	16.1	0.0	16.1
1992	104	79	67	358	149	266	147	100	87	1 358	21	16.3	0.0	16.3
1993	104	79	67	359	150	266	147	100	87	1 360	21	16.6	0.0	16.6
1994	103	78	66	354	148	263	145	99	86	1 341	21	16.8	0.0	16.8
1995	99	75	64	340	142	253	139	95	83	1 289	21	17.0	0.0	17.0
1996	93	71	60	321	134	238	131	90	78	1 217	20	17.1	0.0	17.1
1997	89	68	57	306	128	227	125	86	74	1 160	19	17.2	0.0	17.2
1998	81	62	52	280	117	208	115	78	68	1 060	18	17.3	0.0	17.3
1999	76	58	49	261	109	194	107	73	63	988	17	17.2	0.0	17.2
2000	70	53	45	240	100	178	98	67	58	910	15	17.2	0.0	17.2
2001	66	51	43	229	96	170	94	64	56	868	14	17.0	0.0	17.0
2002	65	49	42	222	93	165	91	62	54	843	14	16.8	0.0	16.8
2003	64	49	41	220	92	164	90	62	53	835	13	16.7	0.0	16.7
2004	63	48	41	218	91	162	89	61	53	828	13	16.5	0.0	16.5
2005	63	48	41	218	91	162	89	61	53	826	13	16.3	0.0	16.3
2006	63	48	40	216	90	160	88	60	52	818	13	16.2	0.0	16.2
2007	61	46	39	209	87	155	85	58	51	791	13	16.0	0.0	16.0
2008	58	45	38	201	84	150	82	56	49	763	12	15.8	0.0	15.8
2009	57	44	37	197	82	146	81	55	48	746	12	15.6	0.0	15.6
2010	55	42	36	191	80	142	78	53	46	722	12	15.4	0.0	15.4
2011	53	40	34	183	76	136	75	51	44	692	11	15.2	0.0	15.2
2012	50	38	32	174	72	129	71	48	42	658	11	15.0	0.0	15.0

16.8.3 Wastewater handling

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, 1997) the important factors for CH_4 production from handling of wastewater are: wastewater characteristics, 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 (IPCC, 1997). Temperatures in Greenland rarely exceed 15˚C, and the monthly average temperature has not exceeded 12˚C during the period 1993-2011. 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.

The formula used for calculation of the emission from effluent WWTP discharges is:

$$E_{effluents} = P \cdot F_N \cdot N_{pop} \cdot F_{nc} \cdot F \cdot EF \cdot effluent \cdot \frac{M_{N_2O}}{M_{N_2}}$$

where *P* is the annual protein per capita consumption per person per year set constant to 171.5 g/day (see below text).

F_N is the fraction of nitrogen in protein, i.e. 0.16 (IPCC, 1997).

N_{pop} is the Greenlandic population (source: Statistics Greenland).

F_{nc} is the fraction of the population not connected to the municipal sewer system, i.e. set to 1 as no wastewater treatment plants exists in Greenland at this point.

F is the fraction of non-consumption protein in domestic wastewater. i.e. 1.1 (IPCC, 2006).

$EFN_2O.WWTP.effluent$ is the IPCC GL default emission factor of 0.01 kg N_2O-N/kg sewage-N produced (IPCC, 1996)[1].

MN_2O and MN_2 are the mass ratio. i.e. 44/28 to convert the discharged units in mass of total N to emissions in mass N_2O.

[1] The IPCC (2006) gives a default value for the N_2O emissions from domestic wastewater nitrogen effluent of 0.005 (0.0005 - 0.25) kg N_2O-N/kg N. However, the IPCC EF from the 1996 guidelines has been 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 tons 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, 1996). The IPCC reports a range of 0.3 to 3.1 kg total N/ton 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 2011 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 handling is shown in Table 16.8.8.

Table 16.8.8 N_2O emissions from households and industries 1990-2012.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
N_2O emission, effluents households, Gg	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
N_2O emission, effluents industries, Gg	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038
N_2O emission, effluents sum, Gg	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
N_2O emission, effluents households, Gg	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
N_2O emission, effluents industries, Gg	0.038	0.038	0.038	0.038	0.038	0.039	0.039	0.041	0.032	0.030	0.031
N_2O emission, effluents sum, Gg	0.048	0.048	0.048	0.048	0.048	0.049	0.049	0.051	0.042	0.040	0.041
Continued	2012										
N_2O emission, effluents households, Gg	0.010										
N_2O emission, effluents industries, Gg	0.028										
N_2O emission, effluents sum, Gg	0.038										

Total emission of N_2O increased until 2008 due to an increase in the emission from industrial effluents. However, in 2009-2012 total emission of N_2O decreased to a total level of 0.038-0.042 Gg (which is lower than 1990) due to a temporarily decrease in industrial effluents primaryly caused by a decrease in the catches of shrimps.

16.8.4 Waste incineration

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 6.C. Waste Incineration. Additionally in Greenland open burning of waste occurs at landfill sites. Emissions associated with this are also reported under sector 6.C. Waste Incineration.

Methodological issues

The methodology used follows the IPCC Guidelines. For waste incineration the Danish emission factors are used, as it is trusted that they are also a good representation of Greenlandic conditions.

Neither the revised 1996 IPCC Guidelines (IPCC, 1997) nor the Good Practice Guidance (IPCC, 2000) contains a methodology for estimating emissions from open burning, therefore the methodology provided in the 2006 IPCC Guidelines (IPCC, 2006) is used.

The emission factors used for both waste incineration and open burning are included in Section 16.8.4.4.

Activity data

The amount of waste incinerated without energy recovery is presented in Table 16.8.9. The activity data is provided by the method described in Section 16.8.2.

Table 16.8.9 Activity data for waste incineration without energy recovery, Mg.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Waste incinerated without energy recovery, Mg	NO	NO	NO	NO	56	225	795	1 240	2 663	2 896	3 148
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Waste incinerated without energy recovery, Mg	3 306	3 391	3 415	3 437	3 461	3 485	3 468	3 444	3 466	3 486	3 488
continued	2012										
Waste incinerated without energy recovery, Mg	3 501										

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 8.10. The activity data for open burning is provided by the method described in Section 16.8.2.

Table 16.8.10 Activity data for open burning of waste, Mg.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Open burning of waste, Mg	16 566	16 713	16 808	16 955	17 140	17 235	17 033	16 922	16 093	14 930	12 920
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Open burning of waste, Mg	12 979	12 483	11 804	11 263	11 329	11 350	11 355	11 335	11 371	11 470	11 540
continued	2012										
Open burning of waste, Mg	11 526										

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 Danish emission factors (Nielsen et al., 2010). The greenhouse gas emission factors are shown in Table 16.8.11.

Table 16.8.11 Emission factors for greenhouse gases from waste incineration.

	Emission factor	Unit
CO_2	32.5	Kg pr GJ
CH_4	30	g pr GJ
N_2O	4	g pr GJ

The emission factors used for the indirect greenhouse gases are shown in Table 16.8.12.

Table 16.8.12 Emission factors for indirect greenhouse gases from waste incineration.

	NO_x	SO_2	NMVOC	CO	Unit
Waste incineration	100	6	50	1 000	g pr GJ

Open burning

For open burning emissions are calculated using the methodology, standard parameters and emission factors provided by the 2006 IPCC Guidelines.

The CH_4 emission factor used is the recommended and default is 6,500 g per tonne MSW wet weight. This factor refers to US EPA (2001).

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 16.8.13.

Table 16.8.13 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	0,9	46	1
Cardboard	0,9	46	1
Plastics	1,0	75	100
Organic waste	0,4	38	0
Other	0,9	3	100

Source: 2006 IPCC Guidelines, 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 16.8.14. The emission factors are from the US EPA (1992).

Table 16.8.14 Emission factors for indirect greenhouse gases from open burning of waste.

	NO_x	SO_2	NMVOC	CO	Unit
Open burning of municipal refuse	3	0.5	15	42	Kg pr Mg

Emissions

Total emission of greenhouse gases from sector 6.C. Waste Incineration is shown in Table 16.8.15. Figure 16.8.2 shows total emission of greenhouse gases from sector 6.C. Waste incineration is shown in Figure 16.8.1.

Table 16.8.15 Greenhouse gas emissions from waste incineration.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
CO_2, Gg	2.6	2.6	2.6	2.6	2.7	2.7	2.9	3.1	3.5	3.4	3.2
CH_4, Mg	107.7	108.6	109.2	110.2	111.4	112.1	111.0	110.4	105.4	98.0	85.0
N_2O, Mg	3.5	3.6	3.6	3.6	3.7	3.7	3.7	3.7	3.6	3.3	2.9
CO_2 eqv., Gg	5.9	6.0	6.0	6.0	6.1	6.2	6.4	6.5	6.8	6.5	5.9
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
CO_2, Gg	3.3	3.2	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
CH_4, Mg	85.4	82.2	77.8	74.3	74.7	74.9	74.9	74.8	75.0	75.7	76.1
N_2O, Mg	2.9	2.8	2.7	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
CO_2 eqv., Gg	6.0	5.8	5.6	5.4	5.5	5.5	5.5	5.4	5.5	5.5	5.5
Continued	2012										
CO_2, Gg	3.1										
CH_4, Mg	76.0										
N_2O, Mg	2.6										
CO_2 eqv., Gg	5.5										

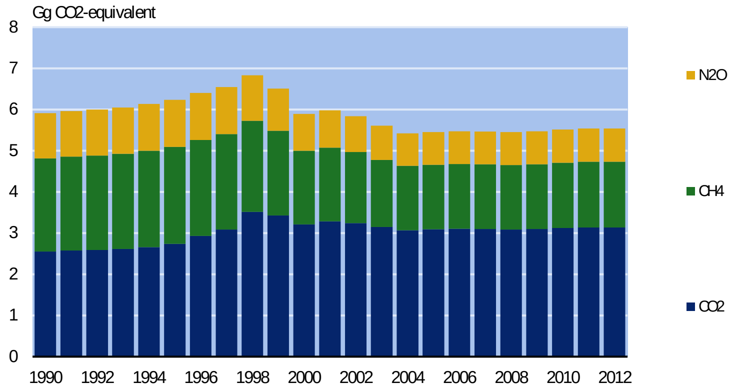

Figure 16.8.1 Emission of greenhouse gases from waste incineration.

The emissions of indirect greenhouse gases from waste incineration are shown in Table 16.8.16.

Table 16.8.16 Emissions of indirect greenhouse gases from waste incineration, Mg.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
NO_x	49.7	50.1	50.4	50.9	51.5	51.9	51.9	52.1	51.1	47.8	42.1
SO_2	8.3	8.4	8.4	8.5	8.6	8.6	8.6	8.5	8.2	7.6	6.6
NMVOC	248.5	250.7	252.1	254.3	257.1	258.6	255.9	254.5	242.8	225.5	195.5
CO	695.8	701.9	705.9	712.1	720.4	726.1	723.7	723.7	703.9	657.5	575.7
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
NO_x	42.4	41.0	39.0	37.4	37.6	37.7	37.7	37.6	37.8	38.1	38.3
SO_2	6.7	6.4	6.1	5.8	5.9	5.9	5.9	5.9	5.9	5.9	6.0
NMVOC	196.4	189.0	178.9	170.7	171.7	172.1	172.1	171.8	172.4	173.9	174.9
CO	579.8	559.9	531.6	509.1	512.1	513.3	513.3	512.2	514.0	518.3	521.3
Continued	2012										
NO_x	38.3										
SO_2	6.0										
NMVOC	174.7										
CO	520.9										

16.8.5 Uncertainties

A tier 1 uncertainty assessment has been carried out in accordance with the IPCC GPG (IPCC, 2000). 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 16.8.17.

Table 16.8.17 Uncertainties for activity data and emission factors for the waste sector.

Subsector	Pollutant	Activity data uncertainty	Emission factor uncertainty
6C Waste incineration	CO_2	10	25
6A Solid Waste Disposal on Land	CH_4	10	100
6C Waste incineration	CH_4	10	50
6B Wastewater Handling	N_2O	30	100
6C Waste incineration	N_2O	10	100

The amount of waste incinerated and burned is relatively well known and the uncertainty is set to 10 %. The same is the case for the waste deposited to landfills. For waste water 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 GPG. 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 16.8.18.

Table 16.8.18 Uncertainties for the emission estimates.

	Uncertainty %	Trend 1990-2012 %	Trend uncertainty %
GHG	± 61	-13.1	± 21.5
CO_2	± 27	22.9	± 17.4
CH_4	± 73	-6.8	± 14.0
N_2O	± 98	-21.1	± 31.3

16.8.6 Source specific QA/QC

The elaboration of a formal QA/QC plan is to be completed.

However, data on solid waste disposal, waste water 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, waste water 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. In other words, no information is typed manually into the CRF Reporter. Instead, all information is imported to the CRF Reporter through XML-files to ensure maximum accuracy and completeness.

16.8.7 Source specific recalculations and improvements

The sector *Waste Water Handling* (6B) was included in the inventory for the first time in the 2010 emission inventory submission. No improvements have been carried out regarding waste water handling in the 2014 submission.

Table 16.8.19 shows recalculations in the waste sector compared to the 2013 submission. No changes occurs.

Table 16.8.19 Changes in GHG emission in the waste sector compared with the 2013 submission.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Previous inventory, Gg CO_2 eqv.	24.4	24.5	24.6	24.7	24.9	25.1	25.3	25.5	25.8	25.6	25.0
Recalculated, Gg CO_2 eqv.	24.4	24.5	24.6	24.7	24.9	25.1	25.3	25.5	25.8	25.6	25.0
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-	-
Change in pct.	-	-	-	-	-	-	-	-	-	-	-
continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Previous inventory, Gg CO_2 eqv.	25.1	24.9	24.7	24.5	24.5	24.5	24.6	25.2	22.4	21.9	22.1
Recalculated, Gg CO_2 eqv.	25.1	24.9	24.7	24.5	24.5	24.5	24.6	25.2	22.4	21.9	22.1
Change in Gg CO_2 eqv.	-	-	-	-	-	-	-	-	-	-	-
Change in pct.	-	-	-	-	-	-	-	-	-	-	-
continued	2012										
Previous inventory, Gg CO_2 eqv.	-										
Recalculated, Gg CO_2 eqv.	21.2										
Change in Gg CO_2 eqv.	-										
Change in pct.	-										

16.8.8 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 waste water handling

In future inventories attempts will be made in order to improve data on waste water handling in general. However, at the moment the municipal technical departments seem to have no data on waste water handling at all.

16.8.9 References

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16.9 Other

In CRF Sector 7, there are no activities and emissions or removals for the inventory of Greenland.

16.10 Recalculations and improvements

The 2014 submission is the fifth year where Greenland on the request of the ERT submits a full CRF.

For recalculations and improvements please refer to Sections 16.3 - 16.8 and Section 16.11.

16.11 KP-LULUCF

16.11.1 General information

In the following text, the abbreviations used are in accordance with definitions in the IPCC guidelines:

A:	Afforestation
R:	Reforestation
D:	Deforestation
FF:	Forest remaining Forest, areas remaining forest after 1990
FL:	Forest Land meeting the Danish definition of forests
CL:	Cropland
GL:	Grassland
SE:	Settlements
OL:	Other land, unclassified land
FM:	Forest Management, areas managed under article 3.4

CM: Cropland Management, areas managed under article 3.4
GM: Grazing land Management, areas managed under article 3.4

Definition of forest and any other criteria

For the estimation of anthropogenic emissions by sources and removals by sinks associated with afforestation (A), reforestation (R) and deforestation (D) since 1990 under Article 3.3 and forest management (FM) under Article 3.4 of the Kyoto Protocol, the following forest definition will be applied:

- Minimum values for tree crown cover: 10 % tree crown cover for forests.
- Minimum values for land area: 0.5 ha.
- Minimum value for tree height: trees must be able to reach a minimum height of 5 m in the site.

In addition, the forest area includes temporarily unstocked areas, smaller open areas in the forest needed for management purposes and fire breaks. Forests in national parks, reserves or areas under special protection are included. Windbreaks and groves covering more than 0.5 ha and with a minimum width of 20 m are also considered as forests.

Woody biomass does not exist outside the forest and hence not reported under Cropland and Grassland.

Elected activities under Article 3, paragraph 4, of the Kyoto Protocol

As regards the possibility of including in the first commitment period emissions and removals associated with land use, land-use change and forestry activities under Article 3.4 of the Kyoto Protocol, it has been decided to include emissions and removals from forest management (FM), cropland management (CM) and grazing land management (GM).

The national system has identified land areas associated with the activities under Article 3.4 of the Kyoto Protocol in accordance with definitions, modalities, rules and guidelines relating to land use, land-use change and forestry activities under the protocol by Land Parcel Information System (LPIS), detailed crop information data on field level, soil mapping and forest maps.

Inventories of emissions and removals under Article 3.3 and Article 3.4 are prepared and reported annually together with the other greenhouse gas inventory information.

Description of how the definitions of each activity under Article 3.3 and each elected activity under Article 3.4 have been implemented and applied consistently over time

The definition of afforestation, reforestation and deforestation is in accordance with the GPG (IPCC 2003).

Afforestation or reforestation is identified when areas have wooded treecover and fulfils the forest definition given above. The time of the AF is given by the time of action, i.e. planting of trees. No deforestation and reforestation is reported for Greenland as this is not occurring. All types of establishment of forest (AF or RF) are considered human induced.

As no reforestation has taken place Table 5(KP-I)A.1.2 “Units of land harvested since the beginning of the commitment period” is filled in as included elsewhere although it is not occurring.

As for the forest management (Article 3.4), the forest areas fulfilling the definition given above are included under this activity. All forest areas are considered managed except for the remote Qinngua-valley.

For Cropland and Grassland the area accounted for under Art. 3.4 has been estimated with the best knowledge from the Greenlandic Agricultural Consulting Services. As the agriculture in Greenland is economically subsidized the area is estimated with a high accuracy. Only areas that are reported as CL and GL are included in the accounted area.

Description of precedence conditions and/or hierarchy among article 3.4 activities and how they have been consistently applied in determining how land was classified

All Forest activities have precedence, after this Cropland activities and then Grassland activities.

Afforestation has precedence. All land converted to forest are included as afforested area. Deforestated areas are not reported as this is not occurring. The following categories in the Convention reporting are included under afforestation:

- 5A25 OL to A

FM activities are only related to:

- 5A1 Forest remaining Forest

CM activities are related to:

- 5B22 GL to CL

GM activities area related to:

- 5C1 GL remaining GL

No elected land has left land that is not accounted for. Land conversion between elected activities (FM, CM and GM) has been allowed but is currently not occurring. No land elected under article 3.4 activities has been converted to Other Land. Other land converted to elected activities is included in the respective category. As a consequence there has been a steady increase in the land which is accounted for under article 3.3 and 3.4 with 111 hectares from 1990 to 2011.

The Land Use matrix developed for the purpose of reporting article 3.3 and 3.4 activities for 2008 are shown in Table 16.11.1.

Table 16.11.1 Land Use matrix for art. 3.3 and 3.4 activities in 2012.

From previous inventory year \ To current inventory		Article 3.3 activities		Article 3.4 activities				Other (5)	Total area at the beginning of the current inventory year(6)
		Afforestation and Reforestation	Deforestation	Forest Management (if elected)	Cropland Management (if elected)	Grazing Land Management (if elected)	Revegetation (if elected)		
		(kha)							
Article 3.3 activities	Afforestation and Reforestation	0.01	NO						0.01
	Deforestation		NA						NA
Article 3.4 activities	Forest Management (if elected)		NO	0.20					0.20
	Cropland Management(4) (if elected)	NO	NO		0.01	NO	NA		0.01
	Grazing Land Management(4) (if elected)	NO	NO		0.00	241.99	NA		241.99
	Revegetation(4) (if elected)	NA			NA	NA	NA		NA
Other (5)		NO	NO	NO	NO	NO	NA	216,366.38	216,366.38
Total area at the end of the current inventory year		0.01	NA,NO	0.20	0.01	241.99	NA	216,366.38	216,608.60

16.11.2 Spatial assessment unit used for determining the areas of the units of land under Article 3.3

Afforestation and reforestation are identified as areas which not were covered by forest in 1990. The increase in the forest area is planted.

Methodology used to develop the land transition matrix

The land use matrix is based on the best available data. No vector maps exist of the individual forests, cropland and grassland.

Maps and/or database to identify the geographical locations, and the system of identification codes for the geographical locations

The forests have been given individual names. For the Cropland and Grassland area no identification has been made.

16.11.3 Afforestation, Reforestation & Deforestation (ARD)

Methods for carbon stock change and GHG emission and removal estimates

For afforestation the carbon stock change in the period 1990 - 2012 is based both on the area of afforestation and the information on species composition.

In the afforestation a steady increase in carbon stock is found.

Description of the methodologies and the underlying assumptions used

See Chapter 16.7.

Justification when omitting any carbon pool or GHG emissions/removals from ARD

C stock changes in the soil is not expected due to the cold climate to occur and hence following the guidelines for a Tier 1 approach. As the afforestation is made by hand planting no damages of the existing soil C is expected to take place.

Information on whether or not indirect and natural GHG emissions and removals have been factored out

No factoring out has been performed in the emission and removal estimates.

Changes in data and methods since the previous submission (recalculations)

No recalculation has been performed.

Uncertainty estimates

Uncertainty estimates are given in Table 16.11.2.

Table 16.11.2 Uncertain estimates for 1990 and 2012 for the KP sector.

	1990			2012		
	Emission, Gg CO_2 yr-1	**Total uncertainty, %**	**Uncertainty 95 %, Gg CO_2 eqv.**	**Emission, Gg CO_2 yr-1**	**Total uncertainty, %**	**Uncertainty 95 %, Gg CO_2 eqv.**
KP total	**0.179**	**55.1**	**0.1**	**1.322**	**78.3**	**1.035**
A. Article 3.3 activities	IE,NA,NO,NR	-	-	IE,NA,NO,NR	-	-
B. Article 3.4 activities	0.179	57.8	0.1	1.322	78.6	1.038
KP A.1.1 Afforestation and Reforestation						
Area subject to the activity	NO	-	-	0.014	-	0.000
Area of organic soils(8)	NO	-	-	0.001	-	-
Net CO_2 emissions/ removals (9)	NO	-	-	IE,NO,NR	-	-
KP A.2 Deforestation						
Area subject to the activity	NO			NO		
Area of organic soils	NO			NO		
Net CO_2 emissions/ removals	NO			NO		
KP B.1 Forest Management						
Area subject to the activity	-	-	-	0.205		
Area of organic soils(8)	-	-	-	0.025		
Net CO_2 emissions/ removals (9)	-	-	-	-0.042	36.0	0.0
KP B.2 Cropland Management						
Area subject to the activity	NO	-	-	0.011		
Area of organic soils(8)	NO	-	-	0.003		
Net CO_2 emissions/ removals (9)	IE,NA	-	-	0.048	90.6	0.0
KP B.3 Grassland Management						
Area subject to the activity	242.0			242.0		
Area of organic soils(8)	7.368			7.493		
Net CO_2 emissions/ removals (9)	0.171	57.8	0.1	1.312	83.9	1.1
KP-II 4 Lime consumption						
Total amount of lime applied	18.5			9.3		
Emission	0.008	50.2	0.0	0.004	50.2	0.0
Carbon	0.008	50.2	0.0	0.000	0.0	0.0

Information on other methodological issues
See Chapter 16.7.

The year of the onset of an activity, if after 2008
Not applicable.

16.11.4 Forest Management (FM)

Methods for carbon stock change and GHG emission and removal estimates
See Chapter 16.7 in LULUCF on "Forest remaining forest (5.A.1)".

Methodologies and the underlying assumptions
See Chapter 16.7 in LULUCF on "Forest remaining forest (5.A.1)".

Omission of pools from FM
C changes in forest soils are omitted and hereby following GPG 2003 guidelines at a Tier 1 level.

Factoring out
No factoring out has been performed.

Recalculations
No recalculation has been performed.

Uncertainty estimates
See Table 16.11.2

Information on other methodological issues
See Chapter 16.7 in LULUCF on "Forest remaining forest (5.A.1)".

The year of the onset of an activity, if after 2008
Not applicable.

16.11.5 Cropland Management (CM)

Methods for carbon stock change and GHG emission and removal estimates
Methodologies and the underlying assumptions used

The area with agricultural Cropland is reported as the area given in Statistics Greenland.

The same methodology as used in the Convention reporting is used in the KP reporting.

Omission of pool from CM
Aboveground and belowground living biomass, litter and dead organic are only reported for perennial woody crops in accordance with IPCC GPG 2003. No litter and dead organic matter are reported under Cropland as these are not occurring. Therefore only aboveground living biomasses are reported under Cropland. Below-ground biomass is included in aboveground biomass.

Factoring out
No factoring out has been made.

Recalculations
None.

Uncertainty estimates
See Table 16.11.2.

Information on other methodological issues
None.

The year of the onset of an activity, if after 2008
Not applicable.

16.11.6 Grazing land management (GM)

Methods for carbon stock change and GHG emission and removal estimates
Grazing land is defined as land improved grassland and unmanaged grassland.

Description of the methodologies and the underlying assumptions used
The major part of the grassland is unmanaged (241 000 hectare). Only 1 060 hectares is improved grassland with occasional reseeding and fertiliser application. The methodology used is the default Tier 1. This is in accordance with IPCC GPG 2003 (3.4.1.2.1.2) as the total emission from LULUCF consists of less than 0.12 % of the total emission from Greenland.

Omission of pools from GM
Aboveground and belowground living biomass, litter and dead organic are only reported for perennial woody crops in accordance with IPCC GPG 2003. No litter and dead organic matter are reported under Cropland as these are not occurring. Therefore only aboveground living biomasses are reported under Cropland. Below-ground biomass is included in aboveground biomass.

Factoring out
No factoring out has been made.

Recalculations
No recalculation has been performed.

Uncertainty estimates
See Table 16.11.2.

Information on other methodological issues
None.

The year of the onset of an activity, if after 2008
Not applicable.

16.11.7 Article 3.3

Information that demonstrates that activities under Article 3.3 began on or after 1 January 1990 and before 31 December 2012 and are direct human-induced
All forests in Greenland are planted except for the Qinngua valley, which is in a remote area.

Information on how harvesting or forest disturbance that is followed by the re-establishment of forest is distinguished from deforestation
No deforestation is occurring and therefore not applicable.

Information on the size and geographical location of forest areas that have lost forest cover but which are not yet classified as deforested
Not applicable.

16.11.8 Article 3.4

Information that demonstrates that activities under Article 3.4 have occurred since 1 January 1990 and are human-induced

Forest Management
In Forest Management all forest areas are under management and changes in carbon stock are hence seen as human induced.

Cropland Management
Due to the cold climate and the recent increase in temperature it has only very recently been possible to grow agricultural crops in Greenland with the first fields established around 2001. Today it is estimated that 10.5 hectares are regularly ploughed.

Grassland Management
Due to the cold climate in Greenland and the recent increase in temperature it has only recently been valuable to introduce management activities in the grassland to increase the crop yield. This is well documented in the Greenlandic subsidiary system to the farmers.

Information relating to Cropland Management, Grazing Land Management and Revegetation, if elected, for the base year
No further information is available.

Information relating to Forest Management
No further information is available.

16.11.9 Other information

Key category analysis for Article 3.3 activities and any elected activities under Article 3.4
According to the IPCC Good Practice Guidance for LULUCF a category that is identified as key in the UNFCCC inventory should also be considered key under the Kyoto Protocol (IPCC, 2003).

No LULUCF categories are reported as a key source. The total emission from the LULUCF sector is less than 0.2 % of the total emission from Greenland.

16.11.10 Information relating to Article 6

There are no Article 6 projects (Joint Implementation) on the Greenlandic territory.

16.12 Annex 1 Key categories

A Key Category Analysis (KCA) for year 1990 and 2012 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 2012

The entries in the results of KCA in Tables 16.12.1 to 16.12.3 for the years 1990 and 2012 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 2012, but are only included in Table 16.12.2 to make it more uniform with Tables 16.12.1 and 16.12.3.

The result of the Tier 1 KCA level assessment for Greenland for 1990 is shown in Table 16.12.1. For the assessment, 5 categories were identified as key categories and marked as shaded, refer Table 16.12.1.

The result of the Tier 1 KCA level assessment for Greenland for 2011 is shown in Table 16.12.2. For the assessment, 6 categories were identified as key categories, refer Table 16.12.2.

The result of the Tier 1 KCA trend assessment for Greenland for 1990/1995-2012 is shown in Table 16.12.3. For the trend assessment, 9 categories were identified as key categories, refer Table 16.12.3. 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. The LULUCF activities are in the table included with their sign, i.e. emissions: +, removals: -.

In Table 16.12.4 a summary of Key Category Analysis for Greenland is given for level assessment for year 1990/95 and 2012 and for trend for years 1990-2012. All the categories are listed by sector and key sources are shown with their ranking.

Table 16.12.1 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	517.812	0.795	0.795
Energy	Civil aviation		CO_2	38.321	0.059	0.854
Energy	Road transportation		CO_2	36.058	0.055	0.909
Energy	Domestic navigation		CO_2	20.732	0.032	0.941
Waste	Wastewater handling		N_2O	14.884	0.023	0.964
Agriculture	Enteric fermentation		CH_4	6.018	0.009	0.973
Waste	Solid waste disposal on land		CH_4	3.636	0.006	0.979
Waste	Waste incineration		CO_2	2.550	0.004	0.983
Waste	Waste incineration		CH_4	2.261	0.003	0.986
Energy	Combustion excluding transport	Other fuels	CO_2	1.674	0.003	0.989
Energy	Combustion excluding transport		N_2O	1.392	0.002	0.991
Agriculture	Direct emissions from agricultural soils		N_2O	1.281	0.002	0.993
Waste	Waste incineration		N_2O	1.099	0.002	0.995
Energy	Combustion excluding transport		CH_4	0.950	0.001	0.996
Agriculture	Indirect emissions from agricultural soils		N_2O	0.697	0.001	0.997
Agriculture	Manure management		N_2O	0.641	0.001	0.998
Energy	Civil aviation		N_2O	0.336	0.001	0.999
Solvents and other product use	Solvents		CO_2	0.263	0.000	0.999
LULUCF	Grassland remaining grassland		CO_2	0.214	0.000	0.999
Agriculture	Manure management		CH_4	0.140	0.000	1.000
Energy	Road transportation		N_2O	0.093	0.000	1.000
Energy	Road transportation		CH_4	0.064	0.000	1.000
Energy	Domestic navigation		N_2O	0.053	0.000	1.000
Industry	Consumption of SF_6		SF_6	0.036	0.000	1.000
Energy	Domestic navigation		CH_4	0.030	0.000	1.000
Industry	Consumption of HFC's		HFCs	0.025	0.000	1.000
Energy	Civil aviation		CH_4	0.006	0.000	1.000
Industry	Road Paving with asphalt		CO_2	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		CO_2	0.000	0.000	1.000
LULUCF	Conversion to cropland		CO_2	0.000	0.000	1.000
Total				651.268	1.000	

Table 16.12.2 Key Category Analysis year 2012, 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 2012 Estimate Ex,t Gg CO_2-eqv	Year 2012 Level Assessment Lx,t	Year 2012 Cumulative total of Col. E
Energy	Combustion excluding transport	Liquid fuels	CO_2	517.812	452.736	0.740	0.740
Energy	Civil aviation		CO_2	38.321	46.669	0.076	0.816
Energy	Road transportation		CO_2	36.058	33.231	0.054	0.871
Energy	Domestic navigation		CO_2	20.732	29.741	0.049	0.919
Waste	Wastewater handling		N_2O	14.884	11.793	0.019	0.939
Industry	Consumption of HFC's		HFCs	0.025	7.185	0.012	0.950
Energy	Combustion excluding transport	Other fuels	CO_2	1.674	6.936	0.011	0.962
Agriculture	Enteric fermentation		CH_4	6.018	5.386	0.009	0.970
Waste	Solid waste disposal on land		CH_4	3.636	3.898	0.006	0.977
Waste	Waste incineration		CO_2	2.550	3.135	0.005	0.982
Agriculture	Direct emissions from agricultural soils		N_2O	1.281	2.069	0.003	0.985
Waste	Waste incineration		CH_4	2.261	1.597	0.003	0.988
Energy	Combustion excluding transport		N_2O	1.392	1.401	0.002	0.990
LULUCF	Grassland remaining grassland		CO_2	0.214	1.316	0.002	0.992
Agriculture	Indirect emissions from agricultural soils		N_2O	0.697	1.113	0.002	0.994
Energy	Combustion excluding transport		CH_4	0.950	0.928	0.002	0.996
Waste	Waste incineration		N_2O	1.099	0.810	0.001	0.997
Agriculture	Manure management		N_2O	0.641	0.646	0.001	0.998
Energy	Civil aviation		N_2O	0.336	0.409	0.001	0.999
Solvents and other product use	Solvents		CO_2	0.263	0.230	0.000	0.999
Agriculture	Manure management		CH_4	0.140	0.126	0.000	0.999
Energy	Road transportation		CH_4	0.064	0.104	0.000	0.999
Energy	Road transportation		N_2O	0.093	0.087	0.000	1.000
Energy	Domestic navigation		N_2O	0.053	0.077	0.000	1.000
LULUCF	Conversion to cropland		CO_2	0.000	0.048	0.000	1.000
Energy	Domestic navigation		CH_4	0.030	0.043	0.000	1.000
LULUCF	Forest land remaining forest		CO_2	0.000	-0.042	0.000	1.000
Industry	Limestone and dolomite use		CO_2	0.000	0.020	0.000	1.000
Energy	Civil aviation		CH_4	0.006	0.007	0.000	1.000
Industry	Consumption of SF_6		SF_6	0.036	0.003	0.000	1.000
Industry	Asphalt roofing		CO_2	0.000	0.000	0.000	1.000
Industry	Road Paving with asphalt		CO_2	0.000	0.000	0.000	1.000
Total				651.268	611.702	1.000	

Table 16.12.3 Key Category Analysis years 1990/1995-2012, 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 2012 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	517.812	452.736	0.052	0.448	0.448
Energy	Civil aviation		CO_2	38.321	46.669	0.016	0.142	0.590
Energy	Domestic navigation		CO_2	20.732	29.741	0.016	0.137	0.726
Industry	Consumption of HFC's		HFCs	0.025	7.185	0.011	0.095	0.822
Energy	Combustion excluding transport	Other fuels	CO_2	1.674	6.936	0.008	0.071	0.893
Waste	Wastewater handling		N_2O	14.884	11.793	0.003	0.029	0.922
LULUCF	Grassland remaining grassland		CO_2	0.214	1.316	0.002	0.015	0.937
Agriculture	Direct emissions from agricultural soils		N_2O	1.281	2.069	0.001	0.012	0.949
Waste	Waste incineration		CO_2	2.550	3.135	0.001	0.010	0.959
Energy	Road transportation		CO_2	36.058	33.231	0.001	0.008	0.967
Waste	Waste incineration		CH_4	2.261	1.597	0.001	0.007	0.974
Waste	Solid waste disposal on land		CH_4	3.636	3.898	0.001	0.006	0.981
Agriculture	Indirect emissions from agricultural soils		N_2O	0.697	1.113	0.001	0.006	0.987
Agriculture	Enteric fermentation		CH_4	6.018	5.386	0.000	0.004	0.990
Waste	Waste incineration		N_2O	1.099	0.810	0.000	0.003	0.993
Energy	Civil aviation		N_2O	0.336	0.409	0.000	0.001	0.994
Energy	Combustion excluding transport		N_2O	1.392	1.401	0.000	0.001	0.996
LULUCF	Conversion to cropland		CO_2	0.000	0.048	0.000	0.001	0.996
Agriculture	Manure management		N_2O	0.641	0.646	0.000	0.001	0.997
Energy	Road transportation		CH_4	0.064	0.104	0.000	0.001	0.997
LULUCF	Forest land remaining forest		CO_2	0.000	-0.042	0.000	0.001	0.998
Energy	Combustion excluding transport		CH_4	0.950	0.928	0.000	0.000	0.998
Industry	Consumption of SF_6		SF_6	0.036	0.003	0.000	0.000	0.999
Energy	Domestic navigation		N_2O	0.053	0.077	0.000	0.000	0.999
Industry	Limestone and dolomite use		CO_2	0.000	0.020	0.000	0.000	0.999
Solvents and other product use	Solvents		CO_2	0.263	0.230	0.000	0.000	1.000
Energy	Domestic navigation		CH_4	0.030	0.043	0.000	0.000	1.000
Agriculture	Manure management		CH_4	0.140	0.126	0.000	0.000	1.000
Energy	Civil aviation		CH_4	0.006	0.007	0.000	0.000	1.000
Energy	Road transportation		N_2O	0.093	0.087	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
Total				651.268	611.702		1.000	

Table 16.12.4 Summary of Key Category Analysis for Greenland for level assessment for year 1990/95 and 2012 and for trend for years 1990-2012.

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 2012	Trend Tier1 1990-2012
Energy	Combustion excluding transport	Liquid fuels	CO_2	1	1	1
Energy	Combustion excluding transport	Other fuels	CO_2			5
Energy	Combustion excluding transport		CH_4			
Energy	Combustion excluding transport		N_2O			
Energy	Road transportation		CO_2	3	3	
Energy	Road transportation		CH_4			
Energy	Road transportation		N_2O			
Energy	Civil aviation		CO_2	2	2	2
Energy	Civil aviation		CH_4			
Energy	Civil aviation		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	Asphalt roofing		CO_2			
Industry	Road Paving with asphalt		CO_2			
Industry	Consumption of HFC's		HFCs		6	4
Industry	Consumption of SF_6		SF_6			
Solvents and other product use	Solvents		CO_2			
Agriculture	Enteric fermentation		CH_4			
Agriculture	Manure management		CH_4			
Agriculture	Manure management		N_2O			
Agriculture	Direct emissions from agricultural soils		N_2O			8
Agriculture	Indirect emissions from agricultural soils		N_2O			
Waste	Solid waste disposal on land		CH_4			
Waste	Wastewater handling		N_2O	5	5	6
Waste	Waste incineration		CO_2			9
Waste	Waste incineration		CH_4			
Waste	Waste incineration		N_2O			
LULUCF	Forest land remaining forest		CO_2			
LULUCF	Conversion to cropland		CO_2			
LULUCF	Grassland remaining grassland		CO_2			7

16.13 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 16.3.

16.14 Annex 3 Other detailed methodological descriptions for individual source or sink categories

All methodological descriptions are included in Sections 16.3 – 16.8 and Section 16.11.

16.15 Annex 4 CO_2 reference approach and comparison with sectoral approach, and relevant information on the national energy balance

See Section 16.3.5.1 of this annex for the results of the comparison between the sectoral and reference approach.

16.16 Annex 5 Assessment of completeness and (potential) sources and sinks of greenhouse gas emissions and removals excluded

16.16.1 GHG inventory

The Greenlandic greenhouse gas emission inventories for 1990-2012 include all sources identified by the Revised 1996 IPCC Guidelines and the 2000 IPCC Good Practice Guidance except the following:

In the Solvent and other product use sector currently no N_2O emissions are included in CRF category 3D, Greenland will try to obtain activity data if they exist for uses of N_2O.

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. No methodology is recommended in IPCC-GPG.

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.g. harvested wood products. For more detail please see Section 16. 7.

In the Waste sector CO_2 emissions from managed waste disposal on land are not estimated. According to the 1996 IPCC Guidelines: "Decomposition of organic material derived from biomass sources (e.g., crops, forests), which are re-grown on an annual basis is the primary source of CO_2 released from waste. Hence, these CO_2 emissions are not treated as net emissions from waste in the IPCC Methodology.".

16.16.2 KP-LULUCF inventory

The KP-LULUCF inventory is considered complete. The carbon pools not estimated has been documented as not being sources, please see Section 16.11 for further documentation.

16.17 Annex 6 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

No additional information for Greenland is deemed relevant.

16.18 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 Gg CO_2 eq	Input data Gg CO_2 eq	Input data %	Input data %	%	%	%	%	%	%	%
1A Liquid fuels	CO_2	613	562	2	2	2.828	2.600	-0.020	0.864	-0.040	2.442	2.443
1A Municipal waste	CO_2	2	7	2	25	25.080	0.284	0.008	0.011	0.206	0.030	0.208
1A Liquid fuels	CH_4	1	1	2	100	100.020	0.158	0.000	0.001	0.001	0.004	0.004
1A Municipal waste	CH_4	0	0	2	100	100.020	0.009	0.000	0.000	0.006	0.000	0.006
1A Biomass	CH_4	0	0	2	100	100.020	0.011	0.000	0.000	0.008	0.000	0.008
1A Liquid fuels	N_2O	2	2	2	500	500.004	1.423	0.000	0.003	0.026	0.008	0.027
1A Municipal waste	N_2O	0	0	2	500	500.004	0.086	0.000	0.000	0.062	0.000	0.062
1A Biomass	N_2O	0	0	2	200	200.010	0.042	0.000	0.000	0.030	0.001	0.030
1B2 Oil exploration	CO_2	0	0	2	1 000	1000.002	0.000	0.000	0.000	0.000	0.000	0.000
1B2 Oil exploration	CH_4	0	0	2	1 000	1000.002	0.000	0.000	0.000	0.000	0.000	0.000
1B2 Oil exploration	N_2O	0	0	2	1 000	1000.002	0.000	0.000	0.000	0.000	0.000	0.000
2A3 Limestone and dolomite use	CO_2	0	0	5	5	7.071	0.000	0.000	0.000	0.000	0.000	0.000
2A5 Asphalt roofing	CO_2	0	0	5	25	25.495	0.000	0.000	0.000	0.000	0.000	0.000
2A6 Road paving with asphalt	CO_2	0	0	5	25	25.495	0.000	0.000	0.000	0.000	0.000	0.000
2F Consumption of HFC	HFC	0	7	10	50	50.990	0.599	0.011	0.011	0.550	0.156	0.572
2F Consumption of SF_6	SF_6	0	0	10	50	50.990	0.000	0.000	0.000	-0.002	0.000	0.002
3A Paint application	CO_2	0	0	10	15	18.028	0.000	0.000	0.000	0.000	0.000	0.000
3B Degreasing and dry cleaning	CO_2	0	0	10	15	18.028	0.000	0.000	0.000	0.000	0.000	0.000
3C Chemical products, manufacturing and processing	CO_2	0	0	10	15	18.028	0.000	0.000	0.000	0.000	0.000	0.000
3D5 Other	CO_2	0	0	10	20	22.361	0.008	0.000	0.000	0.000	0.005	0.005
4A Enteric Fermentation	CH_4	6	5	10	100	100.499	0.885	0.000	0.008	-0.041	0.117	0.124
4B Manure Management	CH_4	0	0	10	100	100.499	0.021	0.000	0.000	-0.001	0.003	0.003
4B Manure Management	N_2O	1	1	10	100	100.499	0.106	0.000	0.001	0.007	0.014	0.016
4D1 Direct N_2O emissions from agricultural soils	N_2O	0	1	20	50	53.852	0.125	0.001	0.002	0.074	0.062	0.097

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	%	%	%	%	%	%	%	%	%
Continued												
4D2 Pasture range and paddock	N_2O	1	1	20	25	32.016	0.034	0.000	0.001	-0.004	0.028	0.028
4D3 Indirect N_2O emissions from agricultural soils (Atmospheric deposition)	N_2O	1	1	20	50	53.852	0.098	0.001	0.002	0.035	0.048	0.060
5A Forest	CO_2	0	0	5	50	50.249	-0.003	0.000	0.000	-0.003	0.000	0.003
5B Cropland	CO_2	0	0	5	50	50.249	0.004	0.000	0.000	0.004	0.001	0.004
5C Grassland	CO_2	0	1	5	50	50.249	0.108	0.002	0.002	0.086	0.014	0.087
6A Solid Waste Disposal on Land	CH_4	4	4	10	100	100.499	0.640	0.001	0.006	0.074	0.085	0.113
6B Wastewater Handling	N_2O	15	12	30	100	104.403	2.013	-0.003	0.018	-0.336	0.768	0.838
6C Waste incineration	CO_2	3	3	10	25	26.926	0.138	0.001	0.005	0.028	0.068	0.074
6C Waste incineration	CH_4	2	2	10	50	50.990	0.133	-0.001	0.002	-0.040	0.035	0.053
6C Waste incineration	N_2O	1	1	10	100	100.499	0.133	0.000	0.001	-0.034	0.018	0.038
Total		651	612				14,610					7,105
Total uncertainties				Overall uncertainty in the year (%):			3.822			Trend uncertainty (%):		2.665

16.19 Annex 8 Results of a technical analysis conducted on the Greenlandic gas oil

In 2013 a technical analysis has been conducted on the arctic gas oil 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 gas oil.

Table 16.19.1 shows the results of the technological analysis on the Greenlandic gas oil.

Table 16.19.1 Results on the technical analysis on the Greenlandic gas oil.

	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	72.237	Calculation

17 Information regarding the aggregated submission for Denmark and Greenland

This chapter contains information on the aggregated submission for Denmark and Greenland submitted under the Kyoto Protocol. This chapter contains a trend discussion, a tier 1 uncertainty analysis, information on the aggregated reference approach, information relating to key categories and information on recalculations. Sector specific information is included for Denmark in Chapter 3-11 and for Greenland in Chapter 16.

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, the UNFCCC and the Kyoto Protocol, 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 17.7.

In Chapter 17.6 a description of the aggregation process is provided. The chapter explains the technical issues in aggregating two CRF submissions, including the software used in the process and the handling of background data.

17.1 Trends in emissions

Due to the small emission originating from Greenland the trends for Denmark and Greenland are practically identical to the trends for Denmark presented in Chapter 2.

17.1.1 Greenhouse Gas Emissions

The greenhouse gas emissions are estimated according to the IPCC guidelines and are aggregated into seven main sectors. The greenhouse gases include CO_2, CH_4, N_2O, HFCs, PFCs and SF_6. Figure 17.1 shows the estimated total greenhouse gas emissions in CO_2 equivalents from 1990 to 2012. The emissions are not corrected for electricity trade or temperature variations. CO_2 is the most important greenhouse gas contributing in 2012 to the national total in CO_2 equivalents excluding LULUCF (Land Use and Land Use Change and Forestry) with 76.5 % followed by N_2O with 11.4 %, CH_4 10.5 % and F-gases (HFCs, PFCs and SF_6) with 0.7 %. Seen over the time series from 1990 to 2012 these percentages have been increasing for F-gases and CH_4, almost constant for CO_2 and falling for N_2O. Stationary combustion plants, transport and agriculture represent the largest categories, followed by industrial processes, waste and solvents, see Figure 17.1. The net CO_2 uptake by LULUCF in 2012 is 1.6 % of the total emission in CO_2 equivalents excl. LULUCF. The national total greenhouse gas emission in CO_2 equivalents excluding LULUCF has decreased by 24.6 % from 1990 to 2012 and decreased 31.1 % including LULUCF. Comments on the overall trends seen in Figure 17.1 are given in the sections below on the individual greenhouse gases.

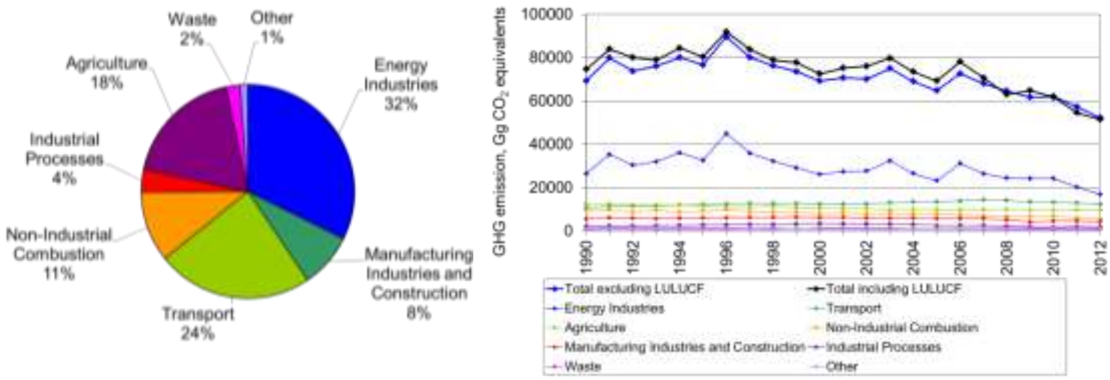

Figure 17.1 Greenhouse gas emissions in CO_2 equivalents distributed on main sectors for 2012 (excluding LULUCF) and time series for 1990 to 2012 (including LULUCF).

17.1.2 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 17.2). Energy Industries contribute with 42 % of the emissions (excl. LULUCF). About 31 % come from the transport sector. The main reason for the fluctuations during the time series is the variations in electricity import/export. The CO_2 emission (excl. LULUCF) decreased by 10.7 % from 2010 to 2012. The main reasons for this decrease were increase in the share of renewable energy, decreasing fuel consumption, mainly for coal and natural gas, and increase in import of electricity. In 2012, the CO_2 emission (excl. LULUCF) was 25.3 % lower than the emission in 1990.

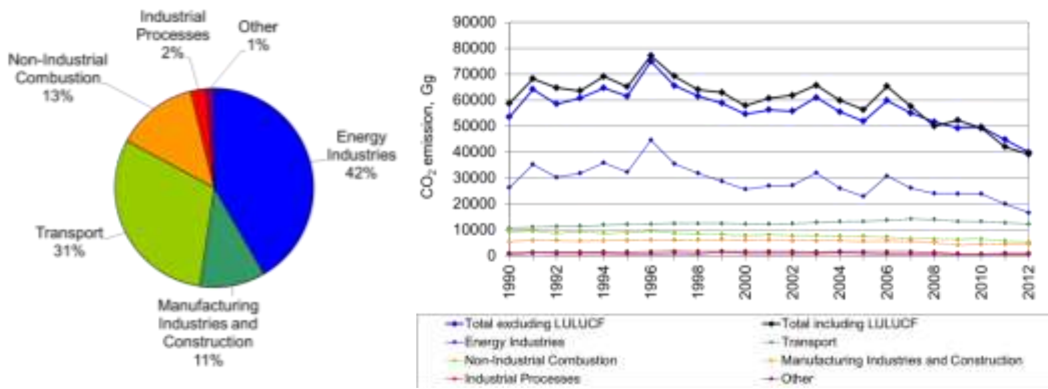

Figure 17.2 CO_2 emissions. Distribution according to the main sectors (2012) and time series for 1990 to 2012.

17.1.3 Nitrous oxide

Agriculture is the most important N_2O emission source in 2012 contributing 90 % (Figure 17.3) of which N_2O from agricultural soils accounts for 84 %. N_2O is emitted as a result of microbial processes in the soil. Substantial emissions also 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 nitrogen fertilisers. The main reason for the drop in the emissions of N_2O in the agricultural sector of 35 % from 1990 to 2012 is legislation to improve the utilisation of nitrogen in manure. The legislation has resulted in less nitrogen excreted per unit of livestock produced and a considerable reduction in the use of nitrogen fertilisers. The basis for the N_2O emission is then reduced. Combustion of fossil fuels in the energy sector, both stationary and mobile sources, contributes 6 %. The N_2O emission from transport contributes by 2 % in 2012. This emission has increased during the nineties because of the increase in the use of catalyst cars but is now decreasing due to improvements in technology. Production of nitric acid stopped in 2004 and the emissions from industrial processes is therefore not occurring from 2005 onwards. Other sources include e.g. use of N_2O for anaesthesia reported under Solvent and Other Product Use.

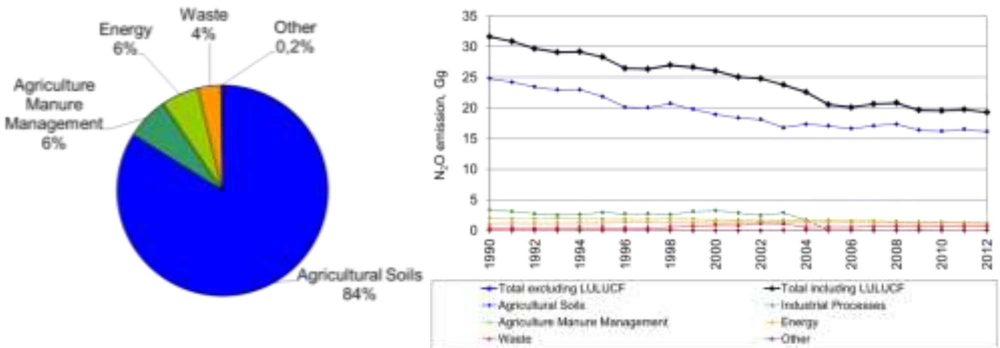

Figure 17.3 N_2O emissions. Distribution according to the main sectors (2012) and time series for 1990 to 2012.

17.1.4 Methane

The largest sources of anthropogenic CH_4 emissions are agricultural activities contributing in 2012 with 76 %, waste (16 %), public power and district heating plants (3 %), see Figure 17.4. The emission from agriculture derives from enteric fermentation and management of animal manure contributing with 53 % and 24 % of the national CH_4 emission in 2012. The CH_4 emission from public power and district heating plants increased in the nineties, mainly 1992-1996, due to the increasing use of gas engines in the decentralised cogeneration plant sector. Up to 3 % of the natural gas in the gas engines is not combusted. The deregulation of the electricity market has made production of electricity in gas engines less favourable, therefore the fuel consumption has decreased and hence the CH_4 emission has decreased. Over the time series from 1990 to 2012, the emission of CH_4 from enteric fermentation has decreased 10.6 % due to the decrease in the number of cattle. However, the emission from manure management has in the same period increased 31.7 % due to a change in traditional animal housing systems towards an increase in slurry-based housing systems. Altogether, the emission of CH_4 from the agriculture sector has decreased by 0.7 % from 1990 to 2012. The emission of CH_4 from waste has decreased 40.8 % since 1990 due to an increase in the recycling, composting and incineration of waste and hence a steep drop in the amount of waste deposited in landfills.

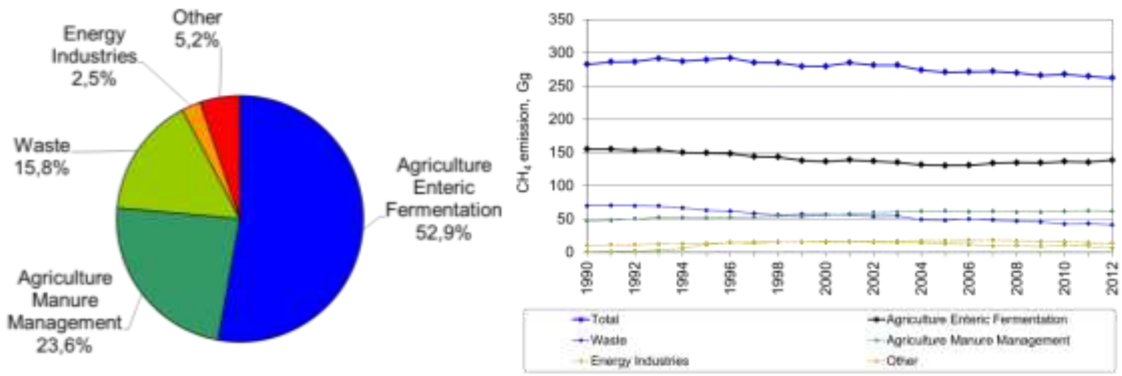

Figure 17.4 CH_4 emissions. Distribution according to the main sectors (2012) and time series for 1990 to 2012.

17.1.5 HFCs, PFCs and SF_6

This part of the Danish KP inventory only comprises a full data set for all substances from 1995. From 1995 to 2000, there has been a continuous and substantial increase in the contribution from the range of F-gases as a whole, calculated as the sum of emissions in CO_2 equivalents, see Figure 17.5. This increase is simultaneous with the increase in the emission of HFCs. For the time series 2000-2012, the increase is lower than for the years 1995 to 2000 and since 2008 the emissions have been decreasing. The increase from 1995 to 2012 for the total F-gas emission is 143 %. SF_6 contributed considerably to the F-gas sum in earlier years, with 33 % in 1995. Environmental awareness and regulation of this gas under Danish law has reduced its use in industry, see Figure 17.5. As a result the contribution of SF_6 to F-gases in 2012 was only 14.9 %. The use of HFCs has increased several folds. HFCs have, therefore, become the even more dominant F-gases, comprising 67 % in 1995, but 84 % in 2012. HFCs are mainly used as a refrigerant. 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. The use of air conditioning in mobile systems and the amount of HFC for this purpose increases.

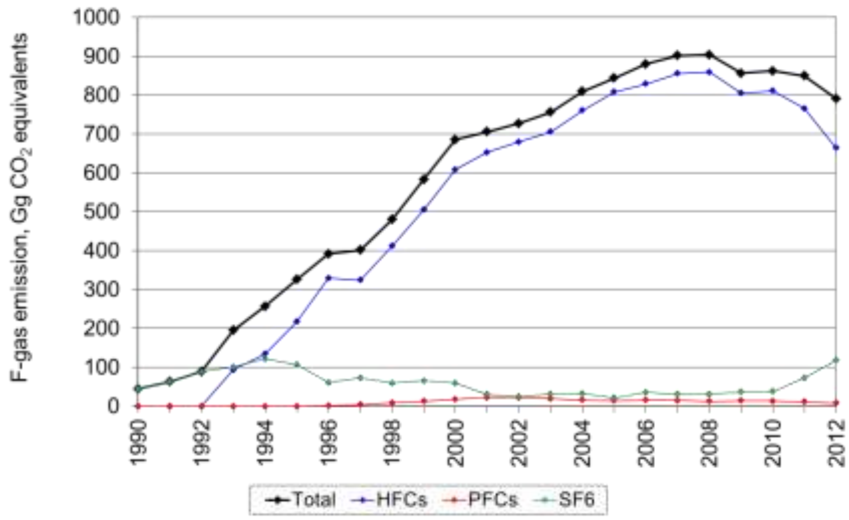

Figure 17.5 F-gas emissions. Time series for 1990 to 2012.

17.2 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 IPCC Reference Manual (IPCC, 1997). 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 Denmark and Greenland is an aggregation of the individual reference approaches for the two. The reference approach for Denmark is described in Chapter 3.4 and the reference approach for Greenland is included in Chapter 16.

In 2012, the fuel consumption rates in the two approaches differ by -0.96 % and the CO_2 emission differs by -0.93 %. In the period 1990-2012, both the fuel consumption and the CO_2 emission differ by less than 2.0%. The differences are below 1 % for all years except 1998, 2009 and 2011. This is almost identical to the reference approach for Denmark, due to the very small emission from Greenland compared to Denmark. A comparison of the national approach and the reference approach is illustrated in Figure 17.6. The differences are related to the statistical differences in the Danish energy statistics, see Chapter 3.4.

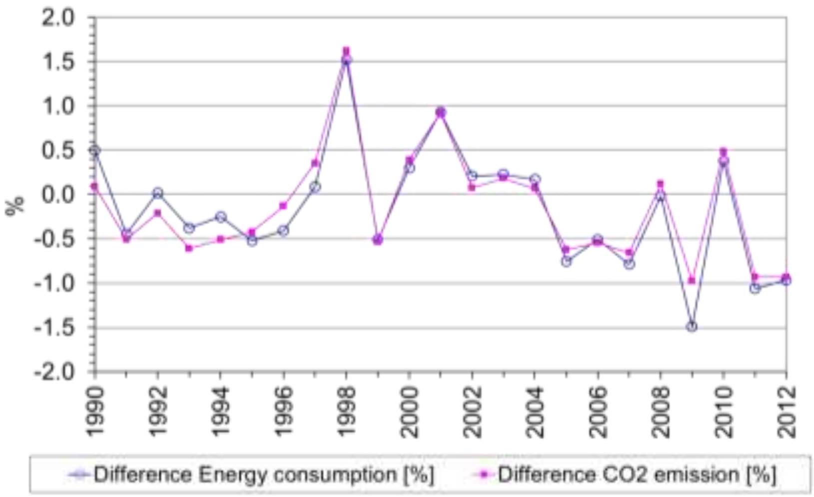

Figure 17.6 Comparison of the reference approach and the national approach.

17.3 Uncertainties

An uncertainty estimate has been calculated for Denmark and Greenland. The uncertainty estimate for Denmark is included in Chapter 1.7 and for Greenland in Chapter 16.

The uncertainty estimates are based on the Tier 1 methodology in the IPCC Good Practice Guidance (GPG) (IPCC, 2000). Uncertainty estimates cover 100 % of the total net greenhouse gas emissions and removals. The emissions from Greenland have been treated separately due to the uncertainties being different than the uncertainties in the Danish inventory. The uncertainty of the Greenlandic emissions has almost no effect on the overall uncertainty estimate, due to the low emissions originating from Greenland.

The estimated uncertainties for total GHG and for CO_2, CH_4, N_2O and F-gases are shown in Table 17.1. The base year for F-gases is 1995 and for all other sources the base year is 1990. The total net GHG emission from Denmark and Greenland is estimated with an uncertainty of ±6.8 % and the trend in net GHG emission since 1990/1995 has been estimated to be -31.3 % ± 2.6 %-age points. The GHG uncertainty estimates do not take into account the uncertainty of the GWP factors.

The uncertainty on N_2O from leaching, CH_4 emission from solid waste disposal on land, N_2O from synthetic fertilizer, N_2O from animal waste applied to soils, N_2O from stationary combustion of biomass, CO_2 from forest remaining forest and CO_2 from cropland, organic soil are the largest sources of uncertainty for the aggregated greenhouse gas inventory for Greenland and Denmark.

Table 17.1 Uncertainties 1990-2012.

	Uncertainty [%]	Trend [%]	Uncertainty in trend [%-age points]
GHG incl. LULUCF	6.8	-31.3	2.6
GHG excl. LULUCF	5.5	-24.9	2.5
CO_2	5.5	-33.4	2.4
CH_4	19.3	-7.3	11.8
N_2O	42	-39	13
F-gases	43	143	41

The uncertainties for the activity rates and emission factors are shown in Table 17.2.

Table 17.2 Uncertainties for activity rates and emission factors.

	IPCC Source category	Gas	Base year emission Input data Gg CO_2 eqv.	2012 emission Input data Gg CO_2 eqv.	Activity data uncertainty Input data %	Emission factor uncertainty Input data %
Denmark	Stationary Combustion, Coal	CO_2	23833.91	10005.25	0.9	0.5
Denmark	Stationary Combustion, BKB	CO_2	10.97	1.41	3.0	5.0
Denmark	Stationary Combustion, Coke	CO_2	137.80	73.81	1.8	5.0
Denmark	Stationary Combustion, Fossil waste	CO_2	573.46	1397.05	5.0	10.0
Denmark	Stationary Combustion, Petroleum coke	CO_2	414.74	627.60	2.0	5.0
Denmark	Stationary Combustion, Residual oil	CO_2	2495.97	570.79	1.2	2.0
Denmark	Stationary Combustion, Gas oil	CO_2	4546.79	742.07	2.2	4.0
Denmark	Stationary Combustion, Kerosene	CO_2	365.68	1.69	2.0	5.0
Denmark	Stationary Combustion, LPG	CO_2	183.88	91.05	1.8	5.0
Denmark	Stationary Combustion, Refinery gas	CO_2	816.13	905.83	1.0	2.0
Denmark	Stationary Combustion, Natural gas	CO_2	4335.40	8293.11	1.0	0.4
Denmark	Stationary Combustion, SOLID	CH_4	12.88	3.12	1.0	100.0
Denmark	Stationary Combustion, LIQUID	CH_4	2.76	1.11	0.8	100.0
Denmark	Stationary Combustion, GAS	CH_4	3.13	5.59	1.0	100.0
Denmark	Natural gas fuelled engines, GAS	CH_4	4.64	120.43	1.0	2.0
Denmark	Stationary Combustion, WASTE	CH_4	0.77	1.54	5.0	100.0
Denmark	Stationary Combustion, BIOMASS	CH_4	101.83	134.83	15.7	100.0
Denmark	Biogas fuelled engines, BIOMASS	CH_4	1.48	31.34	3.9	10.0
Denmark	Stationary Combustion, SOLID	N_2O	68.11	27.45	1.0	400.0
Denmark	Stationary Combustion, LIQUID	N_2O	44.02	11.08	0.8	1000.0
Denmark	Stationary Combustion, GAS	N_2O	16.38	24.45	1.0	750.0
Denmark	Stationary Combustion, WASTE	N_2O	6.58	15.72	5.0	400.0
Denmark	Stationary Combustion, BIOMASS	N_2O	37.92	90.89	2.2	1000.0
Denmark	Transport, Road transport	CO_2	9283.52	11223.78	2.0	5.0
Denmark	Transport, Military	CO_2	119.01	115.79	2.0	5.0
Denmark	Transport, Railways	CO_2	296.75	249.33	2.0	5.0
Denmark	Transport, Navigation (small boats)	CO_2	47.92	98.62	41.0	5.0
Denmark	Transport, Navigation (large vessels)	CO_2	747.83	399.02	11.0	5.0
Denmark	Transport, Fisheries	CO_2	590.60	479.10	2.0	5.0
Denmark	Transport, Agriculture	CO_2	1272.47	1343.48	24.0	5.0
Denmark	Transport, Forestry	CO_2	35.68	16.86	30.0	5.0
Denmark	Transport, Industry (mobile)	CO_2	839.28	1021.40	41.0	5.0
Denmark	Transport, Residential	CO_2	39.06	62.43	35.0	5.0
Denmark	Transport, Commercial/institutional	CO_2	73.72	171.41	35.0	5.0
Denmark	Transport, Civil aviation	CO_2	242.69	132.61	10.0	5.0
Denmark	Transport, Road transport	CH_4	46.90	11.29	2.0	40.0
Denmark	Transport, Military	CH_4	0.11	0.06	2.0	100.0
Denmark	Transport, Railways	CH_4	0.26	0.15	2.0	100.0
Denmark	Transport, Navigation (small boats)	CH_4	0.35	0.51	41.0	100.0
Denmark	Transport, Navigation (large vessels)	CH_4	0.33	0.20	11.0	100.0
Denmark	Transport, Fisheries	CH_4	0.27	0.25	2.0	100.0
Denmark	Transport, Agriculture	CH_4	2.20	2.03	24.0	100.0
Denmark	Transport, Forestry	CH_4	0.44	0.05	30.0	100.0
Denmark	Transport, Industry (mobile)	CH_4	1.25	0.75	41.0	100.0
Denmark	Transport, Residential	CH_4	1.07	1.36	35.0	100.0
Denmark	Transport, Commercial/institutional	CH_4	2.08	3.18	35.0	100.0
Denmark	Transport, Civil aviation	CH_4	0.09	0.05	10.0	100.0
Denmark	Transport, Road transport	N_2O	90.64	116.44	2.0	50.0
Denmark	Transport, Military	N_2O	1.15	1.27	2.0	1000.0

	IPCC Source category	Gas	Base year emission Input data Gg CO_2 eqv.	2012 emission Input data Gg CO_2 eqv.	Activity data uncertainty Input data %	Emission factor uncertainty Input data %
Continued						
Denmark	Transport, Railways	N_2O	2.54	2.13	2.0	1000.0
Denmark	Transport, Navigation (small boats)	N_2O	0.39	1.08	41.0	1000.0
Denmark	Transport, Navigation (large vessels)	N_2O	14.60	7.78	11.0	1000.0
Denmark	Transport, Fisheries	N_2O	11.50	9.39	2.0	1000.0
Denmark	Transport, Agriculture	N_2O	15.27	17.70	24.0	1000.0
Denmark	Transport, Forestry	N_2O	0.17	0.17	30.0	1000.0
Denmark	Transport, Industry (mobile)	N_2O	10.62	13.44	41.0	1000.0
Denmark	Transport, Residential	N_2O	0.19	0.33	35.0	1000.0
Denmark	Transport, Commercial/institutional	N_2O	0.34	0.82	35.0	1000.0
Denmark	Transport, Civil aviation	N_2O	3.19	2.07	10.0	1000.0
Denmark	1.B.2 Flaring in refinery	CO_2	22.95	22.33	11.0	2.0
Denmark	1.B.2 Flaring off-shore	CO_2	301.85	194.57	7.5	2.0
Denmark	1.B.2 Land based activities	CO_2	0.00	0.01	2.0	40.0
Denmark	1.B.2 Off-shore activities	CO_2	2.38	3.70	2.0	30.0
Denmark	1.B.2 Transmission of natural gas	CO_2	0.00	0.00	15.0	2.0
Denmark	1.B.2 Distribution of natural gas	CO_2	0.00	0.00	25.0	10.0
Denmark	1.B.2 Venting in gas storage	CO_2	0.00	0.00	15.0	2.0
Denmark	1.B.2 Flaring in refinery	CH_4	0.16	0.16	11.0	15.0
Denmark	1.B.2 Flaring off-shore	CH_4	0.73	0.32	7.5	125.0
Denmark	1.B.2 Refinery processes	CH_4	0.78	46.76	1.0	125.0
Denmark	1.B.2 Land based activities	CH_4	17.16	17.58	2.0	40.0
Denmark	1.B.2 Off-shore activities	CH_4	14.87	36.62	2.0	30.0
Denmark	1.B.2 Transmission of natural gas	CH_4	3.99	0.29	15.0	2.0
Denmark	1.B.2 Distribution of natural gas	CH_4	5.42	3.08	25.0	10.0
Denmark	1.B.2 Venting in gas storage	CH_4	1.23	1.21	15.0	2.0
Denmark	1.B.2 Flaring in refinery	N_2O	0.06	0.06	11.0	1000.0
Denmark	1.B.2 Flaring off-shore	N_2O	0.71	0.47	7.5	1000.0
Denmark	2A1 Cement production	CO_2	882.40	871.08	1.0	2.0
Denmark	2A2 Lime production	CO_2	115.53	40.17	5.0	5.0
Denmark	2A3 Limestone and dolomite use	CO_2	13.69	25.62	5.0	5.0
Denmark	2A5 Asphalt roofing	CO_2	0.02	0.02	5.0	25.0
Denmark	2A6 Road paving with asphalt	CO_2	1.76	1.77	5.0	25.0
Denmark	2A7a Glass and Glass wool	CO_2	17.41	9.69	5.0	2.0
Denmark	2A7b Yellow bricks	CO_2	23.02	17.48	5.0	2.0
Denmark	2A7c Expanded clay	CO_2	14.93	5.89	5.0	2.0
Denmark	2B5 Catalysts/Fertilizers, Pesticides and Sulphuric acid	CO_2	0.80	1.41	5.0	5.0
Denmark	2C1 Iron and steel production	CO_2	28.45	0.00	5.0	5.0
Denmark	2D2 Food and Drink	CO_2	4.45	2.24	5.0	5.0
Denmark	2G Lubricants	CO_2	49.71	31.70	2.0	5.0
Denmark	2B2 Nitric acid production	N_2O	1042.90	0.00	2.0	25.0
Denmark	2F Consumption of HFC	HFC	217.73	657.20	10.0	50.0
Denmark	2F Consumption of PFC	PFC	0.50	8.54	10.0	50.0
Denmark	2F Consumption of SF_6	SF_6	107.34	117.85	10.0	50.0
Denmark	3A Paint application	CO_2	13.22	7.23	10.0	15.0
Denmark	3B Degreasing and dry cleaning	CO_2	0.00	0.00	10.0	15.0
Denmark	3C Chemical products, manufacturing and processing	CO_2	19.42	12.17	10.0	15.0
Denmark	3D5 Other	CO_2	60.64	43.74	10.0	20.0
Denmark	3D5 Consumption of fireworks	CO_2	0.06	0.15	8.0	100.0

	IPCC Source category	Gas	Base year emission Input data Gg CO_2 eqv.	2012 emission Input data Gg CO_2 eqv.	Activity data uncertainty Input data %	Emission factor un-certainty Input data %
Continued						
Denmark	3D5 Use of candles	CO_2	21.66	81.10	10.0	20.0
Denmark	3D1 Other - Use of N_2O for Anaesthesia	N_2O	0.00	9.34	5.0	5.0
Denmark	3D5 Use of tobacco	N_2O	0.25	0.16	20.0	30.0
Denmark	3D5 Use of charcoal for BBQ	N_2O	0.07	0.13	10.0	100.0
Denmark	3D5 Consumption of fireworks	N_2O	0.77	2.09	8.0	100.0
Denmark	3D5 Use of candles	N_2O	0.06	0.21	10.0	20.0
Denmark	4A Enteric Fermentation	CH_4	3246.93	2903.79	2.0	20.0
Denmark	4B Manure Management	CH_4	985.16	1297.17	5.0	20.0
Denmark	4F Field burning of agricultural residues	CH_4	1.82	2.43	25.0	50.0
Denmark	4.B Manure Management	N_2O	599.78	390.77	22.4	100.0
Denmark	4.D1.1 Synthetic Fertilizer	N_2O	2353.53	1103.41	25.2	100.0
Denmark	4.D1.2 Animal waste applied to soils	N_2O	1111.74	1161.35	30.0	100.0
Denmark	4.D1.3 N-fixing crops	N_2O	269.47	256.21	20.0	100.0
Denmark	4.D1.4 Crop Residue	N_2O	361.22	311.19	20.0	100.0
Denmark	4.D1.5 Cultivation of histosols	N_2O	290.23	198.31	20.0	100.0
Denmark	4.D.2 Grassing animals	N_2O	334.25	210.88	25.5	100.0
Denmark	4.D3 Atmospheric deposition	N_2O	496.40	294.60	18.7	100.0
Denmark	4.D3 Leaching	N_2O	2447.13	1429.53	20.0	100.0
Denmark	4.D1.6 Sewage sludge and Industrial waste used as fertiliser	N_2O	27.92	38.76	20.0	100.0
Denmark	4.F Field Burning of Agricultural Residues	N_2O	0.70	0.93	25.0	50.0
Denmark	5.A.1 Forest remaining forest	CO_2	49.60	-4491.37	15.0	2.0
Denmark	5.A.2 Land converted to forest	CO_2	76.62	37.83	15.0	8.7
Denmark	5(II) Forest Land.	N_2O	15.64	12.07	30.0	10.0
Denmark	5.B Cropland, Living biomass	CO_2	-73.52	192.99	10.0	50.0
Denmark	5.B Cropland, Dead organic matter	CO_2	2.93	12.16	10.0	50.0
Denmark	5.B Cropland, Mineral soils	CO_2	1415.31	577.08	10.0	75.0
Denmark	5.B Cropland, Organic soils	CO_2	2887.33	1980.71	10.0	90.0
Denmark	5(III) Disturbance, Land converted to cropland	N_2O	0.25	1.01	50.0	75.0
Denmark	5.C Grassland, Living biomass	CO_2	75.25	463.24	10.0	50.0
Denmark	5.C Grassland, Dead organic matter	CO_2	1.63	7.04	10.0	50.0
Denmark	5.C Grassland, Mineral soils	CO_2	0.16	4.54	10.0	75.0
Denmark	5.C Grassland, Organic soils	CO_2	106.58	78.70	10.0	90.0
Denmark	5.D Wetlands, Living biomass	CO_2	2.57	-0.22	10.0	50.0
Denmark	5.D Wetlands, Dead organic matter	CO_2	0.54	0.00	10.0	100.0
Denmark	5.D Wetlands, Soils	CO_2	84.67	2.50	10.0	100.0
Denmark	5(II) Wetlands	N_2O	0.13	0.13	10.0	100.0
Denmark	5.E Settlements, Living biomass	CO_2	11.41	55.99	10.0	50.0
Denmark	5.E Settlements, Dead organic matter	CO_2	0.55	0.03	10.0	50.0
Denmark	5.E Settlements, Soils	CO_2	0.96	34.78	10.0	50.0
Denmark	5(IV) Cropland Limestone	CO_2	622.92	192.30	5.0	50.0
Denmark	5(V) Biomass Burning	CH_4	0.55	0.02	50.0	30.0
Denmark	5(V) Biomass Burning	N_2O	0.45	0.03	50.0	30.0
Denmark	6 A. Solid Waste Disposal on Land	CH_4	1365.77	698.04	10.0	117.9
Denmark	6 B. Wastewater Handling	CH_4	65.49	74.00	24.0	31.6
Denmark	6 B. Wastewater Handling - Direct	N_2O	22.70	40.70	21.7	49.6
Denmark	6 B. Wastewater Handling - Indirect	N_2O	82.25	32.14	59.2	42.0
Denmark	6.D Accidental fires, buildings	CO_2	11.41	10.79	10.0	300.0
Denmark	6.D Accidental fires, vehicles	CO_2	6.13	5.56	10.0	500.0

	IPCC Source category	Gas	Base year emission Input data Gg CO_2 eqv.	2012 emission Input data Gg CO_2 eqv.	Activity data uncertainty Input data %	Emission factor uncertainty Input data %
Continued						
Denmark	6.C Incineration of corpses	CH_4	0.01	0.01	1.0	150.0
Denmark	6.C Incineration of carcasses	CH_4	0.00	0.00	40.0	150.0
Denmark	6.D Compost production	CH_4	29.11	90.43	40.0	100.0
Denmark	6.D Accidental fires, buildings	CH_4	1.35	1.30	10.0	500.0
Denmark	6.D Accidental fires, vehicles	CH_4	0.27	0.24	10.00	700.00
Denmark	6.C Incineration of corpses	N_2O	0.19	0.19	1.00	150.00
Denmark	6.C Incineration of carcasses	N_2O	0.01	0.09	40.00	150.00
Denmark	6.D Compost production	N_2O	12.85	126.83	40.00	100.00
Greenland	1A Liquid fuels	CO_2	612.92	562.38	2.0	2.0
Greenland	1A Municipal waste	CO_2	1.67	6.94	2.0	25.0
Greenland	1A Liquid fuels	CH_4	1.02	0.96	2.0	100.0
Greenland	1A Municipal waste	CH_4	0.01	0.05	2.0	100.0
Greenland	1A Biomass	CH_4	0.02	0.06	2.0	100.0
Greenland	1A Liquid fuels	N_2O	1.82	1.74	2.0	500.0
Greenland	1A Municipal waste	N_2O	0.03	0.10	2.0	500.0
Greenland	1A Biomass	N_2O	0.03	0.13	2.0	200.0
Greenland	1B2 Oil exploration	CO_2	0.00	0.00	2.0	1000.0
Greenland	1B2 Oil exploration	CH_4	0.00	0.00	2.0	1000.0
Greenland	1B2 Oil exploration	N_2O	0.00	0.00	2.0	1000.0
Greenland	2A3 Limestone and dolomite use	CO_2	0.00	0.02	5.0	5.0
Greenland	2A5 Asphalt roofing	CO_2	0.00	0.00	5.0	25.0
Greenland	2A6 Road paving with asphalt	CO_2	0.00	0.00	5.0	25.0
Greenland	2F Consumption of HFC	HFC	0.02	7.19	10.0	50.0
Greenland	2F Consumption of SF6	SF_6	0.04	0.00	10.0	50.0
Greenland	3A Paint application	CO_2	0.01	0.00	10.0	15.0
Greenland	3B Degreasing and dry cleaning	CO_2	0.00	0.00	10.0	15.0
Greenland	3C Chemical products, manufacturing and processing	CO_2	0.00	0.00	10.0	15.0
Greenland	3D5 Other	CO_2	0.25	0.23	10.0	20.0
Greenland	4A Enteric Fermentation	CH_4	6.02	5.39	10.0	100.0
Greenland	4B Manure Management	CH_4	0.14	0.13	10.0	100.0
Greenland	4.B Manure Management	N_2O	0.64	0.65	10.0	100.0
Greenland	4D1 Direct N_2O emissions from agricultural soils	N_2O	0.48	1.42	20.0	50.0
Greenland	4D2 Pasture range and paddock	N_2O	0.80	0.65	20.0	25.0
Greenland	4D3 Indirect N_2O emissions from agricultural soils	N_2O	0.70	1.11	20.0	50.0
Greenland	5A Forest	CO_2	0.00	-0.04	5.0	50.0
Greenland	5B Cropland	CO_2	0.00	0.05	5.0	50.0
Greenland	5.C Grassland	CO_2	0.21	1.32	5.0	50.0
Greenland	6A Solid Waste Disposal on Land	CH_4	3.64	3.90	10.0	100.0
Greenland	6B Wastewater Handling	N_2O	14.88	11.79	30.0	100.0
Greenland	6C Waste incineration	CO_2	2.55	3.13	10.0	25.0
Greenland	6C Waste incineration	CH_4	2.26	1.60	10.0	50.0
Greenland	6C Waste incineration	N_2O	1.10	0.81	10.0	100.0

17.4 Key category analysis

A tier 1 key category analysis (KCA) has been carried out on emissions from Denmark and Greenland. The key category analysis for Denmark is included in Chapter 1.5 and Annex 1, and the key category analysis for Greenland is included in Chapter 16.

The KCA for 1990 and 2012 has been carried out in accordance with the IPCC Guidelines 2006 and IPCC Good Practice Guidance. The KCA has been carried out at CRF level, which is slightly more aggregated than the KCA carried out for Denmark. The categorisation used results in a total of 113 source categories of which 20 are LULUCF categories.

The KCA for Denmark and Greenland includes a total of six different analyses:

- base year, reporting year and trend,
- including and excluding LULUCF.

The six different KCA for Denmark and Greenland point out 16-24 key source categories each and a total of 27 different key source categories. The number of key categories in each of the main sectors is: Energy 7, Industrial Proc. 3, Solvents and other product use 0, Agriculture 10, LULUCF 6 and Waste 1.

An overview for all KCA is given in Table 17.3. The table includes ranking for each key category emission sources.

The six KCA for Denmark and Greenland are shown in Table 17.4-17.9.

Table 17.3 Key Category Analysis for Denmark and Greenland, overview.

IPCC Source Categories		GHG	Excluding LULUCF			Including LULUCF		
			Level Tier1 1990	Level Tier1 2012	Trend Tier1 1990-2012	Level Tier1 1990	Level Tier1 2012	Trend Tier1 1990-2012
Energy	Combustion excluding transport, Liquid Fuels	CO_2	2	4	2	2	4	2
Energy	Combustion excluding transport, Solid Fuels	CO_2	1	2	1	1	2	1
Energy	Combustion excluding transport, Gaseous Fuels	CO_2	4	3	3	4	3	4
Energy	Combustion excluding transport, Other Fuels	CO_2	15	7	8	18	9	11
Energy	Combustion excluding transport, Liquid Fuels	CH_4						
Energy	Combustion excluding transport, Solid Fuels	CH_4						
Energy	Combustion excluding transport, Gaseous Fuels	CH_4						
Energy	Combustion excluding transport, Biomass	CH_4						
Energy	Combustion excluding transport, Other Fuels	CH_4						
Energy	Combustion excluding transport, Liquid Fuels	N_2O						
Energy	Combustion excluding transport, Solid Fuels	N_2O						
Energy	Combustion excluding transport, Gaseous Fuels	N_2O						
Energy	Combustion excluding transport, Biomass	N_2O						
Energy	Combustion excluding transport, Other Fuels	N_2O						
Energy	Road transportation	CO_2	3	1	4	3	1	5
Energy	Road transportation	CH_4						
Energy	Road transportation	N_2O						
Energy	Civil aviation	CO_2						
Energy	Civil aviation	CH_4						
Energy	Civil aviation	N_2O						
Energy	Domestic navigation	CO_2	13	14	13	15	17	18
Energy	Domestic navigation	CH_4						
Energy	Domestic navigation	N_2O						
Energy	Railways	CO_2		19			23	
Energy	Railways	CH_4						
Energy	Railways	N_2O						
Energy	Fugitive emissions , 1B2ai Oil Exploration	CO_2						
Energy	Fugitive emissions , 1B2ai Oil Exploration	CH_4						
Energy	Fugitive emissions , 1B2ai Oil Exploration	N_2O						
Energy	Fugitive emissions , 1B2aii Oil Production	CO_2						
Energy	Fugitive emissions , 1B2aii Oil Production	CH_4						
Energy	Fugitive emissions , 1B2aii Oil Production	N_2O						

IPCC Source Categories		GHG	Excluding LULUCF			Including LULUCF		
			Level Tier1 1990	Level Tier1 2012	Trend Tier1 1990-2012	Level Tier1 1990	Level Tier1 2012	Trend Tier1 1990-2012
Continued								
Energy	Fugitive emissions , 1B2aiv, Oil refining and storage	CH_4						
Energy	Fugitive emissions , 1B2b Natural gas transmission and distribution	CO_2						
Energy	Fugitive emissions , 1B2biii, Gas transmission	CH_4						
Energy	Fugitive emissions , 1B2biv, Gas distribution	CH_4						
Energy	Fugitive emissions , 1B2c Venting	CO_2						
Energy	Fugitive emissions , 1B2c Venting	CH_4						
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	CO_2						
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	CH_4						
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	N_2O						
Energy	Fugitive emissions , 1B2c2i, Flaring oil	CO_2						
Energy	Fugitive emissions , 1B2c2i, Flaring oil	CH_4						
Energy	Fugitive emissions , 1B2c2i, Flaring oil	N_2O						
Industrial processes	Cement production	CO_2	12	11		14	13	
Industrial processes	Lime production	CO_2						
Industrial processes	Limestone and dolomite use	CO_2						
Industrial processes	Asphalt roofing	CO_2						
Industrial processes	Road Paving with asphalt	CO_2						
Industrial processes	Glass production	CO_2						
Industrial processes	Yellow bricks	CO_2						
Industrial processes	Expanded clay	CO_2						
Industrial processes	Nitric acid production	N_2O	10		6	12		7
Industrial processes	Catalysts/Fertilizers, Pesticides and Sulphuric acid	CO_2						
Industrial processes	Iron and steel production	CO_2						
Industrial processes	Food and drink	CO_2						
Industrial processes	Refrigeration and AC Equipment	HFC and PFC		13	10		15	13
Industrial processes	Foam Blowing	HFC						
Industrial processes	Aerosols	HFC						
Industrial processes	Electrical equipment	SF_6						
Industrial processes	Other emissions of SF6 i.e. from double glaze windows and laboratories	SF_6						
Industrial processes	Other i.e. Fibre Optics	HFC and PFC						
Industrial processes	Magnesium Production	SF_6						
Industrial processes	Other, lubricants	CO_2						
Solvents and other product use	Paint application	CO_2						
Solvents and other product use	Degreasing and Dry Cleaning	CO_2						
Solvents and other product use	Chemical Products, Manufacture and Processing	CO_2						
Solvents and other product use	Other solvent	CO_2						
Solvents and other product use	Other solvent	N_2O						
Agriculture	Enteric Fermentation	CH_4	5	5	11	5	6	16
Agriculture	Manure Management	CH_4	11	8	12	13	10	17
Agriculture	Manure management	N_2O	14	15	14	17	19	20
Agriculture	Agriculture soils, direct emissions , Synthetic Fertilizers	N_2O	7	10	5	8	12	6
Agriculture	Agriculture soils, direct emissions , Animal Manure Appl. to Soils	N_2O	9	9		11	11	
Agriculture	Agriculture soils, direct emissions , N-fixing Crops	N_2O		18			22	
Agriculture	Agriculture soils, direct emissions , Crop Residue	N_2O	17	16		20	20	
Agriculture	Agriculture soils, direct emissions , Cultivation of Histosols	N_2O						
Agriculture	Agriculture soils, direct emissions , Sludge	N_2O						
Agriculture	Agriculture soils, pasture, range and paddock	N_2O			16	21	24	
Agriculture	Agriculture soils, indirect, Atmospheric Deposition	N_2O	16	17	15	19	21	21
Agriculture	Agriculture soils, indirect, Nitrogen Leaching and Run-off	N_2O	6	6	7	7	8	8
Agriculture	Field Burning of Agricultural Residues	CH_4						
Agriculture	Field Burning of Agricultural Residues	N_2O						
Waste	Solid Waste Disposal Sites	CH_4	8	12	9	10	14	12
Waste	N2O direct, Domestic and Commercial Wastewater	N2O						

IPCC Source Categories		GHG	Excluding LULUCF			Including LULUCF		
			Level Tier1 1990	Level Tier1 2012	Trend Tier1 1990-2012	Level Tier1 1990	Level Tier1 2012	Trend Tier1 1990-2012
Continued								
Waste	N_2O indirect from human sewage	N_2O						
Waste	Waste Water Handling	CH_4						
Waste	Waste incineration	CO_2						
Waste	Waste incineration	CH_4						
Waste	Waste incineration	N_2O						
Waste	Waste, other	CO_2						
Waste	Waste, other	CH_4						
Waste	Waste, other	N_2O						
LULUCF	Forest Land remaining Forest L.	CO_2					5	3
LULUCF	Land converted to Forest L.	CO_2						
LULUCF	Cropland, 5.B Cropland, Living biomass	CO_2						19
LULUCF	Cropland, 5.B Cropland, Dead organic matter	CO_2						
LULUCF	Cropland, 5.B Cropland, Mineral soils	CO_2				9	16	10
LULUCF	Cropland, 5.B Cropland, Organic soils	CO_2				6	7	9
LULUCF	Grassland, 5.C Grassland, Living biomass	CO_2					18	15
LULUCF	Grassland, 5.C Grassland, Dead organic matter	CO_2						
LULUCF	Grassland, 5.C Grassland, Mineral soils	CO_2						
LULUCF	Grassland, 5.C Grassland, Organic soils	CO_2						
LULUCF	Wetlands, 5D Wetlands Living biomass	CO_2						
LULUCF	Wetlands, 5D Wetlands, dead org. matter	CO_2						
LULUCF	Wetlands, 5D Wetlands, soils	CO_2						
LULUCF	Settlements, 5E Total settlements	CO_2						
LULUCF	Non-CO2 drainage of soils and wetlands, 5IID Forest Land.	N_2O						
LULUCF	Non-CO2 drainage of soils and wetlands, 5IID Wetlands. Peatland	N_2O						
LULUCF	N2O Disturbance, Land converted to cropland, 5III Cropland	N_2O						
LULUCF	Agricultural lime application, 5IV Cropland Lime-stone	CO_2				16		14
LULUCF	Biomass burning, 5V Biomass burning	CH_4						
LULUCF	Biomass burning, 5V Biomass burning	N_2O						

Table 17.4 Key Category Analysis for Denmark and Greenland, level assessment for the base year, excl. LULUCF.

IPCC Source Categories (LULUCF excluded)		GHG	Base Year Estimate Ex,o Gg CO_2 eqv.	Base Year Level Assess-ment Lx,o	Base Year Cumula-tive total
Energy	Combustion excluding transport, Solid Fuels	CO_2	23982.67	0.3448	0.3448
Energy	Combustion excluding transport, Liquid Fuels	CO_2	12310.84	0.1770	0.5218
Energy	Road transportation	CO_2	9319.58	0.1340	0.6558
Energy	Combustion excluding transport, Gaseous Fuels	CO_2	4335.40	0.0623	0.7181
Agriculture	Enteric Fermentation	CH_4	3252.95	0.0468	0.7649
Agriculture	Agriculture soils, indirect, Nitrogen Leaching and Run-off	N_2O	2447.73	0.0352	0.8000
Agriculture	Agriculture soils, direct emissions , Synthetic Fertiliz-ers	N_2O	2353.58	0.0338	0.8339
Waste	Solid Waste Disposal Sites	CH_4	1369.41	0.0197	0.8536
Agriculture	Agriculture soils, direct emissions , Animal Manure Appl. to Soils	N_2O	1112.06	0.0160	0.8696
Industrial processes	Nitric acid production	N_2O	1042.90	0.0150	0.8845
Agriculture	Manure Management	CH_4	985.30	0.0142	0.8987
Industrial processes	Cement production	CO_2	882.40	0.0127	0.9114
Energy	Domestic navigation	CO_2	816.48	0.0117	0.9231
Agriculture	Manure Management	N_2O	600.42	0.0086	0.9318
Energy	Combustion excluding transport, Other Fuels	CO_2	575.14	0.0083	0.9400
Agriculture	Agriculture soils, indirect, Atmospheric Deposition	N_2O	496.50	0.0071	0.9472
Agriculture	Agriculture soils, direct emissions , Crop Residue	N_2O	361.27	0.0052	0.9524
Agriculture	Agriculture soils, pasture, range and paddock	N_2O	335.05	0.0048	0.9572
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	CO_2	301.85	0.0043	0.9615
Energy	Railways	CO_2	296.75	0.0043	0.9658
Agriculture	Agriculture soils, direct emissions , Cultivation of Histosols	N_2O	290.29	0.0042	0.9700
Energy	Civil aviation	CO_2	281.01	0.0040	0.9740
Agriculture	Agriculture soils, direct emissions , N-fixing Crops	N_2O	269.47	0.0039	0.9779
Industrial processes	Foam Blowing	HFC	182.58	0.0026	0.9805
Industrial processes	Lime production	CO_2	115.53	0.0017	0.9822
Energy	Combustion excluding transport, Biomass	CH_4	103.75	0.0015	0.9837
Energy	Road transportation	N_2O	90.74	0.0013	0.9850
Waste	N2O indirect from human sewage	N_2O	85.23	0.0012	0.9862
Energy	Combustion excluding transport, Liquid Fuels	N_2O	84.59	0.0012	0.9874
Solvents and other product use	Other solvent	CO_2	82.61	0.0012	0.9886
Energy	Combustion excluding transport, Solid Fuels	N_2O	68.11	0.0010	0.9896
Industrial processes	Other emissions of SF6 i.e. from double glaze win-dows and laboratories	SF_6	67.62	0.0010	0.9905
Waste	Waste Water Handling	CH_4	65.49	0.0009	0.9915
Industrial processes	Other, lubricants	CO_2	49.71	0.0007	0.9922
Energy	Road transportation	CH_4	46.97	0.0007	0.9929
Energy	Combustion excluding transport, Biomass	N_2O	41.58	0.0006	0.9935
Industrial processes	Refrigeration and AC Equipment	HFC and PFC	35.68	0.0005	0.9940
Waste	N2O direct, Domestic and Commercial Wastewater	N_2O	34.60	0.0005	0.9945
Energy	Fugitive emissions , 1B2aii Oil Production	CH_4	32.03	0.0005	0.9949
Waste	Waste, other	CH_4	30.72	0.0004	0.9954
Industrial processes	Iron and steel production	CO_2	28.45	0.0004	0.9958
Agriculture	Agriculture soils, direct emissions , Sludge	N_2O	27.92	0.0004	0.9962
Industrial processes	Yellow bricks	CO_2	23.02	0.0003	0.9965
Energy	Fugitive emissions , 1B2c2i, Flaring oil	CO_2	22.95	0.0003	0.9969
Solvents and other product use	Chemical Products, Manufacture and Processing	CO_2	19.42	0.0003	0.9971
Waste	Waste, other	CO_2	17.54	0.0003	0.9974
Industrial processes	Glass production	CO_2	17.41	0.0003	0.9976
Energy	Combustion excluding transport, Gaseous Fuels	N_2O	16.38	0.0002	0.9979
Energy	Domestic navigation	N_2O	15.05	0.0002	0.9981
Industrial processes	Expanded clay	CO_2	14.93	0.0002	0.9983
Industrial processes	Limestone and dolomite use	CO_2	13.69	0.0002	0.9985
Solvents and other product use	Paint application	CO_2	13.23	0.0002	0.9987
Energy	Combustion excluding transport, Solid Fuels	CH_4	12.88	0.0002	0.9989
Waste	Waste, other	N_2O	12.85	0.0002	0.9991
Energy	Combustion excluding transport, Liquid Fuels	CH_4	11.10	0.0002	0.9992
Energy	Combustion excluding transport, Gaseous Fuels	CH_4	7.77	0.0001	0.9993
Energy	Fugitive emissions , 1B2biv, Gas distribution	CH_4	5.42	0.0001	0.9994
Industrial processes	Food and drink	CO_2	4.45	0.0001	0.9995

IPCC Source Categories (LULUCF excluded)		GHG	Base Year Estimate Ex,o Gg CO_2 eqv.	Base Year Level Assess-ment Lx,o	Base Year Cumula-tive total
Continued					
Energy	Fugitive emissions , 1B2biii, Gas transmission	CH_4	3.99	0.0001	0.9995
Industrial processes	Electrical equipment	SF_6	3.91	0.0001	0.9996
Energy	Civil aviation	N_2O	3.53	0.0001	0.9996
Energy	Combustion excluding transport, Other Fuels	N_2O	2.99	0.0000	0.9997
Waste	Waste incineration	CO_2	2.55	0.0000	0.9997
Energy	Railways	N_2O	2.54	0.0000	0.9998
Energy	Fugitive emissions , 1B2aii Oil Production	CO_2	2.38	0.0000	0.9998
Waste	Waste incineration	CH_4	2.27	0.0000	0.9998
Agriculture	Field Burning of Agricultural Residues	CH_4	1.82	0.0000	0.9998
Industrial processes	Road Paving with asphalt	CO_2	1.76	0.0000	0.9999
Waste	Waste incineration	N_2O	1.30	0.0000	0.9999
Energy	Fugitive emissions , 1B2c Venting	CH_4	1.23	0.0000	0.9999
Solvents and other product use	Other solvent	N_2O	1.14	0.0000	0.9999
Industrial processes	Catalysts/Fertilizers, Pesticides and Sulphuric acid	CO_2	0.80	0.0000	0.9999
Energy	Fugitive emissions , 1B2aiv, Oil refining and storage	CH_4	0.78	0.0000	0.9999
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	CH_4	0.73	0.0000	1.0000
Energy	Domestic navigation	CH_4	0.71	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	N_2O	0.71	0.0000	1.0000
Agriculture	Field Burning of Agricultural Residues	N_2O	0.70	0.0000	1.0000
Energy	Combustion excluding transport, Other Fuels	CH_4	0.36	0.0000	1.0000
Energy	Railways	CH_4	0.26	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2i, Flaring oil	CH_4	0.16	0.0000	1.0000
Energy	Civil aviation	CH_4	0.10	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2i, Flaring oil	N_2O	0.06	0.0000	1.0000
Industrial processes	Asphalt roofing	CO_2	0.02	0.0000	1.0000
Energy	Fugitive emissions , 1B2b Natural gas transmission and distribution	CO_2	0.01	0.0000	1.0000
Energy	Fugitive emissions , 1B2c Venting	CO_2	0.00	0.0000	1.0000
Solvents and other product use	Degreasing and Dry Cleaning	CO_2	0.00	0.0000	1.0000
Energy	Fugitive emissions , 1B2ai Oil Exploration	CH_4	0.00	0.0000	1.0000
Energy	Fugitive emissions , 1B2ai Oil Exploration	CO_2	0.00	0.0000	1.0000
Energy	Fugitive emissions , 1B2ai Oil Exploration	N_2O	0.00	0.0000	1.0000
Energy	Fugitive emissions , 1B2aii Oil Production	N_2O	0.00	0.0000	1.0000
Industrial processes	Aerosols	HFC	0.00	0.0000	1.0000
Industrial processes	Magnesium Production	SF_6	0.00	0.0000	1.0000
Industrial processes	Other i.e. Fibre Optics	HFC and PFC	0.00	0.0000	1.0000
Total			**69557.81**	**1.000**	

Table 17.5 Key Category Analysis for Denmark and Greenland, level assessment for the base year, incl. LULUCF.

IPCC Source Categories (LULUCF included)		GHG	Base Year Estimate Ex,o Gg CO_2 eqv	Base Year Level Assessment Lx,o	Base Year Cumulative total
Energy	Combustion excluding transport, Solid Fuels	CO_2	23982.67	0.3198	0.3198
Energy	Combustion excluding transport, Liquid Fuels	CO_2	12310.84	0.1642	0.4840
Energy	Road transportation	CO_2	9319.58	0.1243	0.6083
Energy	Combustion excluding transport, Gaseous Fuels	CO_2	4335.40	0.0578	0.6661
Agriculture	Enteric Fermentation	CH_4	3252.95	0.0434	0.7095
LULUCF	Cropland, 5.B Cropland, Organic soils	CO_2	2887.33	0.0385	0.7480
Agriculture	Agriculture soils, indirect, Nitrogen Leaching and Run-off	N_2O	2447.73	0.0326	0.7806
Agriculture	Agriculture soils, direct emissions , Synthetic Fertilizers	N_2O	2353.58	0.0314	0.8120
LULUCF	Cropland, 5.B Cropland, Mineral soils	CO_2	1415.31	0.0189	0.8309
Waste	Solid Waste Disposal Sites	CH_4	1369.41	0.0183	0.8491
Agriculture	Agriculture soils, direct emissions , Animal Manure Appl. to Soils	N_2O	1112.06	0.0148	0.8640
Industrial processes	Nitric acid production	N_2O	1042.90	0.0139	0.8779
Agriculture	Manure Management	CH_4	985.30	0.0131	0.8910
Industrial processes	Cement production	CO_2	882.40	0.0118	0.9028
Energy	Domestic navigation	CO_2	816.48	0.0109	0.9137
LULUCF	Agricultural lime application, 5IV Cropland Limestone	CO_2	622.93	0.0083	0.9220
Agriculture	Manure Management	N_2O	600.42	0.0080	0.9300
Energy	Combustion excluding transport, Other Fuels	CO_2	575.14	0.0077	0.9377
Agriculture	Agriculture soils, indirect, Atmospheric Deposition	N_2O	496.50	0.0066	0.9443
Agriculture	Agriculture soils, direct emissions , Crop Residue	N_2O	361.27	0.0048	0.9491
Agriculture	Agriculture soils, pasture, range and paddock	N_2O	335.05	0.0045	0.9536
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	CO_2	301.85	0.0040	0.9576
Energy	Railways	CO_2	296.75	0.0040	0.9615
Agriculture	Agriculture soils, direct emissions , Cultivation of Histosols	N_2O	290.29	0.0039	0.9654
Energy	Civil aviation	CO_2	281.01	0.0037	0.9692
Agriculture	Agriculture soils, direct emissions , N-fixing Crops	N_2O	269.47	0.0036	0.9728
Industrial processes	Foam Blowing	HFC	182.58	0.0024	0.9752
Industrial processes	Lime production	CO_2	115.53	0.0015	0.9767
LULUCF	Grassland, 5.C Grassland, Organic soils	CO_2	107.14	0.0014	0.9782
Energy	Combustion excluding transport, Biomass	CH_4	103.75	0.0014	0.9795
Energy	Road transportation	N_2O	90.74	0.0012	0.9808
Waste	N_2O indirect from human sewage	N_2O	85.23	0.0011	0.9819
LULUCF	Wetlands, 5D Wetlands, soils	CO_2	84.67	0.0011	0.9830
Energy	Combustion excluding transport, Liquid Fuels	N_2O	84.59	0.0011	0.9841
Solvents and other product use	Other solvent	CO_2	82.61	0.0011	0.9852
LULUCF	Land converted to Forest L., (blank)	CO_2	76.62	0.0010	0.9863
LULUCF	Grassland, 5.C Grassland, Living biomass	CO_2	74.90	0.0010	0.9873
LULUCF	Cropland, 5.B Cropland, Living biomass	CO_2	73.52	0.0010	0.9882
Energy	Combustion excluding transport, Solid Fuels	N_2O	68.11	0.0009	0.9892
Industrial processes	Other emissions of SF6 i.e. from double glaze windows and laboratories	SF_6	67.62	0.0009	0.9901
Waste	Waste Water Handling	CH_4	65.49	0.0009	0.9909
Industrial processes	Other, lubricants	CO_2	49.71	0.0007	0.9916
LULUCF	Forest Land remaining Forest L., (blank)	CO_2	49.60	0.0007	0.9923
Energy	Road transportation	CH_4	46.97	0.0006	0.9929
Energy	Combustion excluding transport, Biomass	N_2O	41.58	0.0006	0.9934
Industrial processes	Refrigeration and AC Equipment	HFC and PFC	35.68	0.0005	0.9939
Waste	N2O direct, Domestic and Commercial Wastewater	N_2O	34.60	0.0005	0.9944
Energy	Fugitive emissions , 1B2aii Oil Production	CH_4	32.03	0.0004	0.9948
Waste	Waste, other	CH_4	30.72	0.0004	0.9952
Industrial processes	Iron and steel production	CO_2	28.45	0.0004	0.9956
Agriculture	Agriculture soils, direct emissions , Sludge	N_2O	27.92	0.0004	0.9960
Industrial processes	Yellow bricks	CO_2	23.02	0.0003	0.9963
Energy	Fugitive emissions , 1B2c2i, Flaring oil	CO_2	22.95	0.0003	0.9966
Solvents and other product use	Chemical Products, Manufacture and Processing	CO_2	19.42	0.0003	0.9968
Waste	Waste, other	CO_2	17.54	0.0002	0.9971
Industrial processes	Glass production	CO_2	17.41	0.0002	0.9973
Energy	Combustion excluding transport, Gaseous Fuels	N_2O	16.38	0.0002	0.9975
LULUCF	Non-CO2 drainage of soils and wetlands, 5IID Forest Land.	N_2O	15.64	0.0002	0.9977
Energy	Domestic navigation	N_2O	15.05	0.0002	0.9979
Industrial processes	Expanded clay	CO_2	14.93	0.0002	0.9981
Industrial processes	Limestone and dolomite use	CO_2	13.69	0.0002	0.9983
Solvents and other product use	Paint application	CO_2	13.23	0.0002	0.9985
LULUCF	Settlements, 5E Total settlements	CO_2	12.92	0.0002	0.9987
Energy	Combustion excluding transport, Solid Fuels	CH_4	12.88	0.0002	0.9988

IPCC Source Categories (LULUCF included)		GHG	Base Year Estimate Ex,o Gg CO_2 eqv	Base Year Level Assessment Lx,o	Base Year Cumulative total
Continued					
Waste	Waste, other	N_2O	12.85	0.0002	0.9990
Energy	Combustion excluding transport, Liquid Fuels	CH_4	11.10	0.0001	0.9992
Energy	Combustion excluding transport, Gaseous Fuels	CH_4	7.77	0.0001	0.9993
Energy	Fugitive emissions , 1B2biv, Gas distribution	CH_4	5.42	0.0001	0.9993
Industrial processes	Food and drink	CO_2	4.45	0.0001	0.9994
Energy	Fugitive emissions , 1B2biii, Gas transmission	CH_4	3.99	0.0001	0.9994
Industrial processes	Electrical equipment	SF6	3.91	0.0001	0.9995
Energy	Civil aviation	N_2O	3.53	0.0000	0.9995
Energy	Combustion excluding transport, Other Fuels	N_2O	2.99	0.0000	0.9996
LULUCF	Cropland, 5.B Cropland, Dead organic matter	CO_2	2.93	0.0000	0.9996
LULUCF	Wetlands, 5D Wetlands Living biomass	CO_2	2.57	0.0000	0.9997
Waste	Waste incineration	CO_2	2.55	0.0000	0.9997
Energy	Railways	N_2O	2.54	0.0000	0.9997
Energy	Fugitive emissions , 1B2aii Oil Production	CO_2	2.38	0.0000	0.9998
Waste	Waste incineration	CH_4	2.27	0.0000	0.9998
Agriculture	Field Burning of Agricultural Residues	CH_4	1.82	0.0000	0.9998
Industrial processes	Road Paving with asphalt	CO_2	1.76	0.0000	0.9998
LULUCF	Grassland, 5.C Grassland, Dead organic matter	CO_2	1.63	0.0000	0.9999
Waste	Waste incineration	N_2O	1.30	0.0000	0.9999
Energy	Fugitive emissions , 1B2c Venting	CH_4	1.23	0.0000	0.9999
Solvents and other product use	Other solvent	N_2O	1.14	0.0000	0.9999
Industrial processes	Catalysts/Fertilizers, Pesticides and Sulphuric acid	CO_2	0.80	0.0000	0.9999
Energy	Fugitive emissions , 1B2aiv, Oil refining and storage	CH_4	0.78	0.0000	0.9999
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	CH_4	0.73	0.0000	0.9999
Energy	Domestic navigation	CH_4	0.71	0.0000	0.9999
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	N_2O	0.71	0.0000	1.0000
Agriculture	Field Burning of Agricultural Residues	N_2O	0.70	0.0000	1.0000
LULUCF	Biomass burning, 5V Biomass burning	CH_4	0.55	0.0000	1.0000
LULUCF	Wetlands, 5D Wetlands, dead org. matter	CO_2	0.54	0.0000	1.0000
LULUCF	Biomass burning, 5V Biomass burning	N_2O	0.45	0.0000	1.0000
Energy	Combustion excluding transport, Other Fuels	CH_4	0.36	0.0000	1.0000
Energy	Railways	CH_4	0.26	0.0000	1.0000
LULUCF	N2O Disturbance, Land converted to cropland, 5III Cropland	N_2O	0.25	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2i, Flaring oil	CH_4	0.16	0.0000	1.0000
LULUCF	Grassland, 5.C Grassland, Mineral soils	CO_2	0.16	0.0000	1.0000
LULUCF	Non-CO2 drainage of soils and wetlands, 5IID Wetlands. Peat-land	N_2O	0.13	0.0000	1.0000
Energy	Civil aviation	CH_4	0.10	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2i, Flaring oil	N_2O	0.06	0.0000	1.0000
Industrial processes	Asphalt roofing	CO_2	0.02	0.0000	1.0000
Energy	Fugitive emissions , 1B2b Natural gas transmission and distribu-tion	CO_2	0.01	0.0000	1.0000
Energy	Fugitive emissions , 1B2c Venting	CO_2	0.00	0.0000	1.0000
Solvents and other product use	Degreasing and Dry Cleaning	CO_2	0.00	0.0000	1.0000
Energy	Fugitive emissions , 1B2ai Oil Exploration	CH_4	0.00	0.0000	1.0000
Energy	Fugitive emissions , 1B2ai Oil Exploration	CO_2	0.00	0.0000	1.0000
Energy	Fugitive emissions , 1B2ai Oil Exploration	N_2O	0.00	0.0000	1.0000
Energy	Fugitive emissions , 1B2aii Oil Production	N_2O	0.00	0.0000	1.0000
Industrial processes	Aerosols	HFC	0.00	0.0000	1.0000
Industrial processes	Magnesium Production	SF_6	0.00	0.0000	1.0000
Industrial processes	Other i.e. Fibre Optics	HFC and PFC	0.00	0.0000	1.0000
Total			**74987.62**	**1.000**	

Table 17.6 Key Category Analysis for Denmark and Greenland, level assessment for the reporting year, excl. LULUCF.

IPCC Source Categories (LULUCF excluded)		GHG	Reporting Year Estimate Ex,t Gg CO_2 eqv	Reporting Year Level Assessment Lx,t	Reporting Year Cumulative total
Energy	Road transportation	CO_2	11257.01	0.2155	0.2155
Energy	Combustion excluding transport, Solid Fuels	CO_2	10080.46	0.1929	0.4084
Energy	Combustion excluding transport, Gaseous Fuels	CO_2	8293.11	0.1587	0.5671
Energy	Combustion excluding transport, Liquid Fuels	CO_2	6602.22	0.1264	0.6935
Agriculture	Enteric Fermentation	CH_4	2909.18	0.0557	0.7492
Agriculture	Agriculture soils, indirect, Nitrogen Leaching and Run-off	N_2O	1430.55	0.0274	0.7765
Energy	Combustion excluding transport, Other Fuels	CO_2	1403.99	0.0269	0.8034
Agriculture	Manure Management	CH_4	1297.30	0.0248	0.8282
Agriculture	Agriculture soils, direct emissions , Animal Manure Appl. to Soils	N_2O	1161.67	0.0222	0.8505
Agriculture	Agriculture soils, direct emissions , Synthetic Fertilizers	N_2O	1104.26	0.0211	0.8716
Industrial processes	Cement production	CO_2	871.08	0.0167	0.8883
Waste	Solid Waste Disposal Sites	CH_4	701.94	0.0134	0.9017
Industrial processes	Refrigeration and AC Equipment	HFC and PFC	586.60	0.0112	0.9129
Energy	Domestic navigation	CO_2	527.38	0.0101	0.9230
Agriculture	Manure Management	N_2O	391.42	0.0075	0.9305
Agriculture	Agriculture soils, direct emissions , Crop Residue	N_2O	311.30	0.0060	0.9365
Agriculture	Agriculture soils, indirect, Atmospheric Deposition	N_2O	294.70	0.0056	0.9421
Agriculture	Agriculture soils, direct emissions , N-fixing Crops	N_2O	256.21	0.0049	0.9470
Energy	Railways	CO_2	249.33	0.0048	0.9518
Agriculture	Agriculture soils, pasture, range and paddock	N_2O	211.53	0.0040	0.9559
Agriculture	Agriculture soils, direct emissions , Cultivation of Histo-sols	N_2O	198.45	0.0038	0.9597
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	CO_2	194.57	0.0037	0.9634
Energy	Civil aviation	CO_2	179.28	0.0034	0.9668
Energy	Combustion excluding transport, Biomass	CH_4	167.06	0.0032	0.9700
Waste	Waste, other	N_2O	126.83	0.0024	0.9724
Energy	Combustion excluding transport, Gaseous Fuels	CH_4	126.02	0.0024	0.9748
Solvents and other product use	Other solvent	CO_2	125.22	0.0024	0.9772
Energy	Road transportation	N_2O	116.53	0.0022	0.9795
Industrial processes	Other emissions of SF6 i.e. from double glaze windows and laboratories	SF6	104.59	0.0020	0.9815
Energy	Combustion excluding transport, Biomass	N_2O	99.62	0.0019	0.9834
Waste	Waste, other	CH_4	91.97	0.0018	0.9851
Waste	Waste Water Handling	CH_4	74.00	0.0014	0.9866
Industrial processes	Foam Blowing	HFC	66.18	0.0013	0.9878
Energy	Combustion excluding transport, Liquid Fuels	N_2O	55.36	0.0011	0.9889
Energy	Fugitive emissions , 1B2aii Oil Production	CH_4	54.20	0.0010	0.9899
Waste	N2O direct, Domestic and Commercial Wastewater	N_2O	49.46	0.0009	0.9909
Energy	Fugitive emissions , 1B2aiv, Oil refining and storage	CH_4	46.76	0.0009	0.9918
Industrial processes	Lime production	CO_2	40.17	0.0008	0.9925
Agriculture	Agriculture soils, direct emissions , Sludge	N_2O	38.76	0.0007	0.9933
Waste	N2O indirect from human sewage	N_2O	35.17	0.0007	0.9939
Industrial processes	Other, lubricants	CO_2	31.70	0.0006	0.9946
Energy	Combustion excluding transport, Solid Fuels	N_2O	27.45	0.0005	0.9951
Industrial processes	Limestone and dolomite use	CO_2	25.64	0.0005	0.9956
Energy	Combustion excluding transport, Gaseous Fuels	N_2O	24.45	0.0005	0.9960
Energy	Fugitive emissions , 1B2c2i, Flaring oil	CO_2	22.33	0.0004	0.9965
Industrial processes	Yellow bricks	CO_2	17.48	0.0003	0.9968
Waste	Waste, other	CO_2	16.36	0.0003	0.9971
Industrial processes	Aerosols	HFC	15.83	0.0003	0.9974
Industrial processes	Electrical equipment	SF6	13.27	0.0003	0.9977
Solvents and other product use	Chemical Products, Manufacture and Processing	CO_2	12.17	0.0002	0.9979
Solvents and other product use	Other solvent	N_2O	11.93	0.0002	0.9981
Energy	Road transportation	CH_4	11.40	0.0002	0.9983
Industrial processes	Glass production	CO_2	9.69	0.0002	0.9985
Energy	Combustion excluding transport, Liquid Fuels	CH_4	9.59	0.0002	0.9987
Energy	Domestic navigation	N_2O	8.94	0.0002	0.9989
Energy	Combustion excluding transport, Other Fuels	N_2O	7.23	0.0001	0.9990
Solvents and other product use	Paint application	CO_2	7.23	0.0001	0.9992
Industrial processes	Expanded clay	CO_2	5.89	0.0001	0.9993

IPCC Source Categories (LULUCF excluded)		GHG	Reporting Year Estimate Ex,t Gg CO_2 eqv	Reporting Year Level Assessment Lx,t	Reporting Year Cumulative total
Continued					
Industrial processes	Other i.e. Fibre Optics	HFC and PFC	4.31	0.0001	0.9994
Energy	Fugitive emissions , 1B2aii Oil Production	CO_2	3.71	0.0001	0.9994
Waste	Waste incineration	CO_2	3.13	0.0001	0.9995
Energy	Combustion excluding transport, Solid Fuels	CH_4	3.12	0.0001	0.9996
Energy	Fugitive emissions , 1B2biv, Gas distribution	CH_4	3.08	0.0001	0.9996
Energy	Civil aviation	N_2O	2.48	0.0000	0.9997
Agriculture	Field Burning of Agricultural Residues	CH_4	2.43	0.0000	0.9997
Industrial processes	Food and drink	CO_2	2.24	0.0000	0.9997
Energy	Railways	N_2O	2.13	0.0000	0.9998
Industrial processes	Road Paving with asphalt	CO_2	1.77	0.0000	0.9998
Waste	Waste incineration	CH_4	1.61	0.0000	0.9999
Industrial processes	Catalysts/Fertilizers, Pesticides and Sulphuric acid	CO_2	1.41	0.0000	0.9999
Energy	Fugitive emissions , 1B2c Venting	CH_4	1.21	0.0000	0.9999
Waste	Waste incineration	N_2O	1.08	0.0000	0.9999
Agriculture	Field Burning of Agricultural Residues	N_2O	0.93	0.0000	0.9999
Energy	Combustion excluding transport, Other Fuels	CH_4	0.77	0.0000	1.0000
Energy	Domestic navigation	CH_4	0.75	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	N_2O	0.47	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	CH_4	0.32	0.0000	1.0000
Energy	Fugitive emissions , 1B2biii, Gas transmission	CH_4	0.29	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2i, Flaring oil	CH_4	0.16	0.0000	1.0000
Energy	Railways	CH_4	0.15	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2i, Flaring oil	N_2O	0.06	0.0000	1.0000
Energy	Civil aviation	CH_4	0.06	0.0000	1.0000
Industrial processes	Asphalt roofing	CO_2	0.02	0.0000	1.0000
Energy	Fugitive emissions , 1B2b Natural gas transmission and distribution	CO_2	0.01	0.0000	1.0000
Energy	Fugitive emissions , 1B2c Venting	CO_2	0.00	0.0000	1.0000
Solvents and other product use	Degreasing and Dry Cleaning	CO_2	0.00	0.0000	1.0000
Industrial processes	Magnesium Production	SF6	0.00	0.0000	1.0000
Energy	Fugitive emissions , 1B2ai Oil Exploration	CH_4	0.00	0.0000	1.0000
Energy	Fugitive emissions , 1B2ai Oil Exploration	CO_2	0.00	0.0000	1.0000
Energy	Fugitive emissions , 1B2ai Oil Exploration	N_2O	0.00	0.0000	1.0000
Energy	Fugitive emissions , 1B2aii Oil Production	N_2O	0.00	0.0000	1.0000
Industrial processes	Nitric acid production	N_2O	0.00	0.0000	1.0000
Industrial processes	Iron and steel production	CO_2	0.00	0.0000	1.0000
Total			**52247.69**	**1.000**	

Table 17.7 Key Category Analysis for Denmark and Greenland, level assessment for the reporting year, incl. LULUCF.

IPCC Source Categories (LULUCF included)		GHG	Reporting Year Estimate Ex,t Gg CO_2 eqv	Reporting Year Level Assessment Lx,t	Reporting Year Cumulative total
Energy	Road transportation	CO_2	11257.01	0.1864	0.1864
Energy	Combustion excluding transport, Solid Fuels	CO_2	10080.46	0.1669	0.3533
Energy	Combustion excluding transport, Gaseous Fuels	CO_2	8293.11	0.1373	0.4906
Energy	Combustion excluding transport, Liquid Fuels	CO_2	6602.22	0.1093	0.5999
LULUCF	Forest Land remaining Forest L., (blank)	CO_2	4491.41	0.0744	0.6743
Agriculture	Enteric Fermentation	CH_4	2909.18	0.0482	0.7225
LULUCF	Cropland, 5.B Cropland, Organic soils	CO_2	1980.76	0.0328	0.7553
Agriculture	Agriculture soils, indirect, Nitrogen Leaching and Run-off	N_2O	1430.55	0.0237	0.7790
Energy	Combustion excluding transport, Other Fuels	CO_2	1403.99	0.0232	0.8022
Agriculture	Manure Management	CH_4	1297.30	0.0215	0.8237
Agriculture	Agriculture soils, direct emissions , Animal Manure Appl. to Soils	N_2O	1161.67	0.0192	0.8429
Agriculture	Agriculture soils, direct emissions , Synthetic Fertilizers	N_2O	1104.26	0.0183	0.8612
Industrial processes	Cement production	CO_2	871.08	0.0144	0.8756
Waste	Solid Waste Disposal Sites	CH_4	701.94	0.0116	0.8873
Industrial processes	Refrigeration and AC Equipment	HFC and PFC	586.60	0.0097	0.8970
LULUCF	Cropland, 5.B Cropland, Mineral soils	CO_2	577.08	0.0096	0.9065
Energy	Domestic navigation	CO_2	527.38	0.0087	0.9153
LULUCF	Grassland, 5.C Grassland, Living biomass	CO_2	463.33	0.0077	0.9229
Agriculture	Manure Management	N_2O	391.42	0.0065	0.9294
Agriculture	Agriculture soils, direct emissions , Crop Residue	N_2O	311.30	0.0052	0.9346
Agriculture	Agriculture soils, indirect, Atmospheric Deposition	N_2O	294.70	0.0049	0.9394
Agriculture	Agriculture soils, direct emissions , N-fixing Crops	N_2O	256.21	0.0042	0.9437
Energy	Railways	CO_2	249.33	0.0041	0.9478
Agriculture	Agriculture soils, pasture, range and paddock	N_2O	211.53	0.0035	0.9513
Agriculture	Agriculture soils, direct emissions , Cultivation of Histosols	N_2O	198.45	0.0033	0.9546
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	CO_2	194.57	0.0032	0.9578
LULUCF	Cropland, 5.B Cropland, Living biomass	CO_2	192.99	0.0032	0.9610
LULUCF	Agricultural lime application, 5IV Cropland Limestone	CO_2	192.30	0.0032	0.9642
Energy	Civil aviation	CO_2	179.28	0.0030	0.9672
Energy	Combustion excluding transport, Biomass	CH_4	167.06	0.0028	0.9699
Waste	Waste, other	N_2O	126.83	0.0021	0.9720
Energy	Combustion excluding transport, Gaseous Fuels	CH_4	126.02	0.0021	0.9741
Solvents and other product use	Other solvent	CO_2	125.22	0.0021	0.9762
Energy	Road transportation	N_2O	116.53	0.0019	0.9781
Industrial processes	Other emissions of SF6 i.e. from double glaze windows and laboratories	SF6	104.59	0.0017	0.9799
Energy	Combustion excluding transport, Biomass	N_2O	99.62	0.0016	0.9815
Waste	Waste, other	CH_4	91.97	0.0015	0.9830
LULUCF	Settlements, 5E Total settlements	CO_2	90.81	0.0015	0.9845
LULUCF	Grassland, 5.C Grassland, Organic soils	CO_2	79.91	0.0013	0.9859
Waste	Waste Water Handling	CH_4	74.00	0.0012	0.9871
Industrial processes	Foam Blowing	HFC	66.18	0.0011	0.9882
Energy	Combustion excluding transport, Liquid Fuels	N_2O	55.36	0.0009	0.9891
Energy	Fugitive emissions , 1B2aii Oil Production	CH_4	54.20	0.0009	0.9900
Waste	N_2O direct, Domestic and Commercial Wastewater	N_2O	49.46	0.0008	0.9908
Energy	Fugitive emissions , 1B2aiv, Oil refining and storage	CH_4	46.76	0.0008	0.9916
Industrial processes	Lime production	CO_2	40.17	0.0007	0.9923
Agriculture	Agriculture soils, direct emissions , Sludge	N_2O	38.76	0.0006	0.9929
LULUCF	Land converted to Forest L., (blank)	CO_2	37.83	0.0006	0.9935
Waste	N_2O indirect from human sewage	N_2O	35.17	0.0006	0.9941
Industrial processes	Other, lubricants	CO_2	31.70	0.0005	0.9946
Energy	Combustion excluding transport, Solid Fuels	N_2O	27.45	0.0005	0.9951
Industrial processes	Limestone and dolomite use	CO_2	25.64	0.0004	0.9955
Energy	Combustion excluding transport, Gaseous Fuels	N_2O	24.45	0.0004	0.9959
Energy	Fugitive emissions , 1B2c2i, Flaring oil	CO_2	22.33	0.0004	0.9963
Industrial processes	Yellow bricks	CO_2	17.48	0.0003	0.9966
Waste	Waste, other	CO_2	16.36	0.0003	0.9968
Industrial processes	Aerosols	HFC	15.83	0.0003	0.9971
Industrial processes	Electrical equipment	SF6	13.27	0.0002	0.9973
Solvents and other product use	Chemical Products, Manufacture and Processing	CO2	12.17	0.0002	0.9975
LULUCF	Cropland, 5.B Cropland, Dead organic matter	CO_2	12.16	0.0002	0.9977
LULUCF	Non-CO_2 drainage of soils and wetlands, 5IID Forest Land.	N_2O	12.07	0.0002	0.9979

IPCC Source Categories (LULUCF included)		GHG	Reporting Year Estimate Ex,t Gg CO_2 eqv	Reporting Year Level Assessment Lx,t	Reporting Year Cumula-tive total
Continued					
Solvents and other product use	Other solvent	N_2O	11.93	0.0002	0.9981
Energy	Road transportation	CH_4	11.40	0.0002	0.9983
Industrial processes	Glass production	CO_2	9.69	0.0002	0.9985
Energy	Combustion excluding transport, Liquid Fuels	CH_4	9.59	0.0002	0.9986
Energy	Domestic navigation	N_2O	8.94	0.0001	0.9988
Energy	Combustion excluding transport, Other Fuels	N_2O	7.23	0.0001	0.9989
Solvents and other product use	Paint application	CO_2	7.23	0.0001	0.9990
LULUCF	Grassland, 5.C Grassland, Dead organic matter	CO_2	7.04	0.0001	0.9991
Industrial processes	Expanded clay	CO_2	5.89	0.0001	0.9992
LULUCF	Grassland, 5.C Grassland, Mineral soils	CO_2	4.54	0.0001	0.9993
Industrial processes	Other i.e. Fibre Optics	HFC and PFC	4.31	0.0001	0.9994
Energy	Fugitive emissions , 1B2aii Oil Production	CO_2	3.71	0.0001	0.9994
Waste	Waste incineration	CO_2	3.13	0.0001	0.9995
Energy	Combustion excluding transport, Solid Fuels	CH_4	3.12	0.0001	0.9995
Energy	Fugitive emissions , 1B2biv, Gas distribution	CH_4	3.08	0.0001	0.9996
LULUCF	Wetlands, 5D Wetlands, soils	CO_2	2.50	0.0000	0.9996
Energy	Civil aviation	N_2O	2.48	0.0000	0.9997
Agriculture	Field Burning of Agricultural Residues	CH_4	2.43	0.0000	0.9997
Industrial processes	Food and drink	CO_2	2.24	0.0000	0.9998
Energy	Railways	N_2O	2.13	0.0000	0.9998
Industrial processes	Road Paving with asphalt	CO_2	1.77	0.0000	0.9998
Waste	Waste incineration	CH_4	1.61	0.0000	0.9998
Industrial processes	Catalysts/Fertilizers, Pesticides and Sulphuric acid	CO_2	1.41	0.0000	0.9999
Energy	Fugitive emissions , 1B2c Venting	CH_4	1.21	0.0000	0.9999
Waste	Waste incineration	N_2O	1.08	0.0000	0.9999
LULUCF	N2O Disturbance, Land converted to cropland, 5III Cropland	N_2O	1.01	0.0000	0.9999
Agriculture	Field Burning of Agricultural Residues	N_2O	0.93	0.0000	0.9999
Energy	Combustion excluding transport, Other Fuels	CH_4	0.77	0.0000	1.0000
Energy	Domestic navigation	CH_4	0.75	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	N_2O	0.47	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	CH_4	0.32	0.0000	1.0000
Energy	Fugitive emissions , 1B2biii, Gas transmission	CH_4	0.29	0.0000	1.0000
LULUCF	Wetlands, 5D Wetlands Living biomass	CO_2	0.22	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2i, Flaring oil	CH_4	0.16	0.0000	1.0000
Energy	Railways	CH_4	0.15	0.0000	1.0000
LULUCF	Non-CO2 drainage of soils and wetlands, 5IID Wetlands. Peatland	N_2O	0.13	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2i, Flaring oil	N_2O	0.06	0.0000	1.0000
Energy	Civil aviation	CH_4	0.06	0.0000	1.0000
LULUCF	Biomass burning, 5V Biomass burning	N_2O	0.03	0.0000	1.0000
LULUCF	Biomass burning, 5V Biomass burning	CH_4	0.02	0.0000	1.0000
Industrial processes	Asphalt roofing	CO_2	0.02	0.0000	1.0000
Energy	Fugitive emissions , 1B2b Natural gas transmission and distribution	CO_2	0.01	0.0000	1.0000
Energy	Fugitive emissions , 1B2c Venting	CO_2	0.00	0.0000	1.0000
Solvents and other product use	Degreasing and Dry Cleaning	CO_2	0.00	0.0000	1.0000
Industrial processes	Magnesium Production	SF6	0.00	0.0000	1.0000
Energy	Fugitive emissions , 1B2ai Oil Exploration	CH_4	0.00	0.0000	1.0000
Energy	Fugitive emissions , 1B2ai Oil Exploration	CO_2	0.00	0.0000	1.0000
Energy	Fugitive emissions , 1B2ai Oil Exploration	N_2O	0.00	0.0000	1.0000
Energy	Fugitive emissions , 1B2aii Oil Production	N_2O	0.00	0.0000	1.0000
LULUCF	Wetlands, 5D Wetlands, dead org. matter	CO_2	0.00	0.0000	1.0000
Industrial processes	Nitric acid production	N_2O	0.00	0.0000	1.0000
Industrial processes	Iron and steel production	CO_2	0.00	0.0000	1.0000
Total			**60393.85**	**1.000**	

Table 17.8 Key Category Analysis for Denmark and Greenland, trend assessment, excl. LULUCF.

IPCC Source Categories (LULUCF excluded)		**GHG**	**Base Year Estimate Ex,o Gg CO_2 eq**	**Year 2012 Estimate Ex,t Gg CO_2 eq**	**Trend Asses-sment Tx,t**	**Contribution to Trend**	**Cumulative total**
Energy	Combustion excluding transport, Solid Fuels	CO_2	23982.67	10080.46	0.2661	0.4093	0.4093
Energy	Combustion excluding transport, Liquid Fuels	CO_2	12310.84	6602.22	0.1093	0.1681	0.5774
Energy	Combustion excluding transport, Gaseous Fuels	CO_2	4335.40	8293.11	0.0757	0.1165	0.6939
Energy	Road transportation	CO_2	9319.58	11257.01	0.0371	0.0570	0.7509
Agriculture	Agriculture soils, direct emissions , Synthetic Fertilizers	N_2O	2353.58	1104.26	0.0239	0.0368	0.7877
Industrial processes	Nitric acid production	N_2O	1042.90	0.00	0.0200	0.0307	0.8184
Agriculture	Agriculture soils, indirect, Nitrogen Leaching and Run-off	N_2O	2447.73	1430.55	0.0195	0.0299	0.8484
Energy	Combustion excluding transport, Other Fuels	CO_2	575.14	1403.99	0.0159	0.0244	0.8728
Waste	Solid Waste Disposal Sites	CH_4	1369.41	701.94	0.0128	0.0197	0.8924
Industrial processes	Refrigeration and AC Equipment	HFC and PFC	35.68	586.60	0.0105	0.0162	0.9087
Agriculture	Enteric Fermentation	CH_4	3252.95	2909.18	0.0066	0.0101	0.9188
Agriculture	Manure Management	CH_4	985.30	1297.30	0.0060	0.0092	0.9280
Energy	Domestic navigation	CO_2	816.48	527.38	0.0055	0.0085	0.9365
Agriculture	Manure Management	N_2O	600.42	391.42	0.0040	0.0062	0.9426
Agriculture	Agriculture soils, indirect, Atmospheric Deposition	N_2O	496.50	294.70	0.0039	0.0059	0.9486
Agriculture	Agriculture soils, pasture, range and paddock	N_2O	335.05	211.53	0.0024	0.0036	0.9522
Energy	Combustion excluding transport, Gaseous Fuels	CH_4	7.77	126.02	0.0023	0.0035	0.9557
Industrial processes	Foam Blowing	HFC	182.58	66.18	0.0022	0.0034	0.9591
Waste	Waste, other	N_2O	12.85	126.83	0.0022	0.0034	0.9625
Energy	Fugitive emissions, 1B2c2ii, Flaring gas	CO_2	301.85	194.57	0.0021	0.0032	0.9656
Energy	Civil aviation	CO_2	281.01	179.28	0.0019	0.0030	0.9686
Agriculture	Agriculture soils, direct emissions , Cultivation of Histosols	N_2O	290.29	198.45	0.0018	0.0027	0.9713
Industrial processes	Lime production	CO_2	115.53	40.17	0.0014	0.0022	0.9736
Energy	Combustion excluding transport, Biomass	CH_4	103.75	167.06	0.0012	0.0019	0.9754
Waste	Waste, other	CH_4	30.72	91.97	0.0012	0.0018	0.9772
Energy	Combustion excluding transport, Biomass	N_2O	41.58	99.62	0.0011	0.0017	0.9789
Waste	N_2O indirect from human sewage	N_2O	85.23	35.17	0.0010	0.0015	0.9804
Agriculture	Agriculture soils, direct emissions , Crop Residue	N_2O	361.27	311.30	0.0010	0.0015	0.9819
Agriculture	Agriculture soils, direct emissions , Animal Manure Appl. to Soils	N_2O	1112.06	1161.67	0.0009	0.0015	0.9833
Energy	Railways	CO_2	296.75	249.33	0.0009	0.0014	0.9847
Energy	Fugitive emissions , 1B2aiv, Oil refining and storage	CH_4	0.78	46.76	0.0009	0.0014	0.9861
Solvents and other product use	Other solvent	CO_2	82.61	125.22	0.0008	0.0013	0.9873
Energy	Combustion excluding transport, Solid Fuels	N_2O	68.11	27.45	0.0008	0.0012	0.9885
Industrial processes	Other emissions of SF_6 i.e. from double glaze windows and laboratories	SF_6	67.62	104.59	0.0007	0.0011	0.9896
Energy	Road transportation	CH_4	46.97	11.40	0.0007	0.0010	0.9907
Energy	Combustion excluding transport, Liquid Fuels	N_2O	84.59	55.36	0.0006	0.0009	0.9915
Industrial processes	Iron and steel production	CO_2	28.45	0.00	0.0005	0.0008	0.9924
Energy	Road transportation	N_2O	90.74	116.53	0.0005	0.0008	0.9931
Energy	Fugitive emissions , 1B2aii Oil Production	CH_4	32.03	54.20	0.0004	0.0007	0.9938
Industrial processes	Other, lubricants	CO_2	49.71	31.70	0.0003	0.0005	0.9943
Industrial processes	Aerosols	HFC	0.00	15.83	0.0003	0.0005	0.9948
Waste	N_2O direct, Domestic and Commercial Wastewater	N_2O	34.60	49.46	0.0003	0.0004	0.9952
Agriculture	Agriculture soils, direct emissions , N-fixing Crops	N_2O	269.47	256.21	0.0003	0.0004	0.9956
Industrial processes	Limestone and dolomite use	CO_2	13.69	25.64	0.0002	0.0004	0.9960

IPCC Source Categories (LULUCF excluded)		GHG	Base Year Estimate Ex,o Gg CO_2 eq	Year 2012 Estimate Ex,t Gg CO_2 eq	Trend Asses-sment Tx,t	Contribution to Trend	Cumulative total
Continued							
Industrial processes	Cement production	CO_2	882.40	871.08	0.0002	0.0003	0.9963
Agriculture	Agriculture soils, direct emissions , Sludge	N_2O	27.92	38.76	0.0002	0.0003	0.9966
Solvents and other product use	Other solvent	N_2O	1.14	11.93	0.0002	0.0003	0.9969
Energy	Combustion excluding transport, Solid Fuels	CH_4	12.88	3.12	0.0002	0.0003	0.9972
Industrial processes	Electrical equipment	SF_6	3.91	13.27	0.0002	0.0003	0.9975
Industrial processes	Expanded clay	CO_2	14.93	5.89	0.0002	0.0003	0.9978
Waste	Waste Water Handling	CH_4	65.49	74.00	0.0002	0.0003	0.9980
Energy	Combustion excluding transport, Gaseous Fuels	N_2O	16.38	24.45	0.0002	0.0002	0.9982
Industrial processes	Glass production	CO_2	17.41	9.69	0.0001	0.0002	0.9985
Solvents and other product use	Chemical Products, Manufacture and Processing	CO_2	19.42	12.17	0.0001	0.0002	0.9987
Energy	Domestic navigation	N_2O	15.05	8.94	0.0001	0.0002	0.9989
Solvents and other product use	Paint application	CO_2	13.23	7.23	0.0001	0.0002	0.9990
Industrial processes	Yellow bricks	CO_2	23.02	17.48	0.0001	0.0002	0.9992
Industrial processes	Other i.e. Fibre Optics	HFC and PFC	0.00	4.31	0.0001	0.0001	0.9993
Energy	Combustion excluding transport, Other Fuels	N_2O	2.99	7.23	0.0001	0.0001	0.9995
Energy	Fugitive emissions , 1B2biii, Gas transmission	CH_4	3.99	0.29	0.0001	0.0001	0.9996
Energy	Fugitive emissions , 1B2biv, Gas distribution	CH_4	5.42	3.08	0.0000	0.0001	0.9996
Industrial processes	Food and drink	CO_2	4.45	2.24	0.0000	0.0001	0.9997
Energy	Combustion excluding transport, Liquid Fuels	CH_4	11.10	9.59	0.0000	0.0000	0.9997
Energy	Fugitive emissions , 1B2aii Oil Production	CO_2	2.38	3.71	0.0000	0.0000	0.9998
Waste	Waste, other	CO_2	17.54	16.36	0.0000	0.0000	0.9998
Energy	Civil aviation	N_2O	3.53	2.48	0.0000	0.0000	0.9998
Waste	Waste incineration	CH_4	2.27	1.61	0.0000	0.0000	0.9999
Energy	Fugitive emissions , 1B2c2i, Flaring oil	CO_2	22.95	22.33	0.0000	0.0000	0.9999
Industrial processes	Catalysts/Fertilizers, Pesticides and Sulphuric acid	CO_2	0.80	1.41	0.0000	0.0000	0.9999
Agriculture	Field Burning of Agricultural Residues	CH_4	1.82	2.43	0.0000	0.0000	0.9999
Waste	Waste incineration	CO_2	2.55	3.13	0.0000	0.0000	0.9999
Energy	Combustion excluding transport, Other Fuels	CH_4	0.36	0.77	0.0000	0.0000	0.9999
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	CH_4	0.73	0.32	0.0000	0.0000	1.0000
Energy	Railways	N_2O	2.54	2.13	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	N_2O	0.71	0.47	0.0000	0.0000	1.0000
Agriculture	Field Burning of Agricultural Residues	N_2O	0.70	0.93	0.0000	0.0000	1.0000
Waste	Waste incineration	N_2O	1.30	1.08	0.0000	0.0000	1.0000
Energy	Railways	CH_4	0.26	0.15	0.0000	0.0000	1.0000
Energy	Domestic navigation	CH_4	0.71	0.75	0.0000	0.0000	1.0000
Energy	Civil aviation	CH_4	0.10	0.06	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2c Venting	CH_4	1.23	1.21	0.0000	0.0000	1.0000
Industrial processes	Road Paving with asphalt	CO_2	1.76	1.77	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2i, Flaring oil	CH_4	0.16	0.16	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2b Natural gas transmission and distribution	CO_2	0.01	0.01	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2i, Flaring oil	N_2O	0.06	0.06	0.0000	0.0000	1.0000
Solvents and other product use	Degreasing and Dry Cleaning	CO_2	0.00	0.00	0.0000	0.0000	1.0000
Industrial processes	Asphalt roofing	CO_2	0.02	0.02	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2c Venting	CO_2	0.00	0.00	0.0000	0.0000	1.0000
Industrial processes	Magnesium Production	SF_6	0.00	0.00	0.0000	0.0000	1.0000

IPCC Source Categories (LULUCF excluded)		GHG	Base Year Estimate Ex,o Gg CO_2 eq	Year 2012 Estimate Ex,t Gg CO_2 eq	Trend Asses-sment Tx,t	Contribution to Trend	Cumulative total
Continued							
Energy	Fugitive emissions , 1B2ai Oil Exploration	CH_4	0.00	0.00	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2ai Oil Exploration	CO_2	0.00	0.00	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2ai Oil Exploration	N_2O	0.00	0.00	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2aii Oil Production	N_2O	0.00	0.00	0.0000	0.0000	1.0000
Total			**69557.81**	**52247.69**		**1.0000**	

Table 17.9 Key Category Analysis for Denmark and Greenland, trend assessment, incl. LULUCF.

IPCC Source Categories (LULUCF included)		GHG	Base Year Estimate Ex,o Gg CO_2 eq	Year 2012 Estimate Ex,t Gg CO_2 eq	Trend Assessment Tx,t	Contribition to Trend	Cumulative total
Energy	Combustion excluding transport, Solid Fuels	CO_2	23982.671	10080.462	0.2310	0.3348	0.3348
Energy	Combustion excluding transport, Liquid Fuels	CO_2	12310.843	6602.223	0.0949	0.1376	0.4723
LULUCF	Forest Land remaining Forest L., (blank)	CO_2	49.604	-4491.413	0.0752	0.1090	0.5813
Energy	Combustion excluding transport, Gaseous Fuels	CO_2	4335.403	8293.108	0.0654	0.0948	0.6761
Energy	Road transportation	CO_2	9319.578	11257.010	0.0318	0.0461	0.7221
Agriculture	Agriculture soils, direct emissions , Synthetic Fertilizers	N_2O	2353.581	1104.262	0.0208	0.0301	0.7522
Industrial processes	Nitric acid production	N_2O	1042.902	0.000	0.0173	0.0251	0.7773
Agriculture	Agriculture soils, indirect, Nitrogen Leaching and Run-off	N_2O	2447.727	1430.546	0.0169	0.0245	0.8018
LULUCF	Cropland, 5.B Cropland, Organic soils	CO_2	2887.334	1980.757	0.0151	0.0219	0.8237
LULUCF	Cropland, 5.B Cropland, Mineral soils	CO_2	1415.313	577.084	0.0139	0.0202	0.8439
Energy	Combustion excluding transport, Other Fuels	CO_2	575.139	1403.989	0.0137	0.0199	0.8638
Waste	Solid Waste Disposal Sites	CH_4	1369.408	701.938	0.0111	0.0161	0.8799
Industrial processes	Refrigeration and AC Equipment	HFC and PFC	35.677	586.597	0.0091	0.0132	0.8931
LULUCF	Agricultural lime application, 5IV Cropland Limestone	CO_2	622.931	192.305	0.0072	0.0104	0.9034
LULUCF	Grassland, 5.C Grassland, Living biomass	CO_2	74.899	463.334	0.0064	0.0093	0.9128
Agriculture	Enteric Fermentation	CH_4	3252.947	2909.179	0.0058	0.0084	0.9212
Agriculture	Manure Management	CH_4	985.298	1297.300	0.0051	0.0074	0.9286
Energy	Domestic navigation	CO_2	816.479	527.378	0.0048	0.0070	0.9356
LULUCF	Cropland, 5.B Cropland, Living biomass	CO_2	-73.524	192.986	0.0044	0.0064	0.9420
Agriculture	Manure Management	N_2O	600.423	391.416	0.0035	0.0050	0.9470
Agriculture	Agriculture soils, indirect, Atmospheric Deposition	N_2O	496.501	294.695	0.0034	0.0049	0.9519
Agriculture	Agriculture soils, pasture, range and paddock	N_2O	335.049	211.525	0.0021	0.0030	0.9549
Energy	Combustion excluding transport, Gaseous Fuels	CH_4	7.769	126.015	0.0020	0.0028	0.9577
Industrial processes	Foam Blowing	HFC	182.578	66.176	0.0019	0.0028	0.9605
Waste	Waste, other	N_2O	12.853	126.828	0.0019	0.0027	0.9632
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	CO_2	301.847	194.572	0.0018	0.0026	0.9658
Energy	Civil aviation	CO_2	281.013	179.283	0.0017	0.0025	0.9683
Agriculture	Agriculture soils, direct emissions , Cultivation of Histosols	N_2O	290.294	198.450	0.0015	0.0022	0.9705
LULUCF	Wetlands, 5D Wetlands, soils	CO_2	84.667	2.497	0.0014	0.0020	0.9725
LULUCF	Settlements, 5E Total settlements	CO_2	12.921	90.806	0.0013	0.0019	0.9743
Industrial processes	Lime production	CO_2	115.532	40.166	0.0013	0.0018	0.9762
Energy	Combustion excluding transport, Biomass	CH_4	103.754	167.060	0.0010	0.0015	0.9777
Waste	Waste, other	CH_4	30.723	91.971	0.0010	0.0015	0.9791
Energy	Combustion excluding transport, Biomass	N_2O	41.576	99.615	0.0010	0.0014	0.9805
Agriculture	Agriculture soils, direct emissions , Crop Residue	N_2O	361.266	311.296	0.0008	0.0012	0.9817
Waste	N2O indirect from human sewage	N_2O	85.233	35.172	0.0008	0.0012	0.9830
Energy	Railways	CO_2	296.745	249.325	0.0008	0.0012	0.9841
Agriculture	Agriculture soils, direct emissions , Animal Manure Appl. to Soils	N_2O	1112.058	1161.673	0.0008	0.0011	0.9852
Energy	Fugitive emissions , 1B2aiv, Oil refining and storage	CH_4	0.778	46.761	0.0008	0.0011	0.9863
Solvents and other product use	Other solvent	CO_2	82.610	125.216	0.0007	0.0010	0.9874
Energy	Combustion excluding transport, Solid Fuels	N_2O	68.113	27.452	0.0007	0.0010	0.9883
LULUCF	Land converted to Forest L., (blank)	CO_2	76.621	37.833	0.0006	0.0009	0.9893
Industrial processes	Other emissions of SF6 i.e. from double glaze windows and laboratories	SF_6	67.616	104.589	0.0006	0.0009	0.9902
Energy	Road transportation	CH_4	46.967	11.398	0.0006	0.0009	0.9910
Energy	Combustion excluding transport, Liquid Fuels	N_2O	84.591	55.364	0.0005	0.0007	0.9917
Industrial processes	Iron and steel production	CO_2	28.447	0.000	0.0005	0.0007	0.9924

IPCC Source Categories (LULUCF included)		GHG	Base Year Estimate Ex,o Gg CO_2 eq	Year 2012 Estimate Ex,t Gg CO_2 eq	Trend Assessment Tx,t	Contribution to Trend	Cumulative total
Continued							
LULUCF	Grassland, 5.C Grassland, Organic soils	CO_2	107.143	79.915	0.0005	0.0007	0.9931
Energy	Road transportation	N_2O	90.736	116.531	0.0004	0.0006	0.9937
Energy	Fugitive emissions , 1B2aii Oil Production	CH_4	32.030	54.200	0.0004	0.0005	0.9942
Industrial processes	Other, lubricants	CO_2	49.706	31.696	0.0003	0.0004	0.9946
Industrial processes	Aerosols	HFC	0.000	15.832	0.0003	0.0004	0.9950
Waste	N2O direct, Domestic and Commercial Wastewater	N_2O	34.604	49.460	0.0002	0.0004	0.9954
Agriculture	Agriculture soils, direct emissions , N-fixing Crops	N_2O	269.467	256.206	0.0002	0.0003	0.9957
Industrial processes	Cement production	CO_2	882.402	871.083	0.0002	0.0003	0.9960
Industrial processes	Limestone and dolomite use	CO_2	13.692	25.645	0.0002	0.0003	0.9963
Agriculture	Agriculture soils, direct emissions , Sludge	N_2O	27.923	38.762	0.0002	0.0003	0.9966
Solvents and other product use	Other solvent	N_2O	1.142	11.928	0.0002	0.0003	0.9968
Energy	Combustion excluding transport, Solid Fuels	CH_4	12.876	3.121	0.0002	0.0002	0.9971
Industrial processes	Electrical equipment	SF6	3.908	13.266	0.0002	0.0002	0.9973
LULUCF	Cropland, 5.B Cropland, Dead organic matter	CO_2	2.930	12.159	0.0002	0.0002	0.9975
Industrial processes	Expanded clay	CO_2	14.929	5.887	0.0002	0.0002	0.9977
Waste	Waste Water Handling	CH_4	65.487	74.001	0.0001	0.0002	0.9979
Energy	Combustion excluding transport, Gaseous Fuels	N_2O	16.380	24.446	0.0001	0.0002	0.9981
Industrial processes	Glass production	CO_2	17.407	9.691	0.0001	0.0002	0.9983
Solvents and other product use	Chemical Products, Manufacture and Processing	CO_2	19.424	12.175	0.0001	0.0002	0.9985
Energy	Domestic navigation	N_2O	15.047	8.943	0.0001	0.0001	0.9986
Solvents and other product use	Paint application	CO_2	13.229	7.230	0.0001	0.0001	0.9988
Industrial processes	Yellow bricks	CO_2	23.016	17.483	0.0001	0.0001	0.9989
LULUCF	Grassland, 5.C Grassland, Dead organic matter	CO_2	1.633	7.042	0.0001	0.0001	0.9990
LULUCF	Grassland, 5.C Grassland, Mineral soils	CO_2	0.156	4.537	0.0001	0.0001	0.9991
Industrial processes	Other i.e. Fibre Optics	HFC and PFC	0.000	4.314	0.0001	0.0001	0.9992
Energy	Combustion excluding transport, Other Fuels	N_2O	2.988	7.234	0.0001	0.0001	0.9993
Energy	Fugitive emissions , 1B2biii, Gas transmission	CH_4	3.995	0.292	0.0001	0.0001	0.9994
LULUCF	Non-CO2 drainage of soils and wetlands, 5IID Forest Land.	N_2O	15.643	12.066	0.0001	0.0001	0.9995
LULUCF	Wetlands, 5D Wetlands Living biomass	CO_2	2.567	-0.222	0.0000	0.0001	0.9996
Energy	Fugitive emissions , 1B2biv, Gas distribution	CH_4	5.415	3.077	0.0000	0.0001	0.9996
Industrial processes	Food and drink	CO_2	4.450	2.241	0.0000	0.0001	0.9997
Energy	Combustion excluding transport, Liquid Fuels	CH_4	11.100	9.591	0.0000	0.0000	0.9997
Energy	Fugitive emissions , 1B2aii Oil Production	CO_2	2.381	3.707	0.0000	0.0000	0.9998
Waste	Waste, other	CO_2	17.538	16.356	0.0000	0.0000	0.9998
Energy	Civil aviation	N_2O	3.525	2.478	0.0000	0.0000	0.9998
LULUCF	N2O Disturbance, Land converted to cropland, 5III Cropland	N_2O	0.253	1.006	0.0000	0.0000	0.9998
Waste	Waste incineration	CH_4	2.272	1.611	0.0000	0.0000	0.9999
Energy	Fugitive emissions , 1B2c2i, Flaring oil	CO_2	22.950	22.333	0.0000	0.0000	0.9999
Industrial processes	Catalysts/Fertilizers, Pesticides and Sulphuric acid	CO_2	0.800	1.407	0.0000	0.0000	0.9999
Agriculture	Field Burning of Agricultural Residues	CH_4	1.824	2.429	0.0000	0.0000	0.9999
Waste	Waste incineration	CO_2	2.550	3.135	0.0000	0.0000	0.9999
LULUCF	Wetlands, 5D Wetlands, dead org. matter	CO_2	0.541	0.000	0.0000	0.0000	0.9999
LULUCF	Biomass burning, 5V Biomass burning	CH_4	0.549	0.025	0.0000	0.0000	0.9999
LULUCF	Biomass burning, 5V Biomass burning	N_2O	0.449	0.034	0.0000	0.0000	0.9999
Energy	Combustion excluding transport, Other Fuels	CH_4	0.361	0.774	0.0000	0.0000	1.0000
Energy	Railways	N_2O	2.535	2.131	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	CH_4	0.730	0.325	0.0000	0.0000	1.0000

IPCC Source Categories (LULUCF included)		GHG	Base Year Estimate Ex,o Gg CO_2 eq	Year 2012 Estimate Ex,t Gg CO_2 eq	Trend Assessment Tx,t	Contribition to Trend	Cumulative total
Continued							
Energy	Fugitive emissions , 1B2c2ii, Flaring gas	N_2O	0.710	0.468	0.0000	0.0000	1.0000
Agriculture	Field Burning of Agricultural Residues	N_2O	0.698	0.930	0.0000	0.0000	1.0000
Waste	Waste incineration	N_2O	1.296	1.083	0.0000	0.0000	1.0000
Energy	Railways	CH_4	0.259	0.153	0.0000	0.0000	1.0000
Energy	Civil aviation	CH_4	0.097	0.056	0.0000	0.0000	1.0000
Energy	Domestic navigation	CH_4	0.710	0.752	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2c Venting	CH_4	1.226	1.206	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2b Natural gas transmission and distribution	CO_2	0.008	0.005	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2i, Flaring oil	CH_4	0.157	0.160	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2c2i, Flaring oil	N_2O	0.060	0.061	0.0000	0.0000	1.0000
Industrial processes	Road Paving with asphalt	CO_2	1.762	1.766	0.0000	0.0000	1.0000
LULUCF	Non-CO2 drainage of soils and wetlands, 5IID Wetlands. Peatland	N_2O	0.135	0.135	0.0000	0.0000	1.0000
Solvents and other product use	Degreasing and Dry Cleaning	CO_2	0.000	0.000	0.0000	0.0000	1.0000
Industrial processes	Asphalt roofing	CO_2	0.019	0.019	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2c Venting	CO_2	0.001	0.001	0.0000	0.0000	1.0000
Industrial processes	Magnesium Production	SF_6	0.000	0.000	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2ai Oil Exploration	CH_4	0.000	0.000	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2ai Oil Exploration	CO_2	0.000	0.000	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2ai Oil Exploration	N_2O	0.000	0.000	0.0000	0.0000	1.0000
Energy	Fugitive emissions , 1B2aii Oil Production	N_2O	0.000	0.000	0.0000	0.0000	1.0000
Total			**74840.574**	**51410.578**		**1.000**	

17.4.1 Key category analysis for KP-LULUCF

The contribution from Greenland to the KP-LULUCF inventory is miniscule and the same categories are therefore identified as key as for the submission from Denmark, see Chapter 11.9 for more information.

17.5 Recalculations

17.5.1 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 small and the changes for the whole time series are between -0.10 % (1990) and 0.46 % (2011). Therefore, the implications of the recalculations on the level and on the trend, 1990-2011, of the recalculations are small, refer Table 17.10.

For the national total CO_2 equivalent emissions with Land-Use, Land-Use Change and Forestry, the general impact of the recalculations is larger due to recalculations in the LULUCF sector. The changes vary between –0.34 % (1990) and 0.54 % (2010), refer Table 17.10.

The impact of recalculation in the Greenlandic inventory 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 10 and in the sectoral Chapters 3-8. The recalculations carried out for the Greenlandic inventory are described in Chapter 16.

Table 17.10 Recalculation performed on national total for 1990-2011. Differences in pct of CO_2 eqv between this submission and the May 2013 submission for Denmark under the Kyoto Protocol, i.e. Denmark & Greenland.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total CO_2 eqv. Emissions with Land-Use Change and Forestry	-0.34	-0.04	-0.03	-0.02	0.00	0.02	0.03	0.05	0.09	0.16	0.45
Total CO_2 eqv. Emissions without Land-Use Change and Forestry	-0.10	-0.08	-0.07	-0.05	-0.03	-0.01	0.00	0.03	0.07	0.15	0.44
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total CO_2 eqv. Emissions with Land-Use Change and Forestry	0.17	0.28	0.34	0.16	-0.11	-0.06	0.26	-0.26	0.52	0.54	0.34
Total CO_2 eqv. Emissions without Land-Use Change and Forestry	0.22	0.34	0.38	0.20	0.22	0.23	0.28	0.21	0.36	0.29	0.46

Table 17.11 Recalculation for CO_2 performed in the 2014 submission for 1990-2011. Differences in Gg CO_2 eqv. between this and the May 2013 submission for Denmark under the Kyoto Protocol, i.e. Denmark & Greenland.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total National Emissions and Removals	-136	81	80	81	80	77	75	78	76	77	223
1. Energy	55	55	55	58	58	55	55	56	56	57	202
1.A. Fuel Combustion Activities	53	53	53	55	58	55	55	56	56	57	202
1.A.1. Energy Industries	-3	-3	-3	-1	66	4	10	9	10	10	10
1.A.2. Manufacturing Industries and Construction	59	59	59	59	47	55	49	51	51	51	51
1.A.3. Transport	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
1.A.4. Other Sectors	-2	-3	-3	-3	-55	-3	-4	-4	-4	-4	142
1.A.5. Other	0	0	0	0	0	0	0	0	0	0	0
1.B. Fugitive Emissions from Fuels	2	3	2	3	0	0	0	0	0	0	0
2. Industrial Processes	-	-	-	-	-	1	0	3	2	3	5
2.A. Mineral Products	-	-	-	-	-	1	1	2	2	3	5
2.B. Chemical Industry	-	-	-	-	-	-	-1	1	-	-	0
2.C. Metal Production	-	-	-	-	-	-	-	-	-	-	-
2.D. Other Production	-	-	-	-	-	-	-	-	-	-	-
2.G. Other	-	-	-	-	-	-	-	-	-	-	-
3. Solvent and Other Product Use	-	-	-	-	-	-	-	-	-	-	-
4. Agriculture	-	-	-	-	-	-	-	-	-	-	-
5. Land Use, Land-Use Change and Forestry (net)	-190	26	25	24	23	22	21	20	19	18	17
5.A. Forest Land	7	7	7	7	7	7	7	7	7	7	7
5.B. Cropland	-192	26	26	27	27	27	27	27	27	27	28
5.C. Grassland	0	0	0	0	0	0	0	0	0	0	0
5.D. Wetlands	-3	-5	-6	-7	-8	-9	-10	-11	-12	-13	-14
5.E. Settlements	-3	-3	-3	-3	-4	-4	-4	-4	-4	-4	-4
5.F. Other Land	-	-	-	-	-	-	-	-	-	-	-
5.G. Other	-	-	-	-	-	-	-	-	-	-	-
6. Waste	-1	-1	-1	-1	-1	-1	-1	0	0	0	0
6.C. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-
6.D. Other	-1	-1	-1	-1	-1	-1	-1	0	0	0	0
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total National Emissions and Removals	33	35	74	75	-126	-112	94	-253	234	242	60
1. Energy	57	57	94	94	94	102	102	45	131	94	139
1.A. Fuel Combustion Activities	57	57	94	94	94	102	102	45	131	94	139
1.A.1. Energy Industries	9	9	32	11	10	6	5	12	32	27	5
1.A.2. Manufacturing Industries and Construction	53	52	84	87	89	85	124	110	107	152	132
1.A.3. Transport	-1	-1	-1	-1	-1	-1	0	-70	0	-4	-13
1.A.4. Other Sectors	-4	-4	-21	-3	-5	11	-26	-7	-8	-81	15
1.A.5. Other	0	0	0	0	0	0	0	0	0	0	0
1.B. Fugitive Emissions from Fuels	0	0	0	0	0	0	0	0	0	0	0
2. Industrial Processes	2	1	1	-1	-1	3	1	1	1	4	-2
2.A. Mineral Products	2	1	1	1	1	3	2	3	2	4	-2
2.B. Chemical Industry	0	0	-1	-2	-2	-1	-1	-1	-1	-	-1
2.C. Metal Production	-	-	-	-	-	-	-	-	-	-	-
2.D. Other Production	-	-	-	-	-	-	-	-	-	-	-
2.G. Other	-	-	-	-	-	-	-	-	-	-	-
3. Solvent and Other Product Use	-	-	-	-	-	-	-	-	-12	-7	1
4. Agriculture	-	-	-	-	-	-	-	-	-	-	-
5. Land Use, Land-Use Change and Forestry (net)	-25	-23	-21	-19	-219	-216	-10	-299	114	150	-78
5.A. Forest Land	-34	-30	-27	-23	-51	-49	157	-132	280	316	88
5.B. Cropland	28	27	27	27	-181	-181	-181	-181	-181	-181	-181
5.C. Grassland	0	0	0	0	32	31	31	31	30	30	29
5.D. Wetlands	-15	-16	-17	-18	-14	-13	-13	-12	-11	-11	-10
5.E. Settlements	-4	-4	-4	-4	-5	-5	-5	-4	-4	-4	-4

Continued											
5.F. Other Land	-	-	-	-	-	-	-	-	-	-	-
5.G. Other	-	-	-	-	-	-	-	-	-	-	-
6. Waste	0	0	0	0	0	0	0	0	0	0	0
6.C. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-
6.D. Other	0	0	0	0	0	0	0	0	0	0	0

Table 17.12 Recalculation for CH_4 performed in the 2014 submission for 1990-2011. Differences in Gg CO_2 eqv. between this and the May 2013 submission for Denmark under the Kyoto Protocol, i.e. Denmark & Greenland.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total National Emissions and Removals	-113.9	-108.2	-101.0	-89.3	-74.7	-60.7	-50.6	-37.5	-28.3	-20.5	-16.8
1. Energy	5.6	6.8	6.4	7.3	7.3	8.6	7.7	7.0	6.1	4.7	6.0
1.A. Fuel Combustion Activities	4.8	5.6	5.8	6.4	6.8	7.1	7.5	6.6	5.7	6.2	7.8
1.A.1. Energy Industries	0.0	0.0	0.0	0.0	0.6	1.9	3.4	2.2	2.0	2.2	2.3
1.A.2. Manufacturing Industries and Construction	0.0	0.0	0.0	0.0	0.0	-1.2	-2.8	-2.5	-2.3	-2.4	-2.5
1.A.3. Transport	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.A.4. Other Sectors	4.9	5.7	5.9	6.5	6.2	6.4	6.9	6.9	6.1	6.3	8.1
1.A.5. Other	-	-	-	-	-	-	-	-	-	0.0	0.0
1.B. Fugitive Emissions from Fuels	0.8	1.2	0.6	0.9	0.5	1.5	0.2	0.4	0.4	-1.5	-1.8
2. Industrial Processes	-	-	-	-	-	-	-	-	-	-	-
3. Solvent and Other Product Use	-	-	-	-	-	-	-	-	-	-	-
4. Agriculture	-8.0	-8.9	-9.6	-10.4	-10.8	-11.6	-12.7	-12.7	-12.6	-12.3	-12.4
4.A. Enteric Fermentation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.B. Manure Management	-8.0	-8.9	-9.6	-10.4	-10.8	-11.6	-12.7	-12.7	-12.6	-12.3	-12.4
4.F. Field Burning of Agricultural Residues	-	-	-	-	-	-	-	-	-	-	-
5. Land Use, Land-Use Change and Forestry (net)	-	-	-	-	-	-	-	-	-	-	-
6. Waste	-111.5	-106.2	-97.8	-86.2	-71.3	-57.7	-45.6	-31.8	-21.8	-12.9	-10.5
6.A. Solid Waste Disposal on Land	-112.0	-106.9	-98.9	-87.5	-72.7	-60.1	-47.6	-34.3	-24.5	-16.4	-14.9
6.B. Waste-water Handling	-0.7	-0.7	-0.7	-0.7	-0.8	-0.8	-1.0	-1.2	-1.1	-1.3	-0.9
6.C. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-
6.D. Other	1.2	1.5	1.8	2.0	2.2	3.2	3.0	3.7	3.8	4.9	5.4
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total National Emissions and Removals	-14.3	-5.7	14.7	16.8	22.6	28.5	37.4	36.7	42.3	22.2	53.4
1. Energy	8.7	9.1	10.8	12.3	14.7	16.2	20.6	18.3	16.7	18.7	17.0
1.A. Fuel Combustion Activities	8.8	9.1	10.6	12.2	14.6	16.1	20.3	18.5	16.9	19.1	16.9
1.A.1. Energy Industries	1.9	2.1	1.9	2.2	2.0	2.0	1.8	1.7	2.0	2.0	2.1
1.A.2. Manufacturing Industries and Construction	-2.1	-2.3	-2.1	-2.3	-2.0	-2.3	-1.8	-2.0	-2.2	-0.9	-0.8
1.A.3. Transport	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.3	0.3	0.3
1.A.4. Other Sectors	9.0	9.3	10.8	12.3	14.6	16.4	20.2	18.7	16.9	17.8	15.3
1.A.5. Other	0.0	0.0	0.0	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	0.1	0.1	0.1	0.1	0.3	-0.2	-0.2	-0.4	0.0
2. Industrial Processes	-	-	-	-	-	-	-	-	-	-	-
3. Solvent and Other Product Use	-	-	-	-	-	-	-	-	-	-	-
4. Agriculture	-13.0	-12.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-0.2
4.A. Enteric Fermentation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
4.B. Manure Management	-13.0	-12.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-0.2
4.F. Field Burning of Agricultural Residues	-	-	-	-	-	-	-	-	-	-	-
5. Land Use, Land-Use Change and Forestry (net)	-	-	-	-	-	-	-	-	-	-	-
6. Waste	-10.0	-2.4	4.0	4.5	7.9	12.3	16.8	18.5	25.6	4.4	36.7
6.A. Solid Waste Disposal on Land	-14.4	-8.2	-1.9	2.0	5.9	9.6	13.9	17.1	21.2	0.2	32.3
6.B. Waste-water Handling	-1.4	-1.8	-1.9	-2.1	-1.9	-1.6	-1.3	-3.0	-1.9	-1.2	-1.3
6.C. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-
6.D. Other	5.7	7.7	7.8	4.6	3.9	4.3	4.2	4.3	6.3	5.5	5.7

Table 17.13 Recalculation for N_2O performed in the 2014 submission for 1990-2011. Differences in Gg CO_2 eqv. between this and the May 2013 submission for Denmark under the Kyoto Protocol, i.e. Denmark & Greenland.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total National Emissions and Removals	-7.6	-6.9	-6.1	-7.4	-6.8	-2.3	-1.2	0.7	26.1	69.6	115.9
1. Energy	1.7	2.3	1.9	1.4	1.4	0.9	1.6	1.8	0.6	2.2	3.6
1.A. Fuel Combustion Activities	1.8	2.4	1.9	1.5	1.4	0.9	1.6	1.8	0.6	2.2	3.6
1.A.1. Energy Industries	0.7	1.2	0.8	0.4	0.4	0.3	0.9	1.2	0.0	1.5	0.0
1.A.2. Manufacturing Industries and Construction	1.1	1.1	1.1	1.1	1.1	0.6	0.7	0.6	0.6	0.6	0.7
1.A.3. Transport	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.A.4. Other Sectors	-	0.0	0.0	0.0	-0.1	0.0	0.0	0.1	0.0	0.0	2.9
1.A.5. Other	-	-	-	-	-	-	-	-	-	0.0	0.0
1.B. Fugitive Emissions from Fuels	-0.1	-0.1	-0.1	-0.1	-	-	-	-	-	-	-
2. Industrial Processes	-	-	-	-	-	-	-	-	-	-	-
3. Solvent and Other Product Use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0-	
4. Agriculture	-10.5	-10.5	-9.7	-10.7	-10.3	-9.8	-8.7	-8.2	-7.6	-6.8	-6.1
4.A. Enteric Fermentation	-	-	-	-	-	-	-	-	-	-	-
4.B. Manure Management	-	-	-	-	-	-	-	-	-	-	-
4.D. Agricultural Soils	-10.5	-10.5	-9.7	-10.7	-10.3	-9.8	-8.7	-8.2	-7.6	-6.8	-6.1
4.F. Field Burning of Agricultural Residues	-	-	-	-	-	-	-	-	-	-	-
5. Land Use, Land-Use Change and Forestry (net)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
5.A. Forest Land	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
5.B. Cropland	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
5.C. Grassland	-	-	-	-	-	-	-	-	-	-	-
5.D. Wetlands	-	-	-	-	-	-	-	-	-	-	-
5.E. Settlements	-	-	-	-	-	-	-	-	-	-	-
5.F. Other Land	-	-	-	-	-	-	-	-	-	-	-
5.G. Other	-	-	-	-	-	-	-	-	-	-	-
6. Waste	1.1	1.3	1.6	1.8	2.1	6.5	5.9	7.0	33.1	74.2	118.4
6.B. Waste-water Handling	-	-	-	-	-	-	-	-	-	-	-
6.C. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-
6.D. Other	1.1	1.3	1.6	1.8	2.1	6.5	5.9	7.0	33.1	74.2	118.4
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total National Emissions and Removals	110.3	184.0	178.3	28.8	27.3	36.5	48.7	49.7	59.7	65.2	73.4
1. Energy	0.8	0.8	1.2	2.3	2.7	2.0	1.9	1.5	1.9	2.1	2.3
1.A. Fuel Combustion Activities	0.8	0.8	1.2	2.3	2.7	2.0	1.9	1.5	1.9	2.1	2.3
1.A.1. Energy Industries	0.1	0.0	0.4	0.7	0.8	0.6	0.0	0.1	0.3	0.0	0.0
1.A.2. Manufacturing Industries and Construction	0.7	0.7	1.3	1.4	1.5	1.4	2.2	1.7	1.9	3.8	3.3
1.A.3. Transport	0.0	0.1	0.1	0.2	0.4	-0.2	-0.1	-0.6	0.0	0.0	0.0
1.A.4. Other Sectors	0.0	0.0	-0.6	0.0	0.0	0.2	-0.4	0.3	-0.3	-1.8	-1.0
1.A.5. Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.B. Fugitive Emissions from Fuels	-	-	-	-	-	-	-	-	-	-	-
2. Industrial Processes	-	-	-	-	-	-	-	-	-	-	-
3. Solvent and Other Product Use	-	-	-	-	-	-	-	-	0.0	0.0	0.0
4. Agriculture	-5.6	-5.0	-5.0	-5.2	-4.8	-4.2	-4.2	-4.6	-3.5	-4.3	-2.8
4.A. Enteric Fermentation	-	-	-	-	-	-	-	-	-	-	-
4.B. Manure Management	-	-	-	-	-	-	-	-	-	-0.6	0.0
4.D. Agricultural Soils	-5.6	-5.0	-5.0	-5.2	-4.8	-4.2	-4.2	-4.6	-3.5	-3.7	-2.8
4.F. Field Burning of Agricultural Residues	-	-	-	-	-	-	-	-	-	-	-
5. Land Use, Land-Use Change and Forestry (net)	0.1	0.1	0.1	0.1	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.0
5.A. Forest Land	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
5.B. Cropland	0.2	0.2	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.2	0.2
5.C. Grassland	-	-	-	-	-	-	-	-	-	-	-

Continued											
5.D. Wetlands	-	-	-	-	-	-	-	-	-	-	-
5.E. Settlements	-	-	-	-	-	-	-	-	-	-	-
5.F. Other Land	-	-	-	-	-	-	-	-	-	-	-
5.G. Other	-	-	-	-	-	-	-	-	-	-	-
6. Waste	115.0	188.1	182.0	31.7	29.6	38.8	51.1	52.9	61.4	67.4	73.9
6.B. Waste-water Handling	-	-	-	-	-	-	-	-	-	-	-
6.C. Waste Incineration	-	-	-	-	-	-	-	-	-	-	-
6.D. Other	115.0	188.1	182.0	31.7	29.6	38.8	51.1	52.9	61.4	67.4	73.9

Table 17.14 Recalculation for HFCs, PFCs and SF_6 performed in the 2014 submission for 1990-2011. Differences in Gg CO_2 eqv. between this and the May 2013 submission for Denmark under the Kyoto Protocol, i.e. Denmark & Greenland.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
HFC	-	-	-	-	-	-	-	-	-	-	-
PFC	-	-	-	-	-	-	-	-	-	-	-
SF_6	-	-	-	-	-	-	-	-	-	-	-
Continued	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
HFC	-	-	-	-	-	-	-	-	0.0	0.0	-
PFC	-	-	-	-	-	-	-	-	-	-	-
SF_6	-	-	-	-	-	-	-	-	-	-0.4	-

17.6 Technical description of the aggregation of the emission inventories of Denmark and Greenland

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 and GRL for Greenland (FRO for the Faroe Islands). Two additional installations are necessary to enable the submission of aggregated submissions under the Kyoto Protocol (Denmark and Greenland) and under UNFCCC (Denmark, Greenland and the Faroe Islands). The country identification codes provided by the UNFCCC secretariat are DKE for the submission under the Kyoto Protocol (Denmark and Greenland) and DNK for the UNFCCC submission (Denmark, Greenland and the Faroe Islands).

These five versions of CRF Reporter are installed on separate virtual MS Windows XP machines. The installations are at the AU VMWare environment, which is operated and maintained by the IT department at AU. As such backups of these systems are performed routinely on a daily basis.

For the aggregation of the submissions three IT tools are used.

- EU CRF Aggregator developed by the European Environment Agency – Aggregation of global CRF variables
- NERI CRF Aggregator developed by NERI (Now DCE) – Aggregation of local CRF variables
- MS Excel

The three main work processes in connection with the aggregation of the submissions are:

- In the EU CRF Aggregator the following work processes take place:
    - o Aggregation of global variables; sum of emissions and activity data, notation keys and comments.
    - o As input data the xml submission files from the CRF Reporter installations for DNM (Denmark), GRL (Greenland) and FRO (Faroe Islands) are used.
    - o As output file a CRF Reporter xml import file is generated. This file is then imported in the installation for the aggregated submission, DKE (KP) or DNK (UNFCCC).

- In NERI CRF Aggregator the following work processes take place:
    - o Aggregation of local variables; sum of emissions and activity data, notation keys and comments. Aggregation of additional information variables either as sums or uniform values.
    - o As input data the simple CRF Reporter xml files from the CRF Reporter installations for DNM (Denmark), GRL (Greenland) and FRO (Faroe Islands) are used.
    - o As output file a CRF Reporter simple xml import file is generated. This file is then imported in the installation for the aggregated submission, DKE (KP) or DNK (UNFCCC).

- In MS Excel the following work processes take place:
    - o Aggregation of additional information variables where average values or weighted average values are used.
    - o Aggregation of KP-LULUCF/NIR-1 and KP-LULUCF/NIR-2.
    - o The aggregated data is at the moment copy/pasted from the CRF Reporter installations of Denmark and Greenland to Excel aggregated and copy/pasted back to the CRF Reporter installations of the KP submission (DKE).

Efforts are ongoing to ensure the highest possible degree of automation to avoid the risk of errors during the manual work processes.

17.7 QA/QC of the aggregated submission for Denmark and Greenland

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 16. 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 QC checks carried out for the aggregated versions of the inventory for reporting to the Kyoto Protocol and the UNFCCC. The PM’s relevant for this are listed in Table 17.15.