Denmark's National Inventory Report 2004

Submitted under the United Nations Framework Convention on Climate Change

1990-2002

Ministry of the Environment, Denmark
National Environmental Research Institute

April 2004

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April 2004

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1 Introduction

1.1 Background information on greenhouse gas inventories and climate change

Annual report
This report is Denmark's National Inventory Report (NIR) due by 15 April 2004 to the United Nations Framework Convention on Climate Change (UNFCCC) and the European Union's Greenhouse Gas Monitoring Mechanism. The report contains information on Denmark's inventories for all years from 1990 to 2002. The structure of the report is in accordance with the UNFCCC Guidelines on reporting and review (UNFCCC, 2002) and the 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 from 1990 to 2002 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. The complete sets of CRF-files are available in Annex 9.

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

According to the instrument of ratification the Danish government has ratified the UN Framework Convention on Climate Change on behalf of Denmark, Greenland and the Faroe Islands. Annex 6.1 contains total emissions for Denmark, Greenland and the Faroe Islands for 1990 to 2002. However, it has not been possible to present a complete inventory in CRF. In Annex 6.2 information on the Greenland and the Faroe Islands inventories are given. Apart from Annexes 6.1 and 6.2 the information in this report only relates to Denmark.

The NIR and the CRF tables are available to the public on NERI's homepage (http://www.dmu.dk/1_Viden/2_Miljoe-tilstand/3_luft/4_adaei/default_en.asp).

Greenhouse gasses
The greenhouse gasses 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 280 to 370 ppm (about 30%) since the pre-industrial era in the nineteenth century. The main cause is the use of fossil fuels, but changing land use, including forest clearance, has also been a significant factor. The concentrations of the greenhouse gasses methane and N_2O, which are highly linked to agricultural production, have increased by 150% and 16%, respectively. Changes in the concentrations of greenhouse gasses are not simply related to these effects on the heat balance, however. The various gasses absorb radiation at different wavelengths and with different efficiency. Moreover, the concentrations of some gasses are so high that the radiation at some wavelengths is already nearly fully absorbed. An increasing concentration will therefore have a limited effect. This must be considered in assessing the effects of changes in the concentrations of various gasses. Further, the lifetime of the gasses in the atmosphere needs to be taken into account – the longer they remain in the atmosphere, the greater their overall effects. The global warming potential of various gasses has been defined as the warming effect of a given weight of a specific substance relative to CO_2. The purpose of this is to be able to compare and integrate the effects of individual substances on the global climate. The typical lifetimes are 100, 10 and 300 years for CO_2, CH_4 and N_2O, respectively, and the time perspective clearly plays a decisive role. The lifetime chosen is typically 100 years. Then the effect of the various greenhouse gasses can 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, the most recent global warming potential values for a 100-year time horizon are:

- 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 N2O is 310 times more powerful. Some of the other greenhouse gasses (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 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 UN Framework Convention on Climate Change (the Climate Convention). On 21 December 1993 the Climate Convention was ratified by enough countries, including Denmark, for it to enter into force on 21 March 1994. One of the provisions 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 gasses by 5.2% up to 2008-2012 compared to the 1990 level. However for the F-gases the nations can freely choose between 1990 and 1995 as the base year. On May 16, 2002, the Danish Parliament voted for Danish ratification of the Kyoto Protocol. Denmark is, thus, under a legal commitment to meet the requirements of the Kyoto Protocol, when it comes into force. The European Union must 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 by each state to the overall EU reduction level of 8%.

Under the Burden Sharing Agreement Denmark must reduce emissions by an average 21% in the period 2008-2012 compared to the 1990 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 the emissions of HFCs, PFCs and SF_6 in 1995 in CO_2-equvivalents. Further more, the removals by sinks are included in the net emissions. Removals by sinks only include sequestration due to afforestation since 1990. When reporting to the Climate Convention the net CO_2 removals by forests existing in 1990 are included in the calculation also.

The role of the European Union
Since the European Union (EU) is also a Party to the UNFCCC and the Kyoto Protocol and has to submit similar data sets and reports for the collective 15 EU Member States as national Parties have, the EU imposes some additional guidelines to EU Member States through the EU Greenhouse Gas Monitoring Mechanism to guarantee that the EU meets its reporting commitments.

1.2 A description of the institutional arrangement for inventory preparation

The National Environmental Research Institute (NERI) under the Danish Ministry of Environment is responsible for the annual preparation and submission to the UNFCCC (and the EU) of the National Inventory Report and the GHG inventories in the Common Reporting Format in accordance with the UNFCCC Guidelines. NERI participates in meetings in the Conference of Parties (COP) to the UN Framework Convention on Climate Change and its subsidiary bodies, where the reporting, rules, are negotiated and settled, and in the EU Monitoring Mechanism on greenhouse gases, where the guidelines and methodologies on inventories to be prepared by the EU member states are regulated.

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

<u>Danish Energy Authority, The Ministry of Economic and Business Affairs:</u> Annual energy statistics in a format suitable for the emission inventory work and fuel consumption data for the large combustion plants.

<u>Danish Environmental Protection Agency, The Ministry of the Environment:</u> Database on waste and emissions of the F-gases

<u>Statistics Denmark, The Ministry of Economic and Business Affairs:</u> Statistical yearbook, Sales Statistics for manufacturing industries and agricultural statistics.

<u>Danish Institute of Agricultural Sciences, The Ministry of Food, Agriculture and Fisheries:</u> Data on use of mineral fertiliser, feeding stuff consumption and nitrogen turnover in animals.

The Road Directorate, The Ministry of Transport. 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, The Royal Veterinary and Agricultural University. Background data for Forestry and CO_2 uptake by forest.

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

Until now the providing of data has been on a voluntary basis but more formal agreements are now being worked out.

1.3 Brief description of the process of inventory preparation

The background data (activity data and emission factors) for estimation the Danish emission inventories is stored in central databases placed at NERI. The databases are in Access format and handled with software developed by the European Environmental Agency and NERI. As input to the databases various sub-models are used to estimate and aggregate the background data so they 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 are part of the QA/QC plan (chapter 1.6) a data structure is proposed that describes the pathway from collection of raw data to data compilation and modelling and final reporting.

Figure 1.1 shows a schematic overview of the process of inventory preparation. Level 3 illustrates the level where the central data bases are placed and level 4 illustrates the process where the reporting schemes are generated to UNFCCC and EU (the CRF) and to UNECE/EMEP (the NFR format). For data handling the software tool is CollectER (Pulles et al., 1999a) and for the CRF reporting the software tool is ReportER (Pulles et al., 1999b) and CRF-correction templates developed by NERI. In Table 1.2 is listed data files and program files used in the inventory preparation process.

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

Level	Name	Application	Path	Type	Input sources	Remarks
5	NFR-tables (UN-ECE/EMEP)	External report	I:\ROSPROJ\LUFT_EMI\2002_unece	MS Excel	NFR_Report_Automatisk.xls	NFR-format
5	CFR-tables (UNFCCC and EU)	External report	I:\ROSPROJ\LUFT_EMI\2002_EU	MS Excel	ReportER CRF-skabeloner CRF-Retteskabelon	CRF-format
4	CRF-Retteskabelon (correction templates)	Help tool	I:\ROSPROJ\LUFT_EMI\2002_EU\2002_EU_15March2004	MS Excel	manual input	Notations keys, etc.
4	CollectER	Management tool	I:\ROSPROJ\LUFT_EMI\programmer\CollectER\programfiler	(exe + mdb)	manual input	Version: 1.3 3 from Spirit
4	ReportER	Reporting tool	I:\ROSPROJ\LUFT_EMI\programmer\ReportER\programfiler	(exe + mdb)	CollectER databases ReportER database	Version: 3.1 Beta dbversion:4 from Spirit
3	dk1972.mdb..dkxxxx.mdb	Datastore	I:\ROSPROJ\LUFT_EMI\Collect	MS Access	CollectER MS Access	CollectER databases
4	NFR-skabelon	Presentation template	I:\ROSPROJ\LUFT_EMI\Collect\v4\NFRsheets_original_koder.xls	MS Excel	none	
4	DMURep.mdb	Help tool	I:\ROSPROJ\LUFT_EMI\DMURep	MS Access	dk1972.mdb..dkxxxx.mdb ReportER database manual input	
4	NFR_Report_Automatisk.xls	Help tool, Report compiler	I:\ROSPROJ\LUFT_EMI\DMURep\Excel skabeloner	MS Excel	DMURep(_ny).mdb;qXLS_NFR_Report NFR-skabelon	
5	EMEP_NFR.xlt	Internal Time series report	I:\ROSPROJ\LUFT_EMI\DMURep\Excel skabeloner	MS Excel	DMURep.mdb	

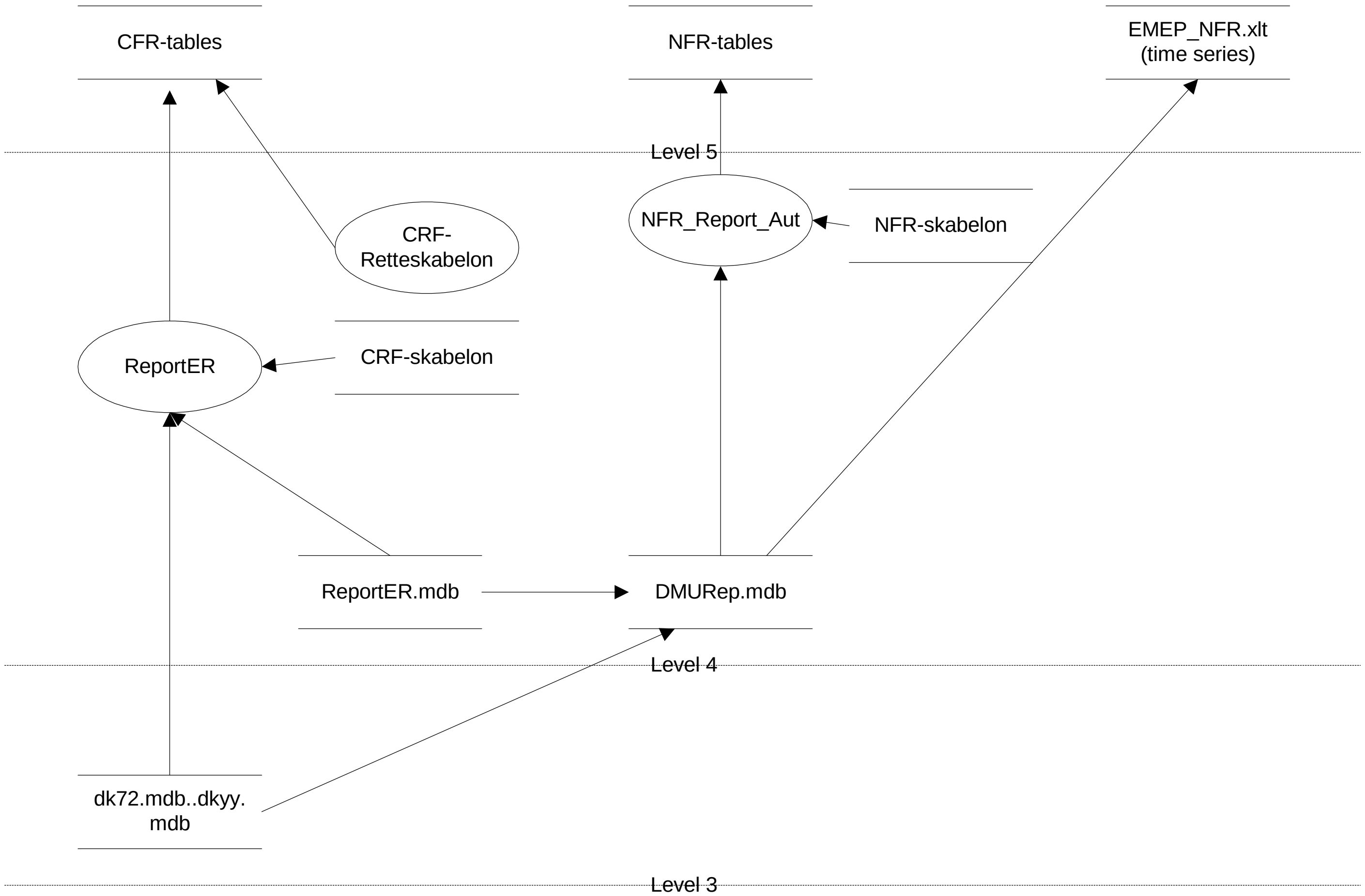


Figure 1.1. Schematic diagram of the process of inventory preparation.

1.4 Brief description of methodologies and data sources used

Denmark's air emission inventories are based on the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Houghton et al., 1997), the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (Penman et al., 2000) and the CORINAIR methodology. CORINAIR (COoRdination of Information on AIR emissions) is an European air emission inventory programme for national sector-wise emission estimations harmonised with the IPCC guidelines. To ensure estimates as timely, consistent, transparent, accurate and comparable as possible, the inventory programme has developed calculation methodologies for most sub-sectors and software for storing and further data processing (Richardson, S. (Ed), 1999).

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 times 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 mainly based on official statistics. The most consistent emission factors have been used, either as national values or default factors proposed by the CORINAIR methodology. The documentation on the CORINAIR methodology can be obtained from the "Joint EMEP/CORINAIR Atmospheric Emission Inventory Guidebook, Second edition (Richardson, S. (Ed), 1999). The documentation on the COPERT III is given in Ntziachristos et al. (2000).

A list of all sub-sectors on the most detailed level is given in Illerup et al., 2000. Incorporated in the CORINAIR software is a feature to serve the specific UNFCCC and UNECE convention needs for emission reporting. The translation between CORINAIR and IPCC codes for sector classifications are listed in Illerup et al, 2000.

The specific methodologies regarding 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 the Emission Inventory Guidebook 3rd edition. The inventory is based on activity rates from the Danish energy statistics and on emission factors for different fuels, plants and sectors.

The Danish Energy Authority aggregates fuel consumption rates in the official Danish energy statistics to SNAP categories.

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/CORINAIR 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 like 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 refers to emission measurements stated in annual environmental reports etc. At present the emission factors for CO_2, CH_4 and N_2O are however not plant specific whereas emission factors of SO_2 and NO_x often are.

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 2002 the CO_2 emission inventory based on the reference approach and the national approach respectively differs 0,05%.

Improved emission factors for cogeneration plants <25MW$_e$ and CO_2 emission from incineration of the plastic part of municipal waste are implemented this year.

Please refer to chapter 3 and annex 3A for further information about emission inventories for stationary combustion plants.

The specific methodologies regarding Fugitive Emissions from Fuels
Fugitive emissions from solid fuels (1.B.1.c)
Storage and handling of coal:
Coal mining is not occurring in Denmark, but power plants use a considerable amount of coal. CH_4 emission from storage and handling of coal is included in the Danish inventory. The CH_4 emission inventory is based on tier 1 in 'IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual'. The CH_4 emission occurring in Denmark is assumed to be half the post-mining emission.

Fugitive emissions from natural gas (1.B.2.b)
Natural gas transmission and distribution:
Inventories of CH_4 emission from gas transmission and distribution is based on annual environmental reports from the Danish gas transmission company, DONG and on a Danish inventory for the years 1999-2002 reported by the Danish gas sector (transmission and distribution companies).

Off-shore activities:
Rough estimates for the emission of CH_4 from extraction of oil and gas are made for the years 1994 to 2002. A project is going on to make consistence inventories from 1990.

Fugitive emissions from oil (1.B.2. a)
Oil Refineries – Petroleum products processing:
The VOC emissions from petroleum refinery processes cover non-combustion emissions from feed stock handling/storage, petroleum products processing, product storage/handling and flaring. SO_2 is also emitted from the non-combustion processes and includes emissions from products processing and sulphur recovery plants. The emission calculations are based on information form the Danish refineries and the Energy statistic.

Please refer to chapter 3 and annex 3A for further information about fugitive emissions from fuels.

<u>The specific methodologies regarding Transport</u>
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; 1A3b (road transport), 1A2f (Industry-other), 1A3a (Civil aviation), 1A3c (Railways), 1A3d (Navigation), 1A4c (Agriculture/forestry/fisheries), 1A4b (Residential) and 1A5 (Other).

The European COPERT III emission model is used to calculate the Danish annual emissions for road traffic. In COPERT III 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 the Danish Road Directorate, and is grouped according to average fuel consumption and emission behaviour. For each group the emissions are estimated by combining vehicle and annual mileage numbers with hot emission factors, cold:hot ratios and evaporation factors (Tier 2 approach).

For air traffic the 2001 and 2002 estimates are made on a city-pair level, using flight data from the Danish Civil Aviation Agency (CAA-DK) and LTO and distance related emission factors from the CORINAIR guidelines (Tier 2 approach). For previous years the background data consist of LTO/aircraft type statistics from Copenhagen Airport and total LTO numbers from CAA-DK. With appropriate assumptions a consistent time series of emissions is produced back to 1990 using also 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, agriculture, forestry, industry and household and gardening. 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 most thorough recalculations have changed the estimates for the navigation and agriculture/forestry/fisheries sectors. In general terms the new estimates rely on a revised fuel allocation for small boats, non-road working machinery and equipment used in the two sectors. For railways updated emission factors for diesel are used based on real emission measurements carried out by the Danish Railways.

For transport the CO_2 emissions are determined with the most accuracy, while the levels of the CH_4 and N_2O estimates are significantly more uncertain. The overall uncertainty in 2002 for CO_2, CH_4 and N_2O are around 4, 32 and 56 %, while the 1990-2002 emission trend uncertainties for the same three components are 4, 4 and 193 %, respectively.

Please refer to chapter 3 and annex 3B for further information about fugitive emission from transport.

<u>The specific methodologies regarding Industrial Processes</u>
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.

Mineral Products: Cement. CRF Table 2(I).A-G Sectoral Background Data for Industrial processes. A.1.
There is only one producer of cement in Denmark, Aalborg Portland ltd. The activity data for the production of cement and the emission factor are obtained from the corporation as accounted for and published in the "Green National Accounts" (In Danish: “Grønne regnskaber”) which the corporation works out according to obligations in Danish law. These accounts are subject to audit. The emission factor is produced as a result of weighting of emission factors resulting from the production of low alkali cement, rapid cement, basis cement, and white cement.

Mineral Products: Lime and bricks. CRF Table 2(I).A-G Sectoral Background Data for Industrial processes. A.2.
The reference for the activity data for production of lime and bricks are the production statistics for manufacturing industries published by Statistics Denmark. The productions of lime and yellow bricks imply CO_2 emissions. For the calculation of these emissions and the emission factors used please refer to Annex 3.C.

Mineral products: Glass and glass wool. CRF Table 2(I).A-G Sectoral Background Data for Industrial processes. A.7.

The reference for activity data for 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 emission.

Chemical Industry. Nitric Acid production: CRF Table 2(I).A-G Sectoral Background Data for Industrial processes. B.2.
There is one producer. The data so far in the inventory relies on information from the producer. The producer only reports NO_x emissions associated with the production. The producer reports these emissions as measured emissions. Information on N_2O emission has been obtained by contact to the producer.

Chemical Industry. Catalysts/fertilisers: CRF Table 2(I).A-G Sectoral Background Data for Industrial processes. B.5 Others.
There is one producer. The data in the inventory relies in information published by the producer in environmental reports.

Metal production. Steelwork: CRF Table 2(I).A-G Sectoral Background Data for Industrial processes. C.1.
There is one producer. 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.

F-gases (HFCs, PFCs and SF_6): CRF Sectoral Report for Industrial Processes Table2(I) and 2(II) and Sectoral Background Data for Industrial Processes Tables 2(II).F
The inventory on the F-gases: HFCs, PFCs and SF_6 is based on work carried out by the Danish Consultant Company "Planmiljø". Their yearly report (Danish Environmental Protection Agency, 2004a) is available in English as documentation of inventory data up to year 2002. The Link to the report is to be found in the list of references. The methodology and the model were in 2002 revised to better reflect the Tier 2 methodology of the IPCC guidelines. This revision was firstly implemented for the 2001 inventory. The inventories in this submission reflect the new methods implemented for the whole time series 1990-2002. For the full information on data, methodology, etc reference is made to the report, The Danish environmental Agency, 2004a.

Please refer to chapter 4 and Annex 3.C. for further information about industrial processes.

<u>The specific methodologies regarding Solvents (3)</u>
The emission inventory for ‘Solvents' is based on reports from the Danish Industry on emissions from various industrial sectors. The reporting is not annual and linear interpolation is used between the reporting years. It is important to notice that not all the use of solvents are included in this agreement and no activity data has been available. A work is going on to improve the emission estimates.

Please refer to chapter 5 for further information about emission inventories for solvents.

<u>The specific methodologies regarding Agriculture (4)</u>
The emission from the agricultural sector in mainly related to the livestock production. The emission is 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 emission from the agricultural sector is based on methods described in the IPCC Guideline (IPCC, 1996), the Good Practice Guidance (IPCC, 2000). Activity data for livestock is one year average from Agriculture Statistics published in Statistics Denmark (2003). Data concerning the landuse and crop yield is as well from the Agricultural Statistic.

The Implied Emission factors for Enteric Fermentation and Manure Management for CH_4 are based on a Tier 2 approach for all animal categories. Background information as e.g. daily feed intake and excretion on a detailed animal categorisation level are based on data from the Danish Institute of Agricultural Science. For Dairy Cattle and Manure Management the emission factor is higher than the IPCC default for cool -Western Europe and for Other Cattle lower. The reasons is that in Denmark the type of feed and excretion, and animal waste management systems, deviates from Western Europe. Further, the counting of subgroups in Other Cattle in the Danish activity data reported here includes several categories, which might have been omitted referring to IPCC guidelines.

Emission of N_2O is closely related to the nitrogen balance. Thus, quite a lot of the activity data is related to the calculations in the ammonia emission inventory. In Denmark a model based system is applied for calculation of the emission of ammonia (Hutchings et al., 2001) and is primarily based on information from Statistics Denmark, The Danish Institute of Agricultural Science and The Danish Agricultural Advisory Centre. The emission of CO_2 from Agricultural Soils is not yet estimated. The emission of CO_2 from Agricultural Soils is not yet estimated.

To ensure the data quality, both data used as activity data and background data to estimate the emission factor are collected and discussed in corporation with specialists and researchers at different institutes and research sections. It means that 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. Considerable variations in time series are explained.

The uncertainties for assessment of emissions from Enteric Fermentation, Manure Management and Agricultural Soil have been estimated. The most significant uncertainties are related to the N_2O emission.

A more detail description of the methodology for the agriculture sector is given in chapter 6 and annex 3D.

<u>The specific methodologies regarding Forestry</u> *CRF Table 5 Sectoral Report for Land-Use Change and Forestry and Table 5.A Sectoral Background Data for Land-Use Change and Forestry.*
This submission of inventories 1990-2002 represents slightly revised data on removals by sinks compared to the submission in 2003 for the period 1990-2001. The main revision is that net annual increment in Danish forests is now estimated using annually specific amounts of harvested wood instead of a ten-year average as used in previous submissions. This revision has only led to slight changes in the reported CO_2 uptake during 1990-2001 for Danish forests planted before 1990. The only exception is the year 2000, which has a low CO_2 uptake due to a severe storm in December 1999. This storm resulted in much larger fellings being recorded in the year 2000. These changes were done to improve the transparency and consistency in the methods.

There has only been a very minor adjustment of Forest sinks due to afforestation since 1990. This is due to an adjustment of afforested areas in the period 1999-2001.

More detailed information on the revisions and further information on the Forestry Census, the calculation methodology, the removal of sinks data and their background data for the new estimates can be found in the chapter 6. In response to the latest evaluation report of the NIR, the chapter has been updated with more information on estimation of net annual uptake of CO_2 in forests planted before 1990 based on the Danish Forestry Census. Comments on uncertainty have also been added together with other relevant information.

The specific methodologies regarding Waste

CRF Table 6 Sectoral Report for Waste Table 6.A Sectoral Background Data for Waste

The data used for the amounts of Municipal Solid Waste deposited at Solid Waste Disposal Sites is according to official registration performed by the Danish Environmental Protection Agency. The data are registered in the ISAG database, the latest yearly report Environmental Protection Agency, 2004b, see the reference list for the link to the report). CH_4 emissions from Solid Waste Disposal Sites are based on a model suited to the Danish conditions. The model is based on the IPCC Tier 2 approach using a First Order Decay approach. The model is unchanged for the whole time-series. The model is described in Sector Chapter 8. All waste incinerated are used for energy and heat production. This production is included in energy statistics, hence emissions are included in Table 1A.1a Public Electricity and Heat Production. The Danish wastewater handling systems treat the wastewater aerobically. They are therefor considered to produce CH_4 emissions of only minor and negligible importance. These CH_4 emissions and possibly N_2O emission is planned considered for next submissions.

Please refer to Chapter 8 and Annex 3E for further information about emission inventories for waste.

1.5 Brief description of key source categories

A key source analyses for year 2002 has been carried out in accordance with the Good Practice Guidance, Penman et al (2000). The analyses as regards the basic source categorisation have been kept unchanged since the analyses for the submissions in 2002 and 2003. The source categorisation used results in total 63 sources, of which 15 are identified as key sources due to both level and trend key source analyses. The Energy Sector contributes to those 15 key sources with 8 key sources of which CO_2 from Coal is the most contributing category with 24.4% of the National total. The category CO_2 emissions from Mobile Combustion, Road Transportation is the second most contributing with 16.6% and CO_2 from Natural gas is the third largest contributor with 16.6%. In the Agriculture Sector, there are four trend and level key sources, of which three are among the seventh most contributing sources to National total. These three sources are direct N_2O emissions from Agriculture Soils, indirect N_2O emissions from Nitrogen used in Agriculture and CH_4 from Enteric Fermentation, contributing 4.3, 4.1 and 4.1% respectively to the National total in 2002. The fourth Agricultural key source is N_2O from Manure Management contributing 0.9%. Finally, the Industrial Sector contributes with three level and trend key sources, which is CO_2 from Cement production (contributes 2.1%), N_2O from Nitric Acid Production (1,1%) and emissions from substitutes for ODS, F-gases (1.0%). The categorisation used, results, etc are included in Annex 1.

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

1.6.1 Introduction

This document outlines a first draft for implementing a Quality Control (QC) and Quality Assurance (QA) plan for greenhouse gas emission inventories performed by the Danish National Environmental Research Laboratory. The plan is in accordance with the guidelines provided by the United Nations Framework Convention on Climate Changes (UNFCCC) and the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC).

In the preparation of Denmark's annual emission inventory several quality control (QC) procedures are carried out already and the QA/QC plan will future improve this activity. The Danish Tier 1 QC includes:

- Check 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.
- Comparison to inventory of the previous year on the level of the categories of the CRF as well as on SNAP source categories. Any major changes are checked, verified, etc.
- Total emissions when aggregated to CRF source categories are compared to totals based on SNAP source categories (control of data transfer).
- A manual log table have been introduced in the emission databases to collect information about recalculations

A part from the UNFCCC's In-Depth-Reviews, Quality Assurance (QA) with independent review of the inventories has not yet been carried out. A strategy for implemented a formal QA/QC plan is given below.

1.6.2 Objectives

The main objective is to implement a plan that comprises a frame for documenting and reporting emissions in way that emphasises transparency, consistency, comparability, completeness and accuracy. To fulfil these high criteria a data structure is proposed that describes the pathway from collection of raw data to data compilation and modelling and final reporting. As a first approach a general structure is proposed, but realising the differences in availability and quality in data from the different sectors, the structure is designed to exhibit flexibility towards varying forms of input data.

1.6.3 Definitions

The UNFCCC Guidelines prescribe the source categories, calculation methodologies and the contents and the format for the inventory report. For the definition of the source categories and calculation methodologies the UNFCCC Guidelines generally refer to the IPCC Guidelines for Greenhouse Gas Inventories and the IPCC Good Practice Guidance reports.

The IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse provides assistance in producing inventories that are neither over nor underestimates, and in which uncertainties are reduced as far as practicable. The IPCC report addresses the Energy, Industrial Processes, Agriculture and Waste sectors, with respect to

- Choice of estimation methods suited to national circumstances
- Advice on the most suitable emission factors and other data necessary for inventory calculations
- Quality assurance and quality control procedures to enable cross-checks during inventory compilation
- Information to be documented, archived and reported to facilitate review of emission estimates
- Uncertainties at the source category level

The IPCC uses the concept of a tiered approach, i.e. a stepwise approach where complexity, advancement and comprehensiveness increase from tier 1 to tier 2 to tier 3 and so on. 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 data and manpower available. The tiered approach helps focussing on areas of the inventories that are relatively weak instead of investing effort on irrelevant subjects. Furthermore the IPCC Guidelines recommends using higher tier methods in particular for key sources.

The plan comprises emission inventories for the six main greenhouse gases:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur hexafluoride (SF6)

In addition to these so-called direct greenhouse gases there are other gases which contribute to heating the atmosphere. Some of these are the indirect greenhouse gases, such as CO, NO_x and NMVOC. These are precursors of tropospheric ozone, which is a greenhouse gas. Furthermore SO_2 leads to aerosol formation with a cooling effect.

Quality Control (QC) is a system of routine technical activities, to measure and control the quality of the inventory as it is being developed. The QC system is designed to:

1. Provide routine and consistent checks to ensure data integrity, correctness and completeness;
2. identify and address errors and omissions
3. Document and archive inventory material and record all QC activities.

Quality Assurance (QA) activities include a planned system of review procedures conducted by personnel not directly involved in the inventory compilation/development process.

A key option for quality is robustness in relation to possible change in conditions. This includes critical external data sources and change in the inventory staff.

1.6.4 1.6.4 Practical considerations in developing a QA/QC system

The QA/QC system will include the following factors:

1. Resources allocated to QC for different source categories and the compilation
2. Time allocated to conduct the checks and reviews of emissions estimates
3. Availability and access to information on activity data and emission factors, including data quality
4. Procedures to ensure confidentiality of inventory and source category information, when required
5. Requirements for archiving information
6. Frequency of QA/QC checks on different parts of the inventory
7. The level QC appropriate for each source category
8. Whether increased effort on QC will result in improved emissions estimates and reduced uncertainties
9. Whether sufficient expertise is available to conduct the checks and reviews

A good praxis system will balance the limited resources for the inventory development process with the resources applied for QC/QA to enable continuos improvement of the inventory.

1.6.5 Elements of a QA/QC system

- An inventory agency responsible for co-ordinating QA/QC activities
- A QA/QC plan
- General QC procedures (Tier 1)
- Source category-specific QC procedures (Tier 2)
- QA review procedure
- Reporting, documentation, and archiving procedures

The Tier2 QC includes the procedures in Tier 1 plus additional source category-specific activities.

1.6.6 Strategy

As a first stage in the QA/QC strategy Critical Control Points (CCP) will be defined. A CCP is an element necessary to be taken into account in order to secure the quality. The second stage is then to set up means in order to apply the CCPs. The third stage is to set up measures, which can quantify how well the means fulfils the needs of the CCP. The two first stages are needed for Quality assurance, while the third stage is needed for Quality Control.

The following CCPs are defined to the QA/QC strategy:

1. ***Transparency*** Transparency plays a key role in relation to both data presentation, handling and calculations. It is also important to have a high degree of transparency in order to obtain robustness in relation the change in staff.
2. ***Consistency*** The basic dataset should be consistent and comprise the same elements from year to year. Deviations from the standard should be noted and explanation of changes in data treatment should be clearly stated. The used methodologies should be consistent from year to year, and if deviations occur they should be clearly stated.
3. ***Accuracy*** The realism of an emission estimate is important to quantify as a key quality parameter. Accordingly the QC/QA also includes assessment of uncertainty.

The following two general means are identified:

1. ***Data structure*** The basic data structure 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 needs to be easy to find the original data background 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 minimise the number of miscalculations and flaws in input value settings. Especially manual typing of numbers needs to be minimised. 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 is necessary for securing accuracy, but they can be difficult to make, do to an important degree of uncertainty related to the uncertainty estimates itself. It is therefore important to include the uncertainty calculation procedures into the data structure so much as

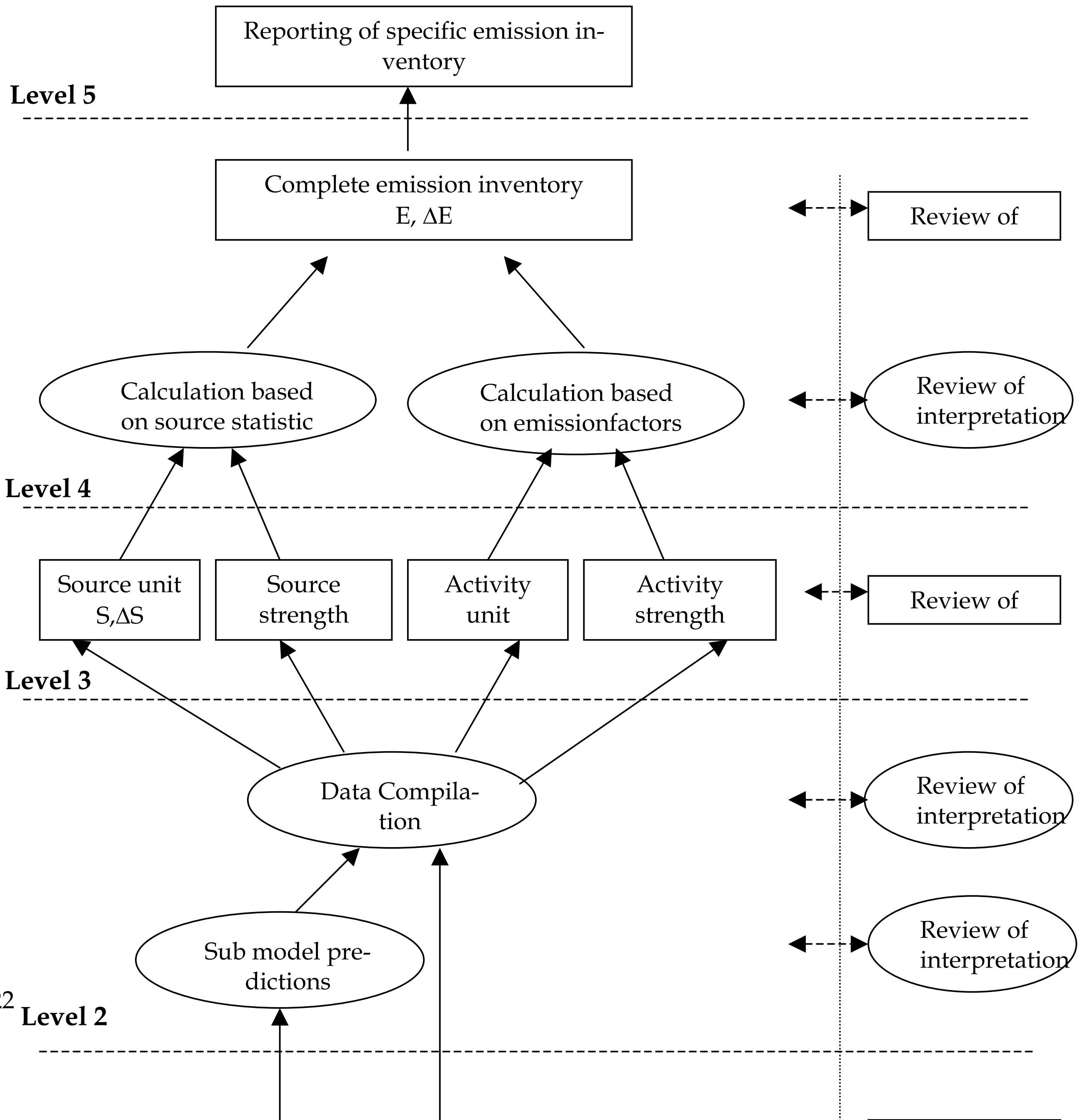
possible. The QC/QA procedures can easily become troublesome and subject for frustration if not highly supported by means based on the data structure.

2. ***Manual for praxis*** The used methodologies needs to be well documented in a manual lining up all the assumptions behind the chosen methodologies and key references. This also includes detail description of the calculation procedures. In this way transparency is improved by documentation of the calculation procedures and by a data structure, where the background for the value setting is easy to trace. The assumptions and methodologies must be clearly described to facilitate replication, documentation and review.

The first priority in the strategy is to evaluate and modify the data structure and afterwards consider the manual for praxis.

1.6.7 Data structure supporting QC/QA

A data structure which can support the demands coming from the QC/QC activity is outlined in the following diagram, where 5 different levels are defined, having increasing data aggregation from level 1 toward level 5.



Level 1

Collection of external data sources from different sectors and statistical surveys typically reported on a yearly basis. Level 1 data consist of raw data, having identical format as the data received and gathered from external sources. Level 1 data acts as a base set, on which al subsequent calculations are based. If alterations in calculation procedures are made they is based the same data set. When new data are introduced they can be implemented in accordance with the QA/QC structure of the inventory. The review of data consists of evaluating the most updated date bases and continuously personal contact to key persons in other institutions. The methodological development in scientific world can inspire the expert to consider new/other external data sources as input, so the review of the data is thus important. Level 1 data acts as verification of the inventory, which means that questions regarding the output of the emission inventory can be assessed by tracing back to the base set. Evaluation of external data quality has to be a part of the level 1 work including valid agreements with external data sources about data quality and delivery.

Level 2

Preparation of input data for the emission inventory based on the external data sources. Some external data may be useful more directly as input while others needs to be interpreted using more or less complicated models. This interpretation is developed as a continuous process in line with the development in the scientific world, so the review of the interpretation is an integrated part of the data interpretation. The data compilation creates a data set designed for the emission inventory. Both the parameters values (S, S_S, A, A_S) and the related uncertainties (ΔS, ΔS_S, ΔA, ΔA_S) are created based on the data compilation. The data preparation in level 2 typically comprises most of the assumptions, simplifications and choices in the overall data treatment procedure. These need therefore to be clearly stated and transparently linked to the raw data in level 1. Activities in level 2 often require the highest workload.

Level 3

Level 3 represents data that have been prepared and compiled in a form that is directly applicable for calculation of emissions. The compiled data is structured in a database for internal use, where the structure and design allows for automatic assessment of the emission inventory calculation program including related uncertainty calculations. The database allows an easy reporting for documentation of the reasoning behind the value setting and estimation of data uncertainty. This induces a need for the database to communicate key information from the data compilation, more than just to value setting and including reference to the external data sources. Level 3 is the link between more or less raw data and data that is ready for reporting. The data is compiled in a way that elucidates the different approaches in emission assessment; 1) Emissions that are estimated as the product of activity statistics and emission factors, and 2) emissions directly found from measurements or by expert judgement. The value setting has to be compared with other emission inventories in other countries in order to review the data compilation step in level 2.

Level 4

The emission inventory calculations result in the emission value (E) and the related uncertainty (ΔE). Level 4 data comprises all emissions from all sectors and activities. The methodology of calculating is reviewed based on the scientific literature and international standards.

Level 5

Dependent on the specific emission inventory that is performed, relevant data are extracted from level 4 and reported in the appropriate format. The informational content of the emissions is limited compared to the large data material that has been used to derive the emissions. If there are any assumptions in the previous levels (typically level 2) that are fundamental for assessing the emission inventory, these need to be stated in level 5.

The exist data structure is related to the general structure above in Chapter 1.3.

1.6.8 QC/QA as lined out in IPCC and in relation to the suggested data structure

In the following the general procedure suggested by IPCC is lined out and related to the data structure lined out above. The first two columns in the table are similar to the table in IPCC (Table 8.1). The last two columns are related to the data structure as it is lined out above. The column heading "Manual" denotes an activity where the inventory personal needs to take action. This action can either be a part of a yearly activity or verification of calculation routines. In case of verification activity "(verification)" is written explicitly. Verification is a check of a calculation routine and thus not a control of a specific result. The benefit of a verification is that once the routine is controlled the following calculations needs not to be controlled and the quality of the calculation will in this way be imbedded in the procedure and thus not demand a continuously effort from the personal. The last column heading is "Automated" and denotes check routines, which is programmed into the calculations. Such routines will support the QC in an effective way when they are possible.

QC Activity	Procedures	Manual	Automated
Check that assumptions and criteria for the selection of activity data and emission factors are documented	Cross-check description of activity data and emission factors with information on source categories and ensure that these are properly recorded and archived	level 3	
Check for transcription errors in data input and references	Confirm that bibliographical data references are properly cited in the internal documentation	level 1	
	Cross-check a sample of input data from each source category (either measurements or parameters used in calculations) for transcription errors.	level 2 (verification)	
Check that emission are calculated correctly	Reproduce a representative sample of emissions calculations	level 2-4 (verification)	
	Selectively mimic complex model calculations with abbreviated calculations to judge relative accuracy	level 2 (verification)	
Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used	Check that units are properly labelled an calculation sheets	level 2-3 (verification)	
	Check that units are correctly carried though from beginning to end of calculations	level 2-4 (verification)	
	Check that conversion factors are correct	level 3	
	Check that temporal and spatial adjustment factors are used correctly	level 3	
Check the integrity of database files	Confirm that the appropriate data processing steps are correctly represented in the database		level 2, 4
	Confirm that data relationships are correctly represented in the database		level 2, 4
	Ensure that data fields are properly labelled and have the correct design specifications		level 2, 4

	Ensure that adequate documentation of data-base and model structure and operation are archived	level 2-4 (writing manu-als)	
Check for consistency in data between source categories	Identify parameters (e.g. activity data, con-stants) that are common to multiple source categories and confirm that there is consis-tency in the values used for these parameters in the emission calculations	level 2-4 (verification)	
Check that the movement of inventory data among process-ing steps is correct	Check that emission data are correctly aggre-gated from lower reporting levels to higher reporting levels when preparing summaries	level 2, 4 (verification)	
	Check that emission data are correctly tran-scribed between different intermediate prod-ucts	level 2, 4 (verification)	
Check that uncertainties in emission and removals are estimated or calculated correctly	Check that qualifications of individuals provid-ing expert judgement for uncertainty estimates are appropriate	level 1, 2	
	Check that qualifications, assumptions and expert judgements are recorded	level 1,2	
	Check that calculated uncertainties are com-plete and calculated correctly	level 1,2 and level 4 (verification)	
	If necessary, duplicate error calculations or a small sample of the probability distributions used by Monte Carlo analyses		level 4
Undertake review of internal documentation	Check that there is detailed internal documen-tation to support the estimates and enable duplication of the emission and uncertainty estimates	level 3 (verification)	
	Check that inventory data, supporting data, and inventory records are archived and stored to facilitate detailed review	level 3 (verification) level 1	
	Check integrity of any data archiving arrange-ments of outside organisations involved in inventory preparation	level 1	
Check methodological and data changes resulting in recalcula-tions	Check for temporal consistency in time series input data for each source category		level 4
	Check for consistency in algorithm/method used for calculations throughout the time se-ries	level 4 (verification)	
Undertake completeness checks	Confirm that estimates are reported for all source categories and for all years from the appropriate base year to the period of the current inventory		level 4
	Check that known data gaps that result in incomplete source category emissions esti-mates are documented	level 1	
Compare estimates to previous estimates	For each source category, current inventory estimates should be compared to previous estimates. If there are significant changes or departures from excepted trends, recheck estimates and explain any differences		level 4

1.6.9 Work plan for the development of a QC/QA procedure

The following activities will be under taken in the work of setting up QA/QC procedures:

Review of existing data structure A construction of the existing data structure (detailed) in order to get a complete overview of all aspects from the raw data to the final emission estimate. There will be more or less separate structures for separate categories in the inventory, but for all of them a structure needs to be made including the interaction between different categories.

Review of existing methods A complete overview of all the applied methods has to be made in a schematic and transparent way, so it becomes clear what challenges there will be associated with the writing of understandable manuals.

Review of the uncertainty calculations A complete overview of the actual uncertainty calculations as their are done in order to identify possible gaps between the needed uncertainty estimates for fulfilling good praxis and the actual running procedure for uncertainty analysis.

Modifying data structure Subsequently after the existing situation is displayed the data structure has to be reconsidered in relation to possible modification, which support the QC/QA procedure.

Filling up methodological gabs Especially the demand of a transparent and valid uncertainty analysis may identify gaps in the methodology that needs to be filled out. A change in data structure may also induce a demand of changing the methodology.

Writing manuals The methods applied for the inventory has to be explained in manuals in order to secure transparency and robustness for change in personal.

Setting up control measures Measures has to be made which can quantify how well the Critical Control Points are taken into account in the inventory. These measures will important in the communication with external reviewers and as guidelines for the ongoing work of improving the inventory.

Two source categories will be processed using the activity plan above during 2004. These two categories are selected in relation to both high importance and difference in type. It is important that the composition of data and procedures are distinct between the two selected source categories because that will facilitate a fast development of a QA/QC system which can handle all classes of sources. In this way the selected source categories will act as training set for a general QA/QC procedure development. The selected categories are:

- Agriculture
- Public electricity and heat production

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

The uncertainty estimates are based on the Tier 1 methodology in IPCC Good Practice Guidance (GPG) (IPCC 2000). Uncertainty estimates for stationary combustion plants, mobile combustion, agriculture and fugitive emissions from fuels are included this year. The aim is to include an increasing part of the emission sources during the next years. The sources included in the uncertainty estimate cover 93% of the total Danish greenhouse gas emission (CO_2 eq.).

The uncertainties of the activity rates and emission factors are shown in Table 1.2.

The estimated uncertainties for total GHG and for CO_2, CH_4 and N_2O are shown in Table 1.3. The total Danish GHG emission is estimated with an uncertainty of ±46% and the trend of GHG emission since 1990 have been estimated to be -1,4%[1] ± 19%-age points. The GHG uncertainty estimates do not take into account the uncertainty of the GWP factors.

[1] Including only emission sources for which the uncertainty have been estimated

The uncertainty on N_2O from agricultural soils is the predominant source of uncertainty for the Danish GHG inventory.

The uncertainty of the GHG emission from combustion (sector 1A) is 8% and the trend uncertainty is 1,8%.

Table 1.2 Uncertainty rates for each emission source

IPCC Source category	Gas	Base year emission (1990) Gg CO2 eq	Year t emission Gg CO2 eq	Activity data uncertainty %	Emission factor uncertainty %
Stationary Combustion, Coal	CO2	24209	16708	1	5
Stationary Combustion, Petroleum coke	CO2	410	762	3	5
Stationary Combustion, Plastic waste	CO2	369	599	5	5
Stationary Combustion, Residual oil	CO2	2505	1923	2	2
Stationary Combustion, Gas oil	CO2	4564	2920	4	5
Stationary Combustion, Kerosene	CO2	366	18	4	5
Stationary Combustion, Orimulsion	CO2	0	1908	1	2
Stationary Combustion, Natural gas	CO2	4330	11090	3	1
Stationary Combustion, LPG	CO2	194	104	4	5
Stationary Combustion, Refinery gas	CO2	806	842	3	5
Stationary combustion plants, gas engines	CH4	2	400	2,2	40
Stationary combustion plants, other	CH4	117	133	2,2	100
Stationary combustion plants	N2O	397	383	2,2	1000
Transport, Civil aviation, Aviation Gasoline	CO2	8	7	2	5
Transport, Civil aviation, Jet Kerosene	CO2	208	139	2	5
Transport, Road transport, Gasoline	CO2	4914	6021	2	5
Transport, Road transport, Diesel Oil	CO2	4436	5369	2	5
Transport, Railways, Diesel Oil	CO2	297	210	2	5
Transport, Navigation, Residual Oil	CO2	278	161	2	5
Transport, Navigation, Gas/Diesel Oil	CO2	246	320	2	5
Transport, Agriculture, Diesel Oil	CO2	1280	1184	20	5
Transport, Agriculture, Gasoline	CO2	38	36	20	5
Transport, Forestry, Diesel Oil	CO2	0	0	20	5
Transport, Forestry, Gasoline	CO2	4	4	20	5
Transport, Industry, Diesel Oil	CO2	687	635	20	5
Transport, Industry, Gasoline	CO2	10	10	20	5
Transport, Industry, LPG	CO2	81	97	20	5
Transport, Household and gardening, Gasoline	CO2	87	82	20	5
Transport, Civil aviation, Aviation Gasoline	CH4	0	0	2	100
Transport, Civil aviation, Jet Kerosene	CH4	0	0	2	100
Transport, Road transport, Gasoline	CH4	48	56	2	40
Transport, Road transport, Diesel Oil	CH4	7	7	2	40
Transport, Railways, Diesel Oil	CH4	0	0	2	100
Transport, Navigation, Residual Oil	CH4	0	0	2	100
Transport, Navigation, Gas/Diesel Oil	CH4	0	0	2	100
Transport, Agriculture, Diesel Oil	CH4	2	1	20	100
Transport, Agriculture, Gasoline	CH4	1	1	20	100
Transport, Forestry, Diesel Oil	CH4	0	0	20	100
Transport, Forestry, Gasoline	CH4	0	0	20	100
Transport, Industry, Diesel Oil	CH4	1	1	20	100
Transport, Industry, Gasoline	CH4	0	0	20	100
Transport, Industry, LPG	CH4	2	2	20	100
Transport, Household and gardening, Gasoline	CH4	3	3	20	100
Transport, Civil aviation, Aviation Gasoline	N2O	0	0	2	1000
Transport, Civil aviation, Jet Kerosene	N2O	3	2	2	1000
Transport, Road transport, Gasoline	N2O	47	276	2	50
Transport, Road transport, Diesel Oil	N2O	84	118	2	50
Transport, Railways, Diesel Oil	N2O	3	2	2	1000
Transport, Navigation, Residual Oil	N2O	5	3	2	1000
Transport, Navigation, Gas/Diesel Oil	N2O	5	6	2	1000
Transport, Agriculture, Diesel Oil	N2O	17	15	20	1000
Transport, Agriculture, Gasoline	N2O	0	0	20	1000
Transport, Forestry, Diesel Oil	N2O	0	0	20	1000
Transport, Forestry, Gasoline	N2O	0	0	20	1000
Transport, Industry, Diesel Oil	N2O	9	8	20	1000
Transport, Industry, Gasoline	N2O	0	0	20	1000
Transport, Industry, LPG	N2O	1	1	20	1000
Transport, Household and gardening, Gasoline	N2O	1	1	20	1000
Energy, fugitive emissions, oil and natural gas	CO2	240	535	15	5
Energy, fugitive emissions, solid fuels	CH4	72	62	2	200
Energy, fugitive emissions, oil and natural gas	CH4	21	70	15	50
Energy, fugitive emissions, oil and natural gas	N2O	1	3	15	50
Agriculture, enteric fermentation	CH4	3100	2798	2	20

Agriculture, manure management	CH4	742	966	10	30
Agriculture, manure management	N2O	686	605	10	500
Agriculture, Agricultural soils	N2O	8297	5765	20	500

Table 1.3 Uncertainty

1)	Uncertainty [%]	Trend [%]	Uncertainty in trend [%-age points]
CO_2	2,0	+2,2	±1,7
CH_4	15	+9,3	±6,3
N_2O	407	-25	±32
GHG	46	-1,4	±19

1. The uncertainty estimates includes stationary combustion plants, mobile combustion, agriculture and fugitive emissions from fuels

1.8 General assessment of the completeness

The Danish greenhouse gas emission inventory due 15 April 2004 includes all sources identified by the Revised IPPC Guidelines except the following (se table A5.1):

- Waste: Wastewater handling systems are considered to produce only minor emissions of CO_2, CH_4 and N_2O but it will be investigated further.
- Industrial processes: CO_2 emission from sugar production and production of expanded clay will be included in the next submission. Also CO_2 emissions from use of coke in iron foundries will be included in the next submission.
- Agriculture: The methane conversion factor for poultry and fur farming is not estimated. There is no default value recommended in IPCC (table A-4 in GPG). The CH_4 emissions from manure storage in the field and from cultivation of organogenic soil are not estimated.

In response to review of previous submissions the use of notation key in the Danish CRF-tables is improved and extended.

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2 Trends in Greenhouse Gas Emissions

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

The greenhouse gas emissions are estimated according to the IPCC guidelines and are aggregated in seven main sectors. The greenhouse gases include CO_2, CH_4, N_2O, HFCs, PFCs and SF_6. Figure 1.1 shows the estimated total greenhouse gas emissions with CO_2 removal by forestry in CO_2 equivalents from 1990 to 2002. The emissions are not corrected for electricity trade or temperature variations. CO_2 is the most important greenhouse gas followed by N_2O and CH_4 in relative importance. The contribution to national totals from HFCs, PFCs and SF_6 is about 1%. Stationary combustion plants, transport and agriculture are the largest sources. The removal by forestry is about 5% of the total emissions in CO_2 equivalents. The national total greenhouse gas emissions in CO_2 equivalents are almost equal in 1990 and in 2002.

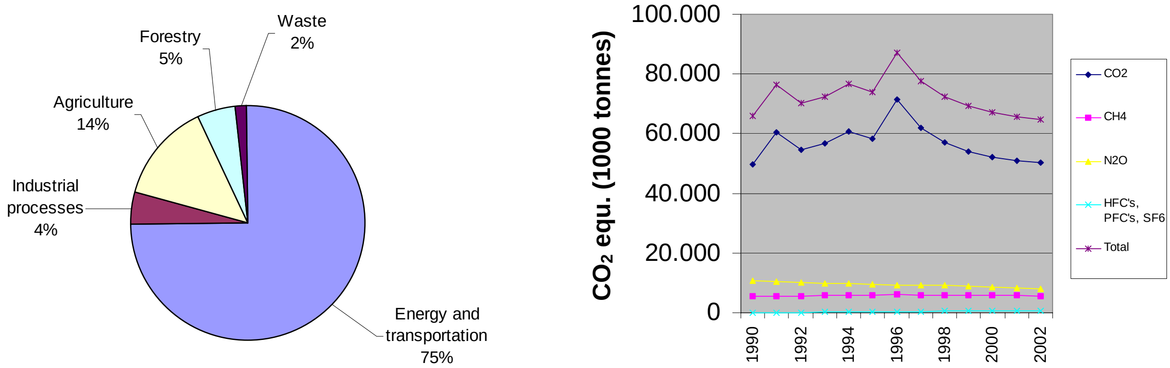


Figure 2.1 Greenhouse gas emissions in CO_2 equivalents without LUCF. Time series for 1990 to 2002 and distribution on main sectors for 2002.

2.2 Description and interpretation of emission trends by gas

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. Public power and district heating plants contribute with about half of the emissions. About 23% come from the transport sector. The CO_2 emission decreased by about 1% from 2001 to 2002. The reason for the small decrease was mainly due to higher outdoor temperature in 2002 compared with 2001. If the CO_2 emission is adjusted for climatic variations and electricity trade with other countries the CO_2 emission has decreased by 13% since 1990 despite an almost constant gross energy consumption and an increase in the gross national product of 29%. This is due to change of fuel from coal to natural gas and renewable energy. As a result of the lower consumption of coal in the recent years the main part of the CO_2 emission comes from oil combustion. In 2002 the actual CO_2 emission was almost the same as the emission in 1990.

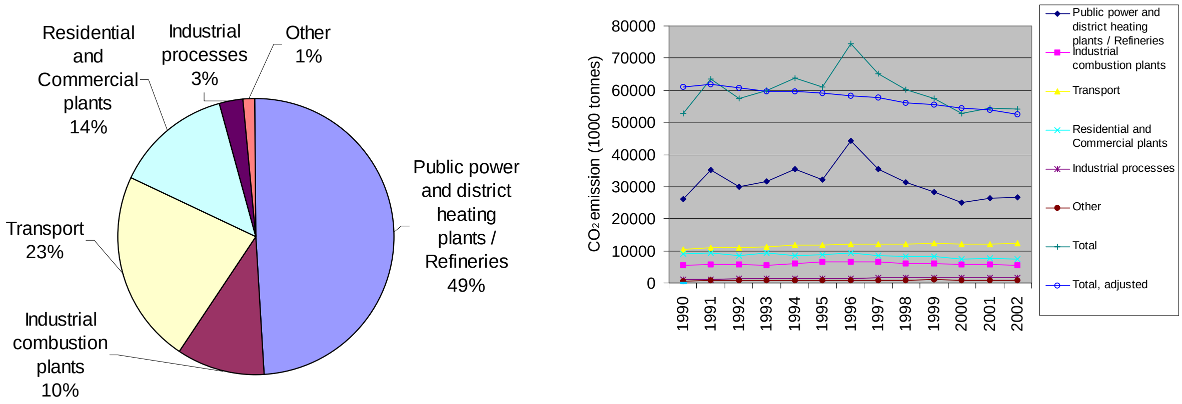


Figure 2.2. CO_2 emissions. Time series for 1990 to 2002 and distribution on main sectors for 2002.

Nitrous oxide

Agriculture is the most important N_2O emission source, Figure 2.3. 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 fertilisers. The main reason for the drop of about 30% from 1990 to 2002 in the emissions is caused by demands according to legislation to an improved utilisation of nitrogen in manure. This results in less nitrogen excreted per unit produced and a considerably reduction in the use of fertilisers. The basis for N_2O emission is then reduced. About 10% come from combustion of fossil fuels and transport accounts for about 5%. The N_2O emission from transport has increased in the nineties because of increasing use of catalyst cars. Emissions of N_2O from Nitric Acid production amounts to about 10% of the total N_2O emission.

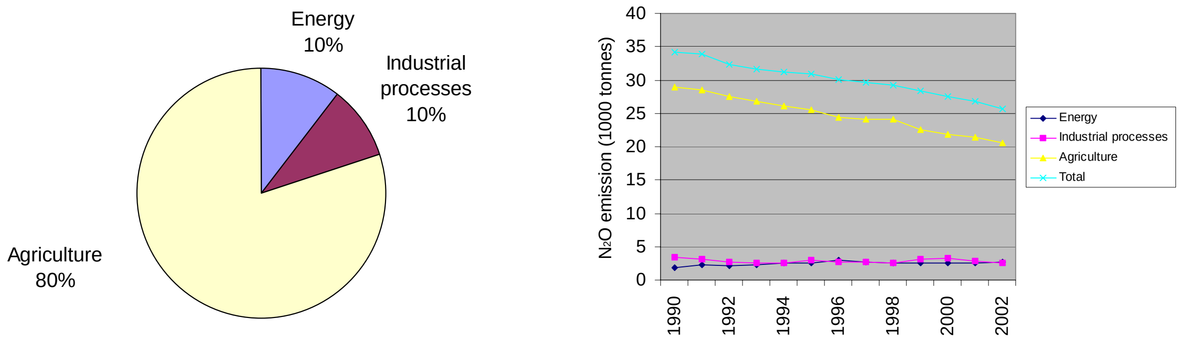
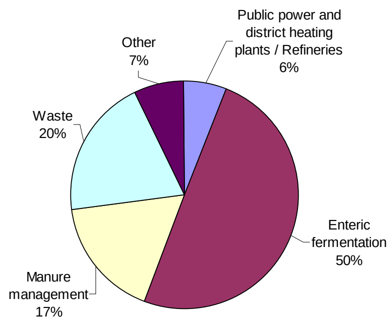


Figure 2.3. N_2O emissions. Time series for 1990 to 2002 and distribution on main sectors for 2002.

Methane

The largest sources to anthropogenic CH_4 emissions are: Agriculture activities, managed waste disposal on land, public power and district heating plants. The emission from agriculture derives from enteric fermentation and management of animal manure. The increasing CH_4 emissions from public power and district heating plants are due to increasing use of gas engines in the decentralised cogeneration plants sector. About 3% of the natural gas in the gas engines are not combusted. From 1990 the emissions of CH_4 from enteric fermentation has decreased because of decreasing numbers of cattle. However the emission from manure management have increased due to change in stable systems towards an increase in slurry based stable systems. Altogether the emission of

CH_4 for the agriculture sector has been almost constant from 1990 to 2002. The emission of CH_4 from waste disposal is decreasing slightly due to increasing use of waste for incineration.



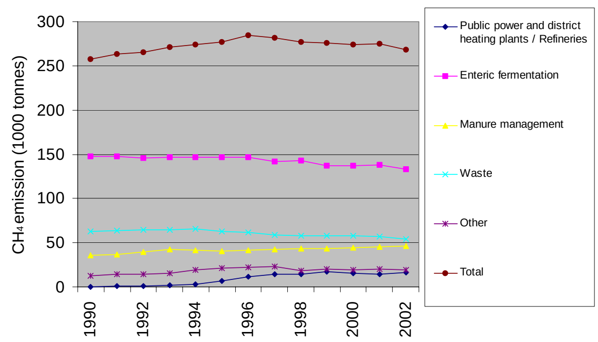


Figure 2.4. CH_4 emissions. Time series for 1990 to 2002 and distribution on main sectors for 2002.

HFCs, PFCs and SF6

This part of the Danish inventory only has data on all substances back to 1995. Since then and until 2000 there has been a continuous and substantial increase in the contribution of the sum of F-gases considering their sum of emissions in CO_2-equivalents. This increase is simultaneously with an increase in emissions of HFCs. For the time-series 2000-2002 the increase has been markedly stagnant. (The falling tendency 2000-2001 reported in the NIR 2003 has disappeared due to recalculations). The reasons for these trends are several. SF_6 contributed considerably in the first part of the trend, in 1993 by 52%. Environmental awareness and facing regulation of this gas in Danish law has decreased its industrial use and its contribution in 2002 is around 3%. The use of HFCs, and especially HFC-134a as a main contributor to the HFCs, has increased several folds and the model for the emissions responds with increasing emissions. So HFCs has become a very dominating F-gas from 42% in 1993 to 94% in 2002. A main use of HFC-134a is as a refrigerant. However, the tendency is that the use of HFC-134a for this use as well as the use of other HFCs as refrigerant is stagnant or falling. This is due to Danish law, which in 2007 forbids new HFC based refrigerant stationary systems. Counter to this trend is the increasing use of air conditioning systems, among these mobile systems.

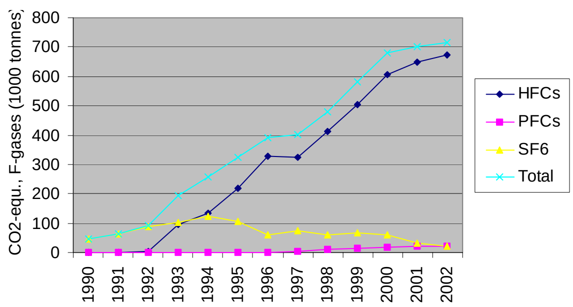


Figure 2.5. F-gas emissions. Time series for 1990 to 2002.

2.3 Description and interpretation of emission trends by source

Energy

The emission of CO_2 from public power and district heating plants has increased by 1 from 1990 to 2002. The relatively large fluctuation in the emission is due to cross-country electricity trade. Thus the high emissions in 1991 and 1996 reflect a large electricity export and the low emission in 1990 is due to a large import of electricity. The increasing emission of CH_4 is due to increasing use of gas engines in the decentralised cogeneration plants. The CO_2 emission from the transport sector has increased by 18% since 1990 mainly due to increasing road traffic.

More details for the energy sector are given in chapter 3.

Agriculture

The agricultural sector contributes with 15% of the total greenhouse gas emission in CO_2- equivalents and is one of the most important sectors regarding the emissions of N_2O and CH_4 and in 2002 the contributions to the total emissions were 80% and 67 % respectively. The N_2O emission has decreased by 29% from 1990 to 2002 while the CH_4 emission has been almost constant.

More details about the agriculture sector are given in chapter 6.

Industrial processes

The emissions from industrial process – that is emissions from processes other than fuel combustion - amount to 4% of the total emissions in CO_2- equivalents. The main sources are cement production, nitric acid production, refrigeration, foam blowing and calcination of limestone. The CO_2 emission from cement production – which is the largest source contributing with 2,1% of the national totals – increased with 65% from 1990 to 2002. The second largest source is N_2O from production of nitric acid. The N_2O emission from this production decreased with 26% from 1990 to 2002.
More details for the industrial processes are given in chapter 4.

Waste

Waste disposal is the third largest source to CH_4 emission. The emission has decreased by 14% from 1990 to 2002 where the contribution was 20% of the total CH_4 emission. The decrease is due to increasing use of waste for power and heat production. Since all incinerated waste is used for power and heat production the emissions are included in the 1A1a IPCC category. More details for the waste sector are given in Chapter 8.

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

NO_x

The three largest - and almost equal in size – sources are combustion in energy industries (mainly public power and district heating plants), road transport and other mobile sources. The transport sector is the sector contributing most to the emission of NO_x and in 2002 40% of the Danish emissions of NO_x stem 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 public power plants and district heating plants have decreased by 57% from 1985 to 2002. In the same period the total emission has decreased by 35%. The reduction is due to increasing use of catalyst cars and installation of low-NO_x-burners and de-NO_x-units on power and district heating plants.

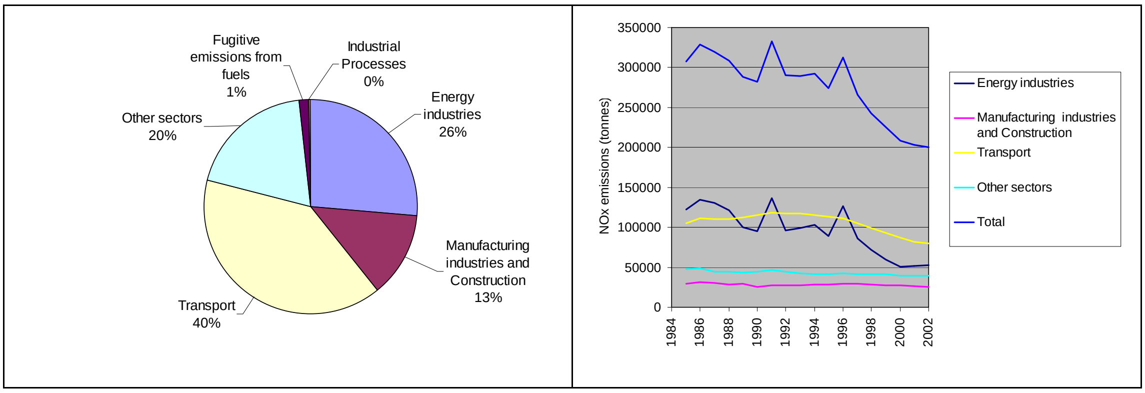


Figure 2.6. NO_4 emissions. Time series for 1990 to 2002 and distribution on main sectors for 2002.

CO

Even though catalyst cars were introduced in 1990, road transport still has the dominant share of the total CO emission. Also other mobile sources and non-industrial combustion plants contribute significantly to the total emission of this pollutant. The drop in the emissions seen in 1990 was a consequence of a law forbidden burning of agricultural waste on fields. The emission decreased by 23 % from 1990 to 2002 mainly because of decreasing emission from road transportation.

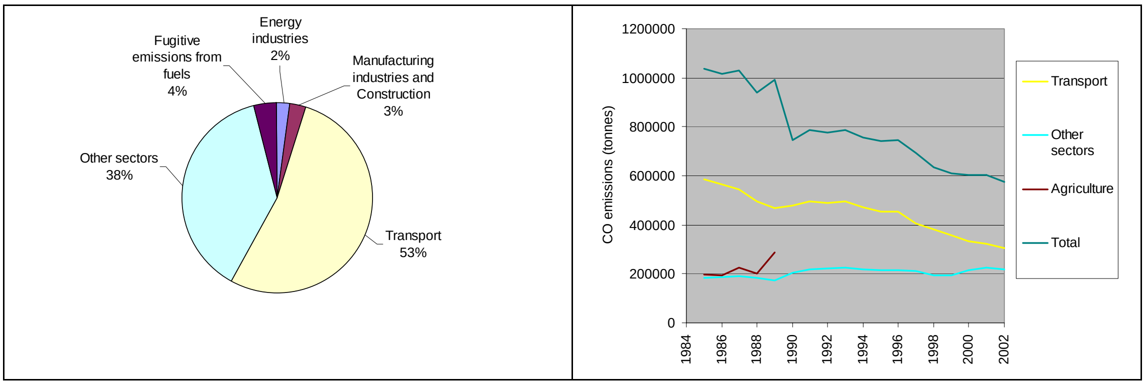


Figure 2.7. CO emissions. Time series for 1990 to 2002 and distribution on main sectors for 2002.

NMVOC

The emissions of NMVOC originate from many different sources and can be divided into two main groups: Incomplete combustion and evaporation. The main sources to NMVOC emissions from incomplete combustion processes are road vehicles and other mobile sources such as national navigation vessels and off-road machinery. Road transportation vehicles are still the main contributors even though the emissions have declined since the introduction of catalyst cars in 1990. The evaporative emissions mainly originate from use of solvents. The emissions from energy industries have increased during the nineties because of increasing use of stationary gas engines that have much higher emissions of NMVOC than conventional boilers. The total anthropogenic emissions have decreased by 36% from 1985 to 2002 mainly due to increasing use of catalyst cars and reduced emissions from use of solvents.

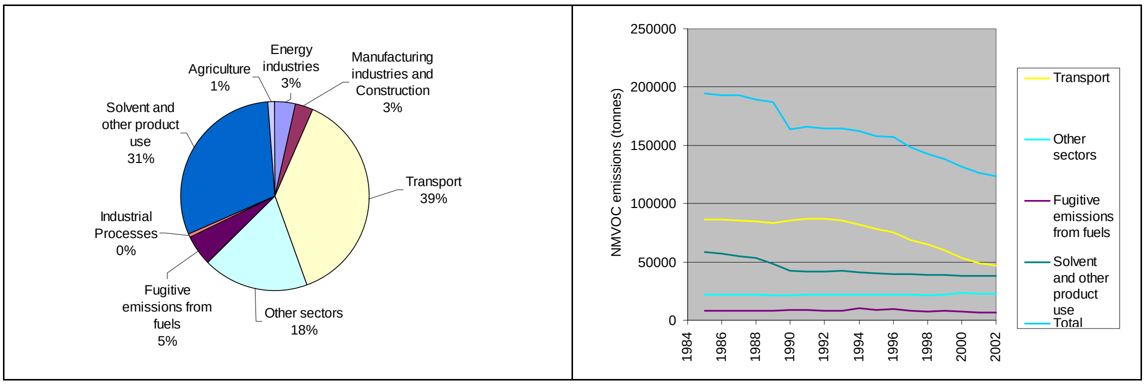


Figure 2.8. NMVOC emissions. Time series for 1990 to 2002 and distribution on main sectors for 2002.

SO_2

The main part of the SO2 emissions originate from combustion of fossil fuels – mainly coal and oil – on public power and district heating plants. From 1980 to 2002 the total emission has decreased by 94%. The large reduction is mainly due installation of desulphurization plants 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 43% f of the total emission. 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 11% of the total SO_2 emission. This is due to the use of residual oil with high content of sulphur.

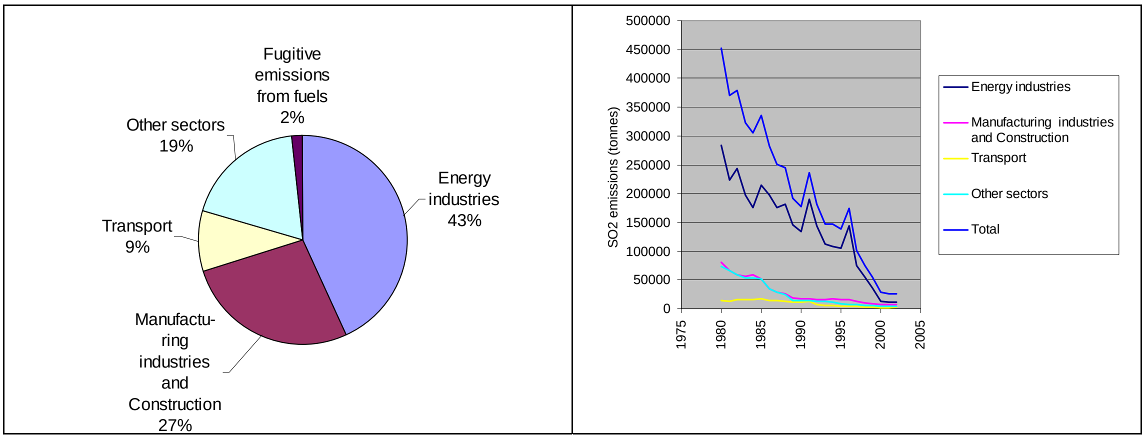


Figure 2.9. SO_2 emissions. Time series for 1990 to 2002 and distribution on main sectors for 2002.

3 Energy (CRF sector 1)

3.1 Overview of the sector

The energy sector have 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 about fuel combustion (CRF sector 1A)
3.5 Fugitive emissions (CRF sector 1B)

Emissions of SO_2, NO_X, NMVOC and CO from container glass production, that are reported in the CRF category 1A2f, is included in the NIR chapter *4 Industry*. Greenhouse gases connected to fuel combustion in this sector are however included in chapter 3.2 Stationary Combustion.

Table 3.1 shows detailed source categories for the energy sector and plant category in which the sector is discussed in this report.

Table 3.1 CRF energy sectors and relevant NIR chapters

IPCC id	IPCC sector name	NIR chapter
1	Energy	Stationary combustion + transport + Fugitive
1A	Fuel Combustion Activities	Stationary combustion + transport
1A1	Energy Industries	Stationary combustion
1A1a	Electricity and Heat Production	Stationary combustion
1A1b	Petroleum Refining	Stationary combustion
1A1c	Solid Fuel Transf./Other Energy Industries	Stationary combustion
1A2	Fuel Combustion Activities/Industry (ISIC)	Stationary combustion + transport
1A2a	Iron and Steel	Stationary combustion
1A2b	Non-Ferrous Metals	Stationary combustion
1A2c	Chemicals	Stationary combustion
1A2d	Pulp, Paper and Print	Stationary combustion
1A2e	Food Processing, Beverages and Tobacco	Stationary combustion
1A2f	Other (please specify)	Stationary combustion + transport + industry
1A3	Transport	Transport
1A3a	Civil Aviation	Transport
1A3b	Road Transportation	Transport
1A3c	Railways	Transport
1A3d	Navigation	Transport
1A3e	Other (please specify)	Transport
1A4	Other Sectors	Stationary combustion + transport
1A4a	Commercial/Institutional	Stationary combustion
1A4b	Residential	Stationary combustion + transport
1A4c	Agriculture/Forestry/Fishing	Stationary combustion + transport
1A5	Other (please specify)	Stationary combustion + transport
1A5a	Stationary	Stationary combustion
1A5b	Mobile	Transport
1B	Fugitive Emissions from Fuels	Fugitive
1B1	Solid Fuels	Fugitive
1B1a	Coal Mining	Fugitive
1B1a1	Underground Mines	Fugitive
1B1a2	Surface Mines	Fugitive
1B1b	Solid Fuel Transformation	Fugitive
1B1c	Other (please specify)	Fugitive
1B2	Oil and Natural Gas	Fugitive
1B2a	Oil	Fugitive
1B2a2	Production	Fugitive
1B2a3	Transport	Fugitive
1B2a4	Refining/Storage	Fugitive
1B2a5	Distribution of oil products	Fugitive
1B2a6	Other	Fugitive
1B2b	Natural Gas	Fugitive
1B2b1	Production/processing	Fugitive
1B2b2	Transmission/distribution	Fugitive
1B2c	Venting and Flaring	Fugitive
1B2c1	Venting and Flaring Oil	Fugitive
1B2c2	Venting and Flaring Gas	Fugitive
1B2d	Other	Fugitive

Summary tables for the energy sector are shown below.

Table 3.2 CO_2 emission from the energy sector

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
	(Gg)												
1. Energy	**51.486**	**62.029**	**56.084**	**58.426**	**62.409**	**59.645**	**72.974**	**63.468**	**58.499**	**55.789**	**51.168**	**52.787**	**52.457**
A. Fuel Combustion (Sectoral Approach)	51.246	61.535	55.573	57.981	61.941	59.280	72.574	62.903	58.077	54.887	50.575	52.153	51.922
1. Energy Industries	26.177	35.123	30.096	31.643	35.353	32.058	44.376	35.395	31.471	28.206	25.070	26.377	26.548
2. Manufacturing Industries and Construction	5.383	5.801	5.645	5.575	6.161	6.464	6.650	6.550	5.952	5.981	5.740	5.760	5.557
3. Transport	10.415	10.914	11.045	11.236	11.684	11.823	12.029	12.160	12.191	12.253	12.120	12.149	12.300
4. Other Sectors	9.152	9.410	8.647	9.290	8.492	8.683	9.342	8.626	8.259	8.265	7.535	7.771	7.428
5. Other	119	287	141	237	252	252	176	171	204	182	111	97	89
B. Fugitive Emissions from Fuels	240	495	511	445	468	365	400	565	422	903	593	633	535
1. Solid Fuels	0	0	0	0	0	0	0	0	0	0	0	0	0
2. Oil and Natural Gas	240	495	511	445	468	365	400	565	422	903	593	633	535

Table 3.3 CH_4 emission from the energy sector

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
	(Gg)												
Total Emissions	**258,52**	**263,71**	**265,46**	**271,39**	**278,15**	**282,02**	**287,79**	**280,77**	**279,86**	**274,33**	**272,91**	**275,76**	**268,32**
1. Energy	**13,19**	**15,53**	**15,72**	**17,76**	**25,36**	**32,16**	**37,36**	**37,59**	**35,72**	**35,81**	**34,32**	**36,06**	**35,21**
A. Fuel Combustion (Sectoral Approach)	8,76	9,78	10,20	11,44	16,69	22,63	27,98	27,54	29,22	28,01	27,76	29,07	28,93
1. Energy Industries	1,06	1,43	1,68	2,45	6,27	11,39	14,94	14,36	16,93	15,51	14,94	16,18	16,18
2. Manufacturing Industries and Construction	0,79	0,83	0,82	0,85	0,95	1,09	1,65	1,64	1,22	1,51	1,66	1,73	1,78
3. Transport	2,69	2,97	3,11	3,38	3,55	3,71	3,98	3,82	3,66	3,58	3,43	3,39	3,15
4. Other Sectors	4,21	4,53	4,58	4,76	5,91	6,43	7,40	7,71	7,40	7,39	7,72	7,75	7,82
5. Other	0,01	0,02	0,01	0,01	0,01	0,02	0,01	0,01	0,01	0,01	0,01	0,01	0,00
B. Fugitive Emissions from Fuels	4,43	5,75	5,52	6,32	8,67	9,53	9,38	10,05	6,50	7,80	6,57	7,00	6,28
1. Solid Fuels	3,45	3,97	3,91	4,79	5,61	6,30	6,36	6,53	3,47	3,37	3,04	3,28	2,97
2. Oil and Natural Gas	0,98	1,78	1,61	1,52	3,06	3,23	3,02	3,52	3,03	4,43	3,53	3,72	3,31

Table 3.4 N_2O emission from the energy sector

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
	(Gg)												
Total Emissions	**34,24**	**33,85**	**32,40**	**31,68**	**31,25**	**30,90**	**30,04**	**29,64**	**29,27**	**28,30**	**27,57**	**26,85**	**25,73**
1. Energy	**1,90**	**2,29**	**2,17**	**2,29**	**2,51**	**2,49**	**2,96**	**2,76**	**2,62**	**2,61**	**2,52**	**2,62**	**2,68**
A. Fuel Combustion (Sectoral Approach)	1,90	2,29	2,16	2,28	2,50	2,48	2,95	2,75	2,61	2,60	2,51	2,61	2,67
1. Energy Industries	0,89	1,17	1,01	1,06	1,17	1,06	1,44	1,15	0,99	0,89	0,79	0,84	0,85
2. Manufacturing Industries and Construction	0,17	0,19	0,18	0,18	0,20	0,20	0,21	0,21	0,18	0,19	0,19	0,19	0,20
3. Transport	0,47	0,55	0,61	0,67	0,79	0,87	0,94	1,05	1,12	1,18	1,23	1,27	1,31
4. Other Sectors	0,36	0,37	0,35	0,36	0,33	0,33	0,35	0,33	0,32	0,32	0,31	0,31	0,30
5. Other	0,00	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,00	0,01	0,00
B. Fugitive Emissions from Fuels	0,00	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,01	0,01	0,01
1. Solid Fuels	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2. Oil and Natural Gas	0,00	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,01	0,01	0,01

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

Fuel consumption and emissions from stationary combustion plants in CRF sector 1A1, 1A2 and 1A4 are all included in this chapter. Further details about the inventories for stationary combustion is enclosed in Annex 3A.

3.2.1 Source category description

Emission source categories, fuel consumption data and emission data are presented in this chapter.

3.2.1.1 Emission source categories

In the Danish emission database all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution). The data from the Danish database are aggregated to the CRF sector codes based on a correspondence list between SNAP and CRF sectors. The correspondence list is enclosed in Annex 3A. Stationary combustion is defined as combustion activities in the SNAP sectors 01-03.

Stationary combustion plants are included in the emission source subcategories:

- *1A1 Energy, Fuel consumption, Energy Industries*
- *1A2 Energy, Fuel consumption, Manufacturing Industries and Construction*
- *1A4 Energy, Fuel consumption, Other Sectors*

The emission sources *1A2* and *1A4* however also include emission from transport subsectors. The emission source *1A2* includes emission from some off road machinery in the industry. The emission source *1A4* includes off road machinery in agriculture, forestry and household/gardening. Further emissions from national fishing are included in subsector *1A4*.

Emission and fuel consumption data shown in tables and figures in Chapter 3.2 only includes emissions originating from stationary combustion plants of a given CRF sector. The CRF sector codes have been applied unchanged, but some source category names have been changed to reflect the stationary combustion part of the source.

3.2.1.2 Fuel consumption

In 2002 the total fuel consumption for stationary combustion plants was 568 PJ of which 490 PJ was fossil fuels.

Fuel consumption of the stationary combustion subsectors is shown in Figure 3.1 and Figure 3.2. The main part – 59% - of the fuels is combusted in the sector *Electricity and heat production*. Other sectors with high fuel consumption are *Residential* and *Industry*.

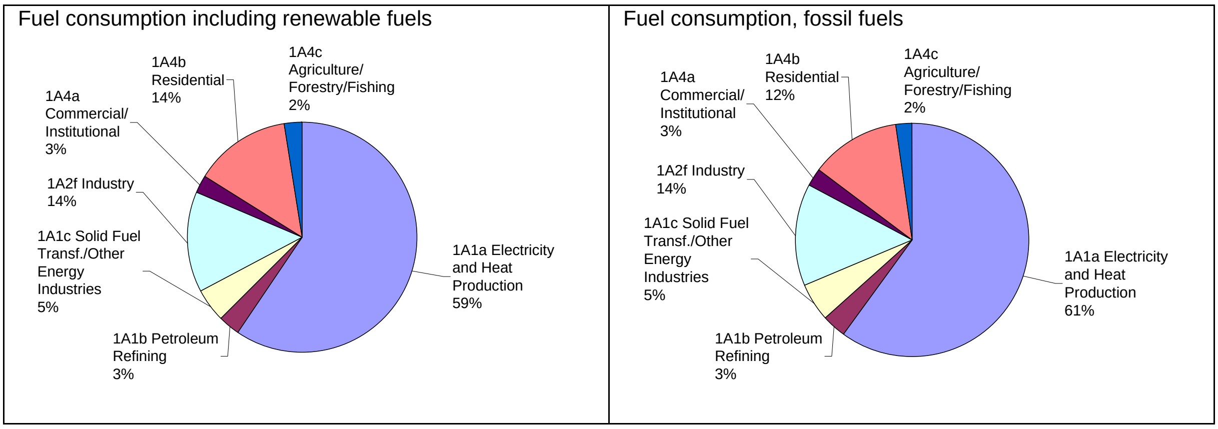


Figure 3.1 Fuel consumption rate of stationary combustion, 2002 (based on DEA 2003a)

Coal and natural gas 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 CHP plants as well as in industry, district heating and households.

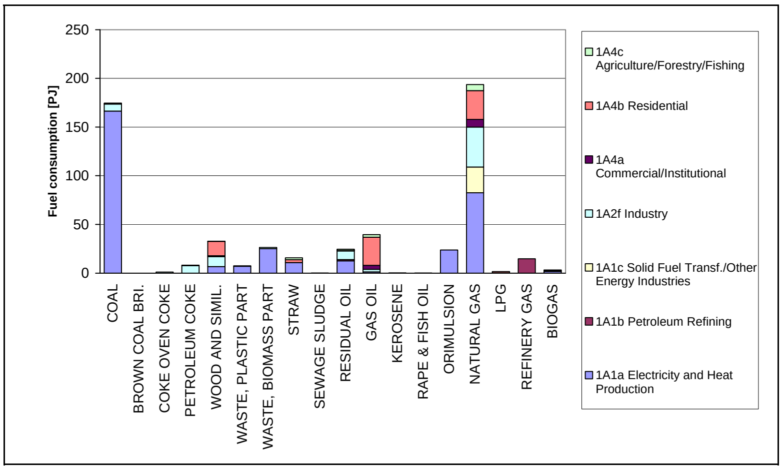


Figure 3.2 Fuel consumption of stationary combustion plants 2002 (based on DEA 2003a)

Fuel consumption time series for stationary combustion plants are shown in Figure 3.3. The total fuel consumption has increased by 14% from 1990 to 2002, while the fossil fuel consumption has only increased by 8%. The consumption of natural gas and renewable fuels has increased since 1990 whereas coal consumption has decreased.

The fuel consumption rate fluctuates considerably mainly due to electricity import/export but also due to outdoor temperature variations. The fuel consumption fluctuation is further discussed in Chapter 3.2.1.3.

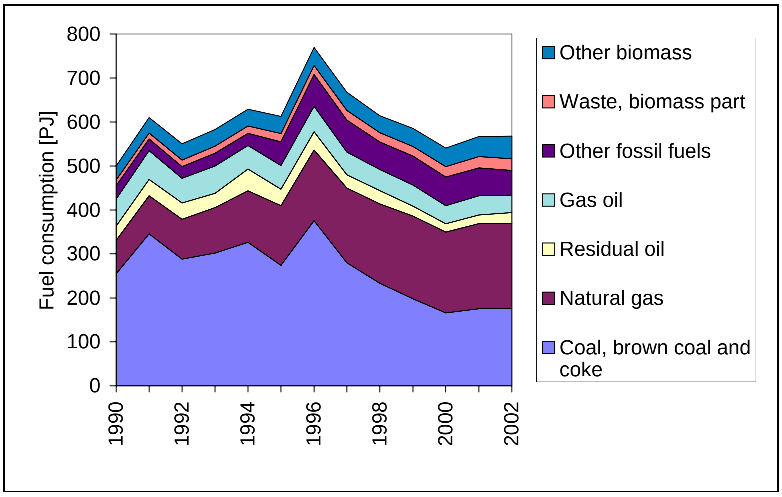


Figure 3.3 Fuel consumption time series, stationary combustion (based on DEA 2003a)

3.2.1.3 Emissions

The GHG emissions from stationary combustion are shown in Table 3.5.

The CO_2 emission from stationary combustion plants accounts for 68% of the total Danish CO_2 emission (gross). CH_4 accounts for 9% of the total Danish CH_4 emission and N_2O for only 5% of the total Danish N_2O emission.

Table 3.5 Greenhouse gas emission for the year 2002

	CO_2	CH_4	N_2O
		Gg CO_2 equivalent	
1A1 Fuel consumption, Energy industries	26548	340	264
1A2 Fuel consumption, Manufacturing Industries and Construction[1)]	4815	34	53
1A4 Fuel consumption, Other sectors [1)]	5510	159	66
Total emission from stationary combustion plants	**36873**	**533**	**383**
Total Danish emission (gross)	54164	5635	7976
		%	
Emission share for stationary combustion	68	9	5

1) Only stationary combustion sources of the sector is included

CO_2 is the most important GHG pollutant accounting for 97,6% of the GHG emission (CO_2 eq.).

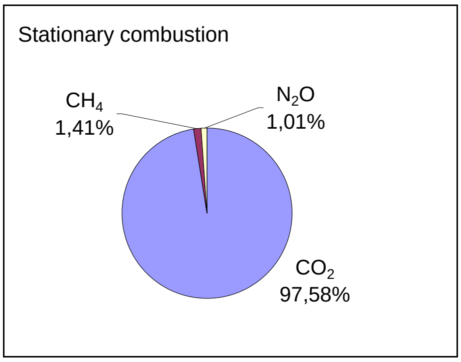


Figure 3.4 GHG emission (CO_2 equivalent) from stationary combustion plants

Figure 3.5 shows the time series for GHG emission (CO_2 eq.) from stationary combustion. It appears that the GHG emission development follows the CO_2 emission development very close. Both the CO_2 and the total GHG emission have decreased a little from 1990 to 2002, CO_2 by 2,3% and GHG by 1,3%. However fluctuations of the GHG emission level are considerable.

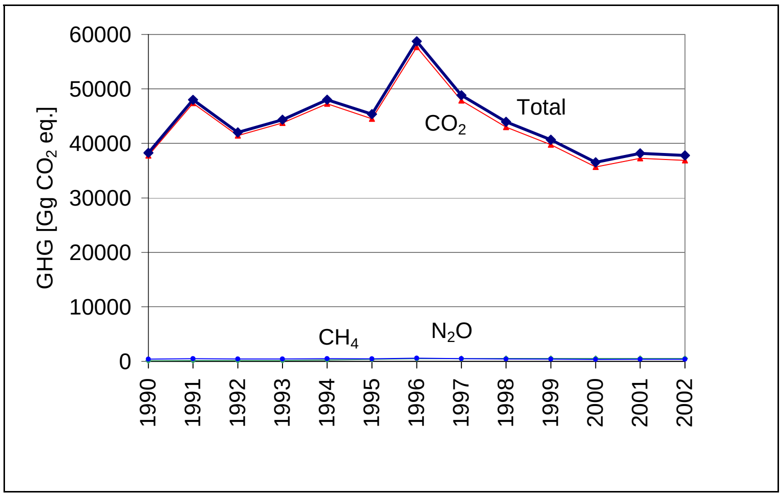


Figure 3.5 GHG emission time series for stationary combustion

The fluctuations in the time series are a result mainly of electricity import/export but also of outdoor temperature variations between years. These fluctuations are shown in Figure 3.6. In 1990 the Danish electricity import was large causing relatively low emissions, whereas the emissions are high in 1996 due to a large electricity export. In 2002 the net electricity export was 7453 TJ.

To be able to follow the national energy consumption and for statistical and reporting purposes the Danish Energy Authority produces a correction of the actual emissions without random variations in electricity imports/exports and in ambient temperature. This emission trend, which is smoothly decreasing, is also shown in Figure 3.6. The corrections are included here to explain the fluctuations in the emission time series. The GHG emission corrected for electricity import/export and ambient temperature has decreased by 20% since 1990, the CO_2 emission by 21%.

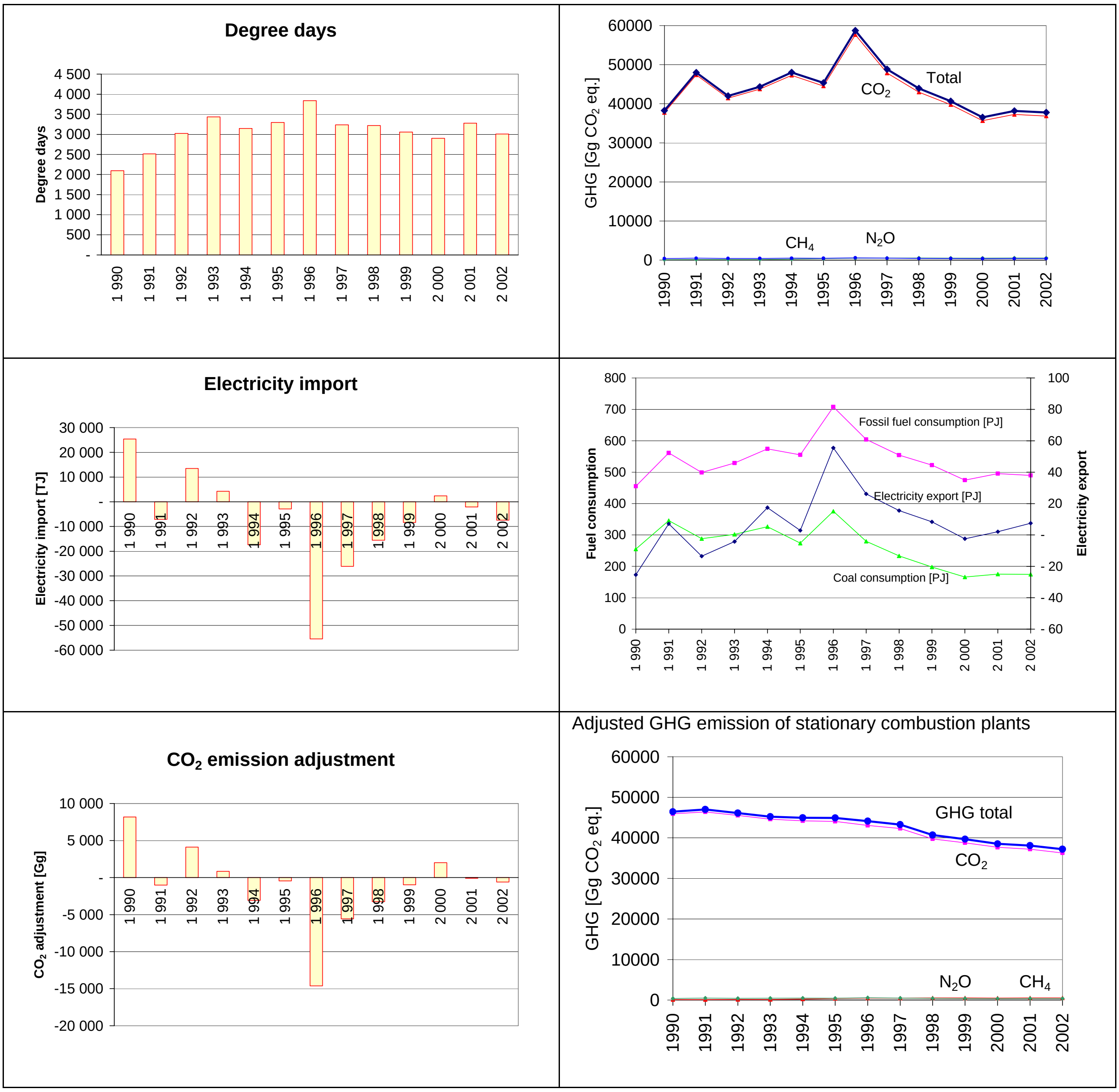


Figure 3.6 GHG emission time series for stationary combustion and adjustment for electricity import/export and temperature variations (DEA 2003b)

3.2.1.3.1 CO_2

The CO_2 emission from stationary combustion plants is one of the most important GHG emission sources. Thus the CO_2 emission from stationary combustion plants accounts for 68% of the total Danish CO_2 emission. Table 3.6 shows the CO_2 emission inventory for stationary combustion plants for 2002. Figure 3.7 shows that *Electricity and heat production* accounts for 65% of the CO_2 emission from stationary combustion. This share is somewhat higher than the fossil fuel consumption share of this sector, which is 61% (Figure 3.1). Other large CO_2 emission sources are industrial plants and residential plants. These are the sectors that also account for a considerable share of the fuel consumption.

Table 3.6 CO_2 emission from stationary combustion plants 2002[1)]

CO_2	2002	
1A1a Electricity and heat production	24083	Gg
1A1b Petroleum refining	948	Gg
1A1c Solid fuel transf. and other energy industries	1517	Gg
1A2f Industry	4815	Gg
1A4a Commercial / Institutional	800	Gg
1A4b Residential	3979	Gg
1A4c Agriculture / Forestry / Fishing	731	Gg
Total	**36873**	**Gg**

1) Only emission from stationary combustion plants included

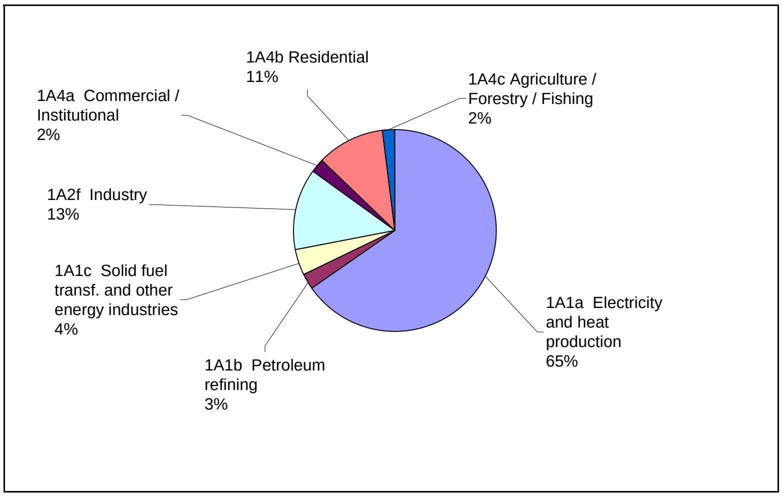


Figure 3.7 CO_2 emission sources, stationary combustion plants, 2002

The sector *Electricity and heat production* consists of the SNAP sectors: *Public power* and *District heating*. The CO_2 emissions from each of these subsectors are shown in Table 3.7. The most important subsector is centralised power plants.

Table 3.7 CO_2 emission from subsectors to *1A1a Electricity and heat production*

SNAP source	SNAP name	2002	
0101	Public power	0	Gg
010101	Combustion plants ≥ 300MW (boilers)	18823	Gg
010102	Combustion plants ≥ 50MW and < 300 MW (boilers)	971	Gg
010103	Combustion plants <50 MW (boilers)	172	Gg
010104	Gas turbines	2247	Gg
010105	Stationary engines	1608	Gg
0102	District heating plants	-	Gg
010201	Combustion plants ≥ 300MW (boilers)	-	Gg
010202	Combustion plants ≥ 50MW and < 300 MW (boilers)	39	Gg
010203	Combustion plants <50 MW (boilers)	223	Gg
010204	Gas turbines	-	Gg
010205	Stationary engines	0	Gg

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 CRF. In 2002 the CO_2 emission from biomass combustion was 8454 Gg.

Time series for CO_2 emission are shown in Figure 3.8. Despite an increase in fuel consumption of 14% since 1990 CO_2 emission from stationary combustion has decreased by 2,3% because of the change of fuel type used.

The fluctuations of CO_2 emission are discussed in Chapter 3.2.1.3.

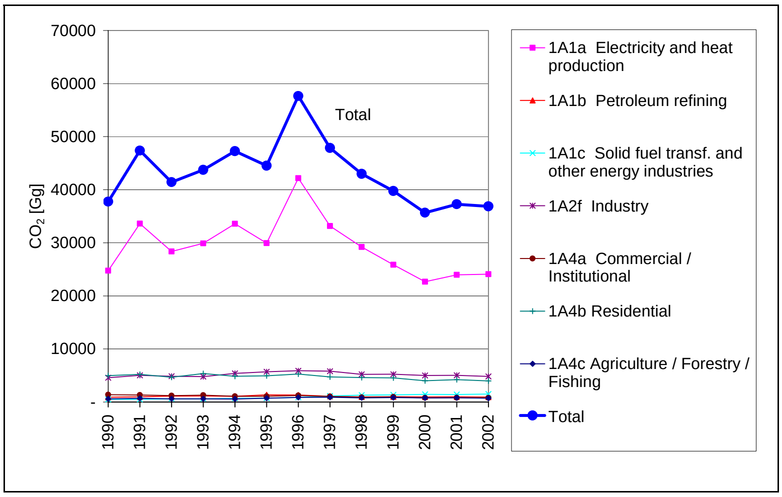


Figure 3.8 CO_2 emission time series for stationary combustion plants

3.2.1.3.2 CH_4

The CH_4 emission from stationary combustion plants accounts for 9% of the total Danish CH_4 emission. Table 3.8 shows the CH_4 emission inventory for stationary combustion plants in 2002. Figure 3.9 shows that *Electricity and heat production* accounts for 63% of the CH_4 emission from stationary combustion and this is close to the fuel consumption share.

Table 3.8 CH_4 emission from stationary combustion plants 2002 [1)]

CH_4	2002	
1A1a Electricity and heat production	16005	Mg
1A1b Petroleum refining	2	Mg
1A1c Solid fuel transf. and other energy industries	177	Mg
1A2f Industry	1635	Mg
1A4a Commercial / Institutional	974	Mg
1A4b Residential	4479	Mg
1A4c Agriculture / Forestry / Fishing	2112	Mg
Total	25384	Mg

1) Only emission from stationary combustion plants included

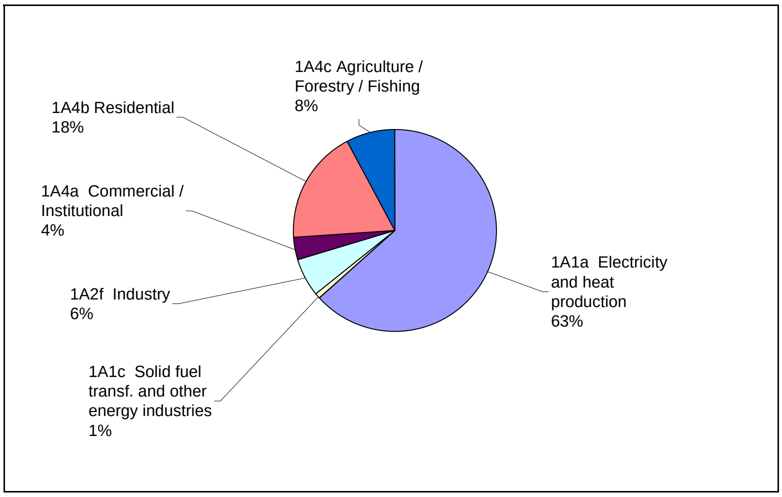


Figure 3.9 CH_4 emission sources, stationary combustion plants, 2002

The CH_4 emission factor for reciprocating lean-burn gas engines is much higher than for other combustion plants due to the continuous ignition/burn out of the gas (see chapter 3.2.2.4.2). A considerable number of lean-burn gas engines are in operation in Denmark and these plants accounts for 75% of the CH_4 emission from stationary combustion plants (Figure 3.10). The engines are installed in CHP plants and the fuel used is either natural gas or biogas.

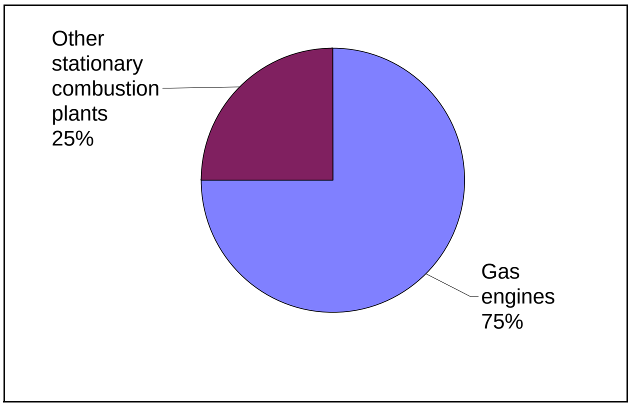


Figure 3.10 Gas engine CH_4 emission share, 2002

The CH_4 emission from stationary combustion increased by a factor 4,5 since 1990 (Figure 3.11). This is a result of the considerable number of lean-burn gas engines that was installed in decentralised CHP plants in Denmark in this period. This increase is also the reason for the increasing IEF (implied emission factor) for gaseous fuels and biomass in CRF sector *1A1*, *1A2* and *1A4*. Figure 3.12 shows time series for the fuel consumption rate in gas engines and the corresponding increase of CH_4 emission.

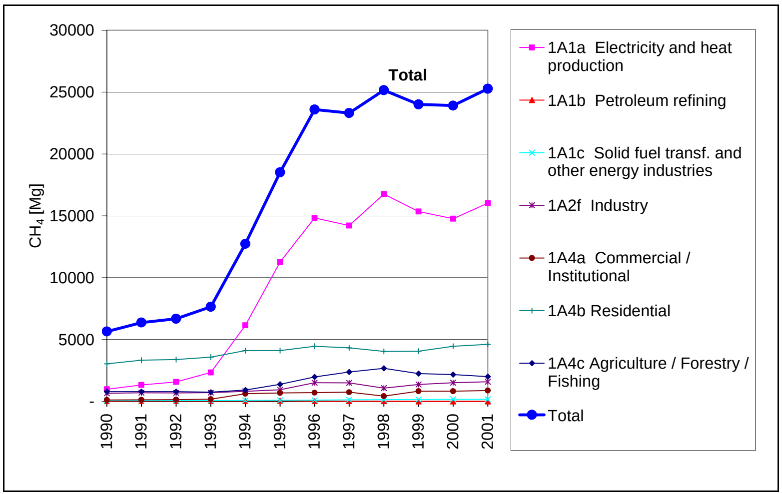


Figure 3.11 CH_4 emission time series for stationary combustion plants

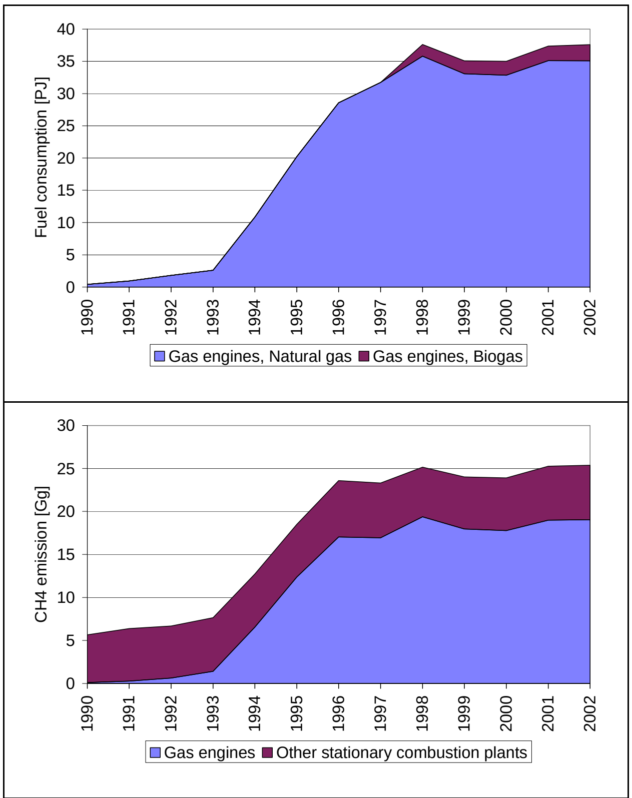


Figure 3.12 Fuel consumption and CH_4 emission from gas engines, time series

3.2.1.3.3 N_2O

The N_2O emission from stationary combustion plants accounts for 5% of the total Danish N_2O emission. Table 3.9 shows the N_2O emission inventory for stationary combustion plants in 2002. Figure 3.13 shows that *Electricity and heat production* accounts for 64% of the N_2O emission from stationary combustion. This is only a little higher than the fuel consumption share.

Table 3.9 N_2O emission from stationary combustion plants 2002 [1)]

N_2O	2002	
1A1a Electricity and heat production	793	Mg
1A1b Petroleum refining	32	Mg
1A1c Solid fuel transf. and other energy industries	27	Mg
1A2f Industry	170	Mg
1A4a Commercial / Institutional	23	Mg
1A4b Residential	163	Mg
1A4c Agriculture / Forestry / Fishing	26	Mg
Total	1234	Mg

1) Only emission from stationary combustion plants included

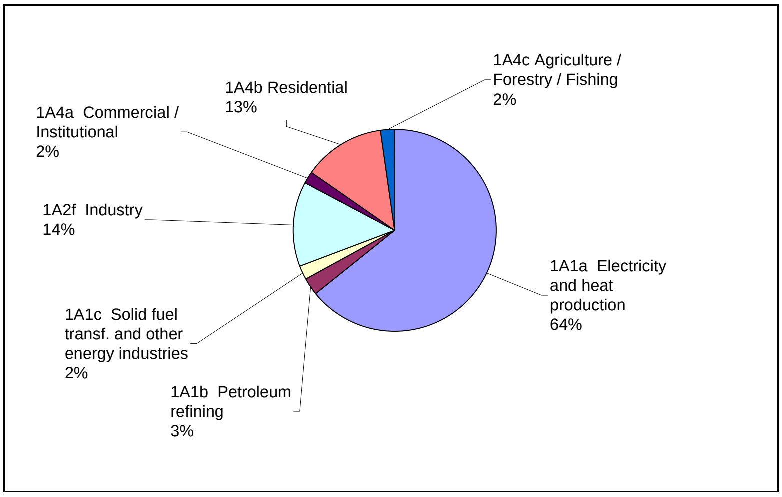


Figure 3.13 N_2O emission sources, stationary combustion plants, 2002

Figure 3.14 shows time series for N_2O emission. The N_2O emission from stationary combustion decreased 3,6% from 1990 to 2002, but again fluctuations of emission level due to electricity import/export are considerable.

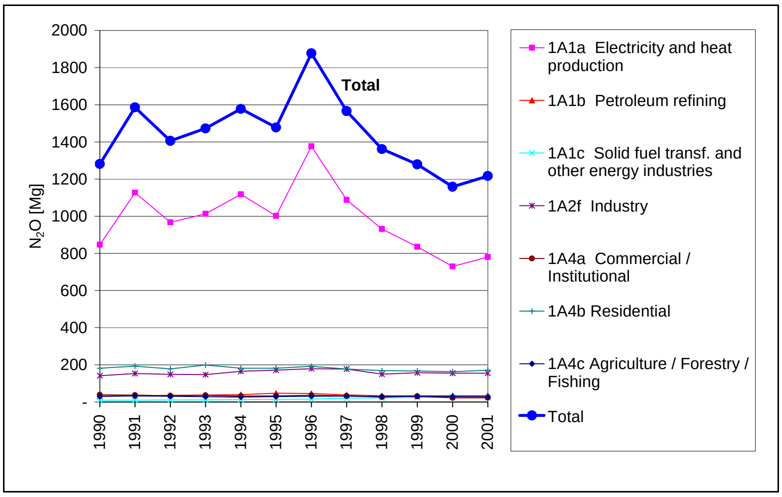


Figure 3.14 N_2O emission time series for stationary combustion plants

3.2.1.3.4 SO_2, NO_X, NMVOC and CO

The emissions of SO_2, NO_X, NMVOC and CO from Danish stationary combustion plants 2002 are shown in Table 3.10. Further details are shown in Annex 3A.

SO_2 from stationary combustion plants accounts for 83% of the total Danish emission. NO_X, CO and NMVOC account for 37%, 29% and 15% of the total Danish emissions respectively.

Table 3.10 SO_2, NO_X, NMVOC and CO emission from stationary combustion plants 2002

Pollutant	NO_x Gg	CO Gg	NMVOC Gg	SO_2 Gg
1A1 Fuel consumption, Energy industries	53,1	12,5	4,3	10,9
1A2 Fuel consumption, Manufacturing Industries and Construction (Stationary combustion)	14,4	5,2	0,9	6,6
1A4 Fuel consumption, Other sectors (Stationary combustion)	7,4	149,4	13,4	3,6
Total emission from stationary combustion plants	**74,9**	**167,2**	**18,6**	**21,1**
Total Danish emission (gross)	200	577	124	25
		%		
Emission share for stationary combustion	37,4	29,0	15,0	83,3

3.2.2 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 3rd edition, prepared by the UNECE/EMEP Task Force on Emissions Inventories and Projections (EMEP/Corinair 2002). Emission data are stored in an Access database, from which data are transferred to the reporting format.

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

3.2.2.1 Large point sources

Large emission sources like power plants, industrial plants and refineries are included as large point sources in the Danish emission database. Each point source might 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 for the plants.

In the inventory for the year 2002 63 stationary combustion plants are specified as large point sources in the Danish emission database. These point sources include:

- Power plants and decentralised CHP plants (combined heat and power plants)
- Municipal waste incineration plants
- A few large industrial combustion plants
- Petroleum refining plants

The fuel consumption of stationary combustion plants registered as large point sources is 326 PJ (2002). This corresponds to 57% of the overall fuel consumption of stationary combustion.

Further details about the large point sources are shown in annex 3A. The number of large point sources registered in the databases increased from 1990 to 2002.

If plant specific emission factors are not available the general area source emission factor is used. Emissions of the greenhouse gases (CO_2, CH_4 and N_2O) from stationary combustion plants defined as large point sources are all based on the area source emission factors.

Plant specific emission data for other pollutants are obtained from:

- Annual environmental reports
- Annual plant specific reporting of SO_2 and NO_X from power plants >25MW_e prepared for the Danish Energy Authority due to Danish legislation
- Emission data reported by Elsam and E2, the two major electricity suppliers
- Emission data reported from industrial plants

Annual environmental reports from 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 might have been calculated from general emission factors.

3.2.2.2 Area sources

Fuels not combusted in large point sources are included as sector specific area sources in the emission database. Plants like 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 about emission factors is given below.

3.2.2.3 Activity rates, fuel consumption

The fuel consumption rates are based on the official Danish energy statistics prepared by the Danish Energy Authority. The Danish Energy Authority aggregates fuel consumption rates to SNAP sector categories (DEA 2003a). Some fuel types in the official Danish energy statistics are added to obtain a less detailed fuel aggregation level, see annex 3A. The calorific values on which the energy statistics are based are also enclosed in the annex.

The fuel consumption of the CRF sector *1A2 Manufacturing industries and construction* (corresponding to SNAP sector *03 Combustion in manufacturing industries)* have not yet been disaggregated to specific industries. In CRF the emissions are included in sector *1A2f Industry, Other* because technically it is not possible to report the emission in the aggregated source category *1A2 Manufacturing industries and construction*. However NERI and the Danish Energy Authority have initiated the work that should ensure that fuel consumption rates of each industrial subsector will be reported next year.

Both traded and not traded fuels are included in the Danish energy statistics. Thus e.g. an estimation of the annual consumption of non-traded wood is included.

Petroleum coke bought abroad and combusted in Danish residential plants (border trade of 251 TJ) are added to the apparent consumption of petroleum coke and the emissions are included in the inventory.

The Danish Energy Authority compile a database for the fuel consumption of each district heating or power producing plant based on data reported by the plant owners. The fuel consumption of large point sources specified in the Danish emission databases refers to this annually updated database (DEA 2003c).

The fuel consumption of area sources is calculated as total fuel consumption minus fuel consumption of large point sources.

Emissions from non-energy use of fuels have not been included in the Danish inventory yet, but it is however included in the CRF reference approach. The Danish energy statistics include three fuels used for non-energy purposes: Bitumen, white spirit and lube oil.

In Denmark all municipal waste incineration is utilised for heat and power production. Thus incineration of waste is included as stationary combustion in the CRF Energy sector (source categories *1A1*, *1A2* and *1A4)*.

Fuel consumption data are presented in chapter 3.2.1.2.

3.2.2.4 Emission factors

For each fuel and SNAP (sector and e.g. type of plant) a set of general area source emission factors has been determined. The emission factors are either national referenced or based on the international guidebooks: EMEP/Corinair Guidebook (EMEP/Corinair 2002) and IPCC Reference Manual (IPCC 1996).

A complete list of emission factors including time series and references is shown in Annex 3A.

CO_2

The CO_2 emission factors applied for 2002 are shown in Table 3.11. The emission factors and reference of each factor is further discussed in Annex 3A.

For municipal waste and for natural gas time series have been estimated. For all other fuels the same emission factor is applied for 1990-2002.

In CRF the CO_2 emission is aggregated to five fuel types: Solid fuel, Liquid fuel, Gas, Biomass and Other fuels. The correspondence list between the NERI fuel categories and the CRF fuel categories is also shown in table 3.11.

The CO_2 emission factors have been confirmed by the two major power plant owners both directly (Christiansen 1996 and Andersen 1996) and indirectly by applying the NERI emission factors in the annual environmental reports for the large power plants and accepting use of the NERI factors in Danish legislation.

Danish legislation concerning CO_2 emission from power plants (Lov nr. 376 1999) has been based on standard CO_2 emission factors for each fuel. Thus power plant owners have not been encouraged to estimate CO_2 emission factors based on their own fuel analysis. In future legislation (Lov om CO_2-kvoter, høringsudgave 2004) owners of large power plants are obliged to verify the applied emission factors and thus improved emission factors will be available for the national emission inventories in the future.

The CO_2 emission from incineration of municipal waste (94,5 + 17,6 kg/GJ) is split in two parts: The emission from combustion of the plastic 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, that is reported as a memo item. In CRF the CO_2 emission from combustion of the plastic part of the waste is reported in fuel category *Other fuels*. However this split is applied for neither fuel consumption nor other emissions, because it is only relevant for CO_2. Thus the full consumption of municipal waste is included in fuel category *Biomass* and the full amount of non-CO_2 emissions from municipal waste combustion is included in fuel category *Biomass*.

Table 3.11 CO_2 emission factors 2002

Fuel	Emission factor Biomass	Emission factor Fossil fuel	Unit	Reference type	CRF fuel
Coal		95	kg/GJ	Country specific	Solid
Brown coal briquettes		94,6	kg/GJ	IPCC reference manual	Solid
Coke oven coke		108	kg/GJ	IPCC reference manual	Solid
Petroleum coke		92	kg/GJ	Country specific	Liquid
Wood	102		kg/GJ	Corinair	Biomass
Municipal waste	94,5	17,6	kg/GJ	Country specific	Biomass / Other fuels
Straw	102		kg/GJ	Country specific	Biomass
Residual oil		78	kg/GJ	Corinair	Liquid
Gas oil		74	kg/GJ	Corinair	Liquid
Kerosene		72	kg/GJ	Corinair	Liquid
Fish & rape oil	102		kg/GJ	Corinair	Biomass
Orimulsion		80	kg/GJ	Country specific	Liquid
Natural gas		57,28	kg/GJ	Country specific	Gas
LPG		65	kg/GJ	Corinair	Liquid
Refinery gas		56,9	kg/GJ	Country specific	Liquid
Biogas	83,6		kg/GJ	Country specific	Biomass

CH_4

The CH_4 emission factors applied for 2002 is shown in table 3.12. In general the same emission factors have been applied for 1990-2002. However for gas engines a time series have been estimated.

Emission factors for gas engines, gas turbines and CHP plants combusting wood, straw or municipal waste all refer to emission measurements carried out on Danish plants (Nielsen & Illerup 2003). Other emission factors refer to the EMEP/Corinair Guidebook (EMEP/Corinair 2002).

Gas engines combusting natural gas or biogas contribute much more to the total CH_4 emission than other stationary combustion plants. The relatively high emission factor for gas engines is well documented based on a very high number of emission measurements on Danish plants. The factor is further discussed in annex 3A. Due to the considerable consumption of natural gas and biogas in gas engines the IEF (implied emission factor) in CRF sector *1A1*, *1A2* and *1A4*, fuel categories *Gaseous fuels* and *Biomass* is relatively high. The considerable change in IEF is a result of the increasing consumption of natural gas and biogas in gas engines as discussed in chapter 3.2.1.2.

Table 3.12 CH_4 emission factors 1990-2002

Fuel	ipcc_id	snap_id	Emission factor [g/GJ]	Reference
COAL	1A1a	010101, 010102, 010103	1,5	EMEP/Corinair 2003
COAL	1A1a, 1A2f, 1A4b, 1A4c	010202, 010203, 0301, 0202, 0203	15	EMEP/Corinair 2003
BROWN COAL BRI.	all	all	15	EMEP/Corinair 2003, assuming same emission factor as for coal
COKE OVEN COKE	all	all	15	EMEP/Corinair 2003, assuming same emission factor as for coal
PETROLEUM COKE	all	all	15	EMEP/Corinair 2003
WOOD AND SIMIL.	1A1a	010102, 010103, 010104	2	Nielsen & Illerup 2003
WOOD AND SIMIL.	1A1a, 1A2f, 1A4a, 1A4b, 1A4c	all other	32	EMEP/Corinair 2003
MUNICIP. WASTES	1A1a	010102, 010103, 010104, 010105	0,59	Nielsen & Illerup 2003
MUNICIP. WASTES	1A1a, 1A2f, 1A4a	all other	6	EMEP/Corinair 2003
STRAW	1A1a	010102, 010103	0,5	Nielsen & Illerup 2003
STRAW	1A1a, 1A2f	010202, 010203, 030102, 030105	32	EMEP/Corinair 2003
STRAW	1A4a, 1A4b, 1A4c	0201, 0202, 0203, 020302	200	EMEP/Corinair 2003
RESIDUAL OIL	all	all	3	EMEP/Corinair 2003
GAS OIL	all	all	1,5	EMEP/Corinair 2003
KEROSENE	all	all	7	EMEP/Corinair 2003
FISH & RAPE OIL	1A1a	010203	32	EMEP/Corinair 2003, assuming same emission factor as straw
FISH & RAPE OIL	1A2f	030105	32	EMEP/Corinair 2003, assuming same emission factor as straw
FISH & RAPE OIL	1A4c	020304	200	EMEP/Corinair 2003, assuming same emission factor as straw
ORIMULSION	1A1a	010101	3	EMEP/Corinair 2003, assuming same emission factor as residual oil
NATURAL GAS	1A1a	0101, 010101, 010102, 010202	6	DGC 2001
NATURAL GAS	1A1a	010103, 010203	15	Gruijthuijsen & Jensen 2000
NATURAL GAS	1A1a, 1Ab, 1Ac, 1A2f, 1A4a, 1A4c	Gas turbines: 010104, 010304, 010504, 030104, 020104, 020303	1,5	Nielsen & Illerup 2003
NATURAL GAS	1A1a, 1A1c, 1A2f, 1A4a, 1A4b, 1A4c	Gas engines: 010105, 010405, 010505, 030105, 020105, 020204, 020304	520	Nielsen & Illerup 2003
NATURAL GAS	1A1c, 1A2f, 1A4a, 1A4b, 1A4c	010502, 0301, 0201, 0202, 0203	6	DGC 2001
NATURAL GAS	1A2f, 1A4a, 1A4b	030103, 030106, 020103, 020202	15	Gruijthuijsen & Jensen 2000
LPG	all	all	1	EMEP/Corinair 2003
REFINERY GAS	1A1b	010303, 010304	2	EMEP/Corinair 2003
BIOGAS	1A1a, 1A1c, 1A2f, 1A4a, 1A4c	Gas engines: 010105, 010405, 010505, 030105, 020105, 020304	323	Nielsen & Illerup 2003
BIOGAS	1A1a, 1A2f, 1A4a, 1A4c	all other	4	EMEP/Corinair 2003

N_2O

The N_2O emission factors applied for the 2002 inventory is shown in table 3.13. The same emission factors have been applied for 1990-2002.

Emission factors for gas engines, gas turbines and CHP plants combusting wood, straw or municipal waste all refer to emission measurements carried out on Danish plants (Nielsen & Illerup 2003). Other emission factors refer to the EMEP/Corinair Guidebook (EMEP/Corinair 2002).

Table 3.13 N_2O emission factors 1990-2002

Fuel	ipcc_id	snap_id	Emission factor [g/GJ]	Reference
COAL	all	all	3	EMEP/Corinair 2003
BROWN COAL BRI.	all	all	3	EMEP/Corinair 2003
COKE OVEN COKE	all	all	3	EMEP/Corinair 2003
PETROLEUM COKE	all	all	3	EMEP/Corinair 2003
WOOD AND SIMIL.	1A1a	010102, 010103, 010104	0,8	Nielsen & Illerup 2003
WOOD AND SIMIL.	1A1a	010105, 010202, 010203, 010205	4	EMEP/Corinair 2003
WOOD AND SIMIL.	1A2f, 1A4a, 1A4b, 1A4c	all	4	EMEP/Corinair 2003
MUNICIP. WASTES	1A1a	010102, 010103, 010104, 010105	1,2	Nielsen & Illerup 2003
MUNICIP. WASTES	1A1a	010203	4	EMEP/Corinair 2003
MUNICIP. WASTES	1A2f, 1A4a	030102, 0201, 020103	4	EMEP/Corinair 2003
STRAW	1A1a	010102, 010103	1,4	Nielsen & Illerup 2003
STRAW	1A1a	010202, 010203	4	EMEP/Corinair 2003
STRAW	1A2f, 1A4a, 1A4b, 1A4c	all	4	EMEP/Corinair 2003
RESIDUAL OIL	all	all	2	EMEP/Corinair 2003
GAS OIL	all	all	2	EMEP/Corinair 2003
KEROSENE	all	all	2	EMEP/Corinair 2003
FISH & RAPE OIL	all	all	4	EMEP/Corinair 2003, assuming same emission factor as municipal waste
ORIMULSION	1A1a	010101	2	EMEP/Corinair 2003, assuming same emission factor as residual oil
NATURAL GAS	1A1a	0101, 010101, 010102, 010103, 010202, 010203	1	EMEP/Corinair 2003
NATURAL GAS	1A1a, 1Ab, 1Ac, 1A2f, 1A4a, 1A4c	Gas turbines: 010104, 010304, 010504, 030104, 020104, 020303	2,2	Nielsen & Illerup 2003
NATURAL GAS	1A1a, 1A1c, 1A2f, 1A4a, 1A4b, 1A4c	Gas engines: 010105, 010405, 010505, 030105, 020105, 020204, 020304	1,3	Nielsen & Illerup 2003
NATURAL GAS	1A1c, 1A2f, 1A4a, 1A4b, 1A4c	010502, 0301, 030103, 030106, 0201, 020103, 0202, 020202, 0203	1	EMEP/Corinair 2003
LPG	all	all	2	EMEP/Corinair 2003
REFINERY GAS	all	all	2	EMEP/Corinair 2003
BIOGAS	1A1a	010102, 010103, 010203	2	EMEP/Corinair 2003
BIOGAS	1A1a, 1A1c, 1A2f, 1A4a, 1A4c	010105, 010405, 010505, 030105, 020105, 020304	0,5	Nielsen & Illerup 2003
BIOGAS	1A2f, 1A4a, 1A4c	0301, 030102, 0201, 020103, 0203	2	EMEP/Corinair 2003

SO_2, NO_x, NMVOC and CO

Emission factors 2002 for SO_2, NO_X, NMVOC and CO including time series and references is shown in annex 3A. Most country specific emission factors refers to:

- Danish legislation
- A emission measurement program for decentralised CHP plants
- Other Danish research reports
- Calculations based on plant specific emissions from a considerable number of power plants
- Calculations based on plant specific emissions from a considerable number of municipal waste incineration plants

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.

Some of the area source emission factors for power plants and municipal waste CHP plants take into account, that the large plants are included in the inventory as large point sources with plant specific emission data. Thus some area source emission factors are default values assuming that the remaining fuel consumption is combusted in smaller units with less effective flue gas cleaning. The area source emission factors are therefore not necessarily average values for these plant categories.

3.2.3 Uncertainties and time-series consistency

Time series for fuel consumption and emission are shown and discussed in chapter 3.2.1.2 and 3.2.1.3.

Uncertainty estimates include uncertainty of the total emission inventory as well as uncertainty of the trend. The GHG emission from stationary combustion plants was estimated with an uncertainty of ±10% and the decrease of the GHG emission was estimated to be 1,3% ± 1,8 %-age points since 1990.

3.2.3.1 Methodology

Greenhouse gases

The Danish uncertainty estimates for GHGs is based on the tier 1 approach in IPCC Good Practice Guidance (IPCC 2000). The uncertainty have been estimated for the following emission source subcategories to stationary combustion:

- CO_2 emission from each of the applied fuel categories [2]
- CH_4 emission from gas engines
- CH_4 emission from all other stationary combustion plants
- N_2O emission from all stationary combustion plants

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. The 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 known with a much smaller uncertainty than the factor for other stationary combustion plants.

Most of the applied uncertainties for activity rates and emission factors are default values from the IPCC Reference Manual. A few of the uncertainty estimates are however based on national estimates.

[2] Brown coal and coke is included in the fuel category coal

Table 3.14 Uncertainty rates for activity rates and emission factors

IPCC Source category	Gas	Activity data uncertainty %	Emission factor uncertainty %
Stationary Combustion, Coal	CO_2	1 [1)]	5 [3)]
Stationary Combustion, Petroleum coke	CO_2	3 [1)]	5 [1)]
Stationary Combustion, Plastic waste	CO_2	5 [4)]	5 [4)]
Stationary Combustion, Residual oil	CO_2	2 [1)]	2 [3)]
Stationary Combustion, Gas oil	CO_2	4 [1)]	5 [1)]
Stationary Combustion, Kerosene	CO_2	4 [1)]	5 [1)]
Stationary Combustion, Orimulsion	CO_2	1 [1)]	2 [3)]
Stationary Combustion, Natural gas	CO_2	3 [1)]	1 [3)]
Stationary Combustion, LPG	CO_2	4 [1)]	5 [1)]
Stationary Combustion, Refinery gas	CO_2	3 [1)]	5 [1)]
Stationary combustion plants, gas engines	CH_4	2,2 [1)]	40 [2)]
Stationary combustion plants, other	CH_4	2,2 [1)]	100 [1)]
Stationary combustion plants	N_2O	2,2 [1)]	1000 [1)]

1) IPCC Reference Manual (default value)
2) Kristensen (2003)
3) Jensen & Lindroth (2002)
4) NERI assumption

Other pollutants

The IPCC methodologies for uncertainty estimates have been adopted for the LRTAP Convention reportings. The methodology is described in a new chapter in the EMEP/Corinair Guidebook (EMEP/Corinair 1996) called *Good Practice Guidance for CLRTAP Emission Inventories* (Pulles & Aardenne 2002). Uncertainty estimates for SO_2, NO_X, NMVOC and CO is based on this methodology. The uncertainty estimates are based on emission data and uncertainties for each of the main SNAP sectors.

The assumed uncertainties for activity rates and emission factors are based on default values from Pulles & Aardenne 2002. 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 uncertainties for emission factors are shown in Table 3.15. The uncertainty for fuel consumption in stationary combustion plants was assumed to be 2%.

Table 3.15 Uncertainty rates for emission factors

SNAP sector	SO_2	NO_x	NMVOC	CO
01	10	20	50	20
02	20	50	50	50
03	10	20	50	20

3.2.3.2 Results

The estimated uncertainties for stationary combustion emission inventories are shown in Table 3.16.

The uncertainty of GHG is estimated to be ±10% and the uncertainty in trend of GHG is ±1,8%-age points. The main sources of uncertainty for GHG emission are N_2O emission (all plants) and CO_2

emission from coal combustion. Main sources of the trend uncertainty for GHG are CO_2 emission from combustion of natural gas and coal.

Detailed calculation sheets are shown in annex 3A.

Table 3.16 Danish uncertainty estimates, 2002

Pollutant	Uncertainty Total emission [%]	Trend 1990-2002 [%]	Uncertainty Trend [%-age points]
GHG	10,4	-1,3	± 1,8
CO_2	2,6	-2,3	± 1,8
CH_4	39	349	± 351
N_2O	1000	-3,6	± 3,0
SO_2	7	-86,9	± 0,6
NO_x	16	-35,2	± 2,5
NMVOC	38	46	± 15
CO	45	15,3	± 3,0

3.2.4 Source specific QA/QC and verification

A formal QA/QC plan has not yet been developed, but a number of quality control (QC) procedures are performed. The QC procedures for stationary combustion includes:

- Check of time series of the CRF and SNAP source categories. Considerable changes are controlled and explained.
- Comparison to inventory of the previous year. Any major changes are verified
- Total emission when aggregated to CRF are compared to totals based on SNAP source categories (control of data transfer)
- A manual log table in the emission databases is applied to collect information about recalculations
- The CRF reference approach validates the fuel consumption rates and CO_2 emissions of fuel combustion. Fuel consumption rates and CO_2 emissions are within 2,0% difference (1990-2002). The reference approach is further discussed in Chapter 3.4.1 and in Annex 3A.
- The emission from each large point source is compared to the emission reported the previous year.
- Some automated checks have been prepared for the emission databases:
  - Check of units for fuel rate, emission factor and plant specific emissions
  - Check of emission factors of large point sources. Emission factors of pollutants that are not plant specific should be the same as the emission factor that are defined for area sources.
  - Additional checks of database consistency
- Most emission factor references are now implemented in the emission database itself.
- Annual environmental reports are kept for subsequent control of plant specific emission data
- QA/QC checks of the country specific emission factors have not been performed but most factors are based on work from companies that have implemented some QA/QC work. The two major power plant owners / operators in Denmark: E2 and Elsam both obtained the ISO 14001 certification for environmental management system. Danish Gas Technology Centre and dk-Teknik both run accredited laboratories for emission measurements.

3.2.5 Source specific recalculations

- The CO_2 emission factors for municipal waste, refinery gas and petroleum coke have been changed for some years.

- ° Petroleum coke: The same CO_2 emission factor (92 kg/GJ) is applied for all years now. In earlier inventories a higher emission factor was applied for 1990-1997. The reference for the emission factor is however based on a fuel analysis carried out in 1993 and thus the change of emission factor was not correct.
- ° Refinery gas: To improve time series consistency the same emission factor (56,9 kg/GJ) is now applied for all years. In the inventory reported last year the emission factor 57,1 kg/GJ was applied for 2000 and 2001.
- ° Municipal waste: An improved CO_2 emission factor for municipal waste has been estimated. See annex 3A for details.

- Fuel consumption rates for a few stationary combustion sectors have been recalculated as a result of a new estimate for off road machinery, see chapter 3.3. The fuel consumption of gas oil and LPG in the SNAP sectors 0203 and 0301 (stationary combustion) are calculated as total emission of the sectors minus the off road consumption.

- Emission factors for combined heat and power plants have been improved based on a Danish project including collection of existing emission data and performance of a large number of new emission measurements (Nielsen & Illerup 2003). The emission measurements included both CH_4, N_2O, SO_2, NO_X, NMVOC and CO.

- Centralised power plants have been included in the emission databases as point sources in 1993-1994 (was already included as point sources all other years). Plant specific SO_2 and NO_X emission factors are applied. However the area source emission factor applied in former inventories took into account the plant specific data and thus the estimated emission is not changed considerably due to this improvement.

- The SO_2 and NO_X emission factors have been examined and time series inconsistencies have been corrected.

Further a few minor errors for large point sources have been corrected. These corrections do not include CO_2, CH_4 or N_2O emission.

The recalculations that have been carried out are not a result of the review process but the documentation have been improved on several subjects that was questioned in the review process:

- The CH_4 emission factor, level and time series
- Reference approach
- Fuel consumption time series, fluctuations
- Emission from gas flaring

Fuel type correspondence lists (Danish Energy Authority, NERI and CRF)

3.2.6 Source specific planned improvements

Some planned improvements of the emission inventories are discussed below. The planned improvements are all related to the comments in the review process.

3.2.6.1 Disaggregation of fuel consumption in the industrial sector

So far the Danish energy statistics aggregated to SNAP sectors have not specified fuel consumption rates for specific industries. Thus the fuel consumption of *1A2 Manufacturing industries and construction* is included in sector *1A2f Manufacturing industries and construction, Other*. The work that is required to make a disaggregation to industrial subsectors possible have been initiated and it is expected to be implemented in the reportings in 2005.

3.2.6.2 Energy statistics update

A full update of fuel consumption according to the updated energy statistics has not been carried out for a few years. A full update is expected to be part of the next emission inventory.

3.2.6.3 Improved documentation for CO_2 emission factors

The CO_2 emission factors applied for the Danish inventories are considered accurate but the documentation will be improved in future inventories.

3.2.6.4 Improved QA/QC and validation

The QA/QC and validation of the inventories for stationary combustion will be improved as part of the work that have been initiated for the Danish inventory as a whole.

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

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 following IPCC categories:

Table 3.17 SNAP – IPCC correspondence table for transport

SNAP classification	IPCC 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

3.3.1 Source category description

In total the energy use for road transport has increased until 2000. After that a stagnation in the total energy use is seen. The CO_2 emissions have developed correspondingly and the most important source is passenger cars followed by heavy-duty vehicles, light duty vehicles and 2-wheelers in decreasing order.

The majority of the CH_4 emissions from road transport come from gasoline passenger cars. The emission development for the latter vehicle category is powered by the somewhat higher emission factors for EURO I gasoline cars (introduced in 1990) than the ones for conventional gasoline cars. For EURO II and III catalyst cars (introduced in 1997 and 2001, respectively) the emission factors are lower than conventional gasoline factors.

An undesirable environmental side effect of the introduction of catalyst cars in 1990 is the increase in the emissions of N_2O. However, the total road transport N_2O and CH_4 emission contributions are still small compared to the emissions from the agricultural sector.

The largest contribution to the total CO_2 emission equivalents for road transport comes from CO_2. In 2002 the most important source was passenger cars followed by heavy-duty vehicles, light duty vehicles and 2-wheelers in decreasing order.

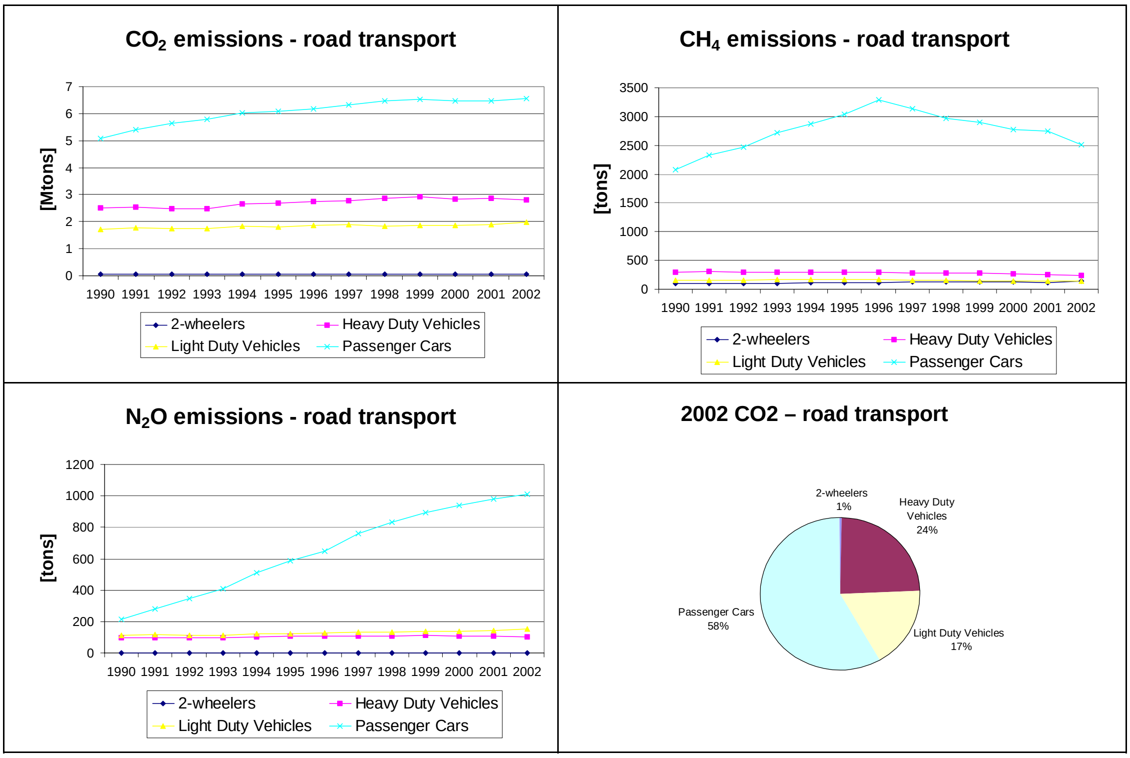


Figure 3.15 Emissions from road transport 1990-2002 and CO_2 equivalents in 2002

It must be noted that the fuel use 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 the fuel use development for other mobile sectors, since DEA statistical figures do not directly provide fuel use information for working equipment and machinery in these sectors.

Except for small boats and pleasure crafts (inland waterways) the fuel use has made a slight constant decrease from 1990 to 2000 in the above mentioned sectors.

For energy and CO_2 the most important sectors are agriculture/forestry/fisheries (1A4c), industry (1A2f), navigation (1A3d), with minor fuel consuming sectors such as civil aviation (1A3a), railways (1A3c), military (other: 1A5) and residential.

In the agriculture/forestry/fisheries sector the fuel use by agricultural machines accounts for two thirds of the total fuel use. The fuel use decrease is the result of fluctuations in the fuel use for fishery and the constant fuel use decrease for agricultural machines between 1990 and 2000.

The navigation sector comprises national sea transport (fuel use between two Danish ports) and small boats and pleasure crafts. For the latter categories the fuel use has increased significantly from 1990 to 2000, due to more private boats. For national sea transport the fuel use has shown some fluctuations in the same time period and the amount of fuel used is actually lower in 2002 than in 1990. The most important explanation for this fuel use decrease is the shut down of ferry service connections in connection with the opening of the Great Belt link in 1997.

Since the building of the Great Belt Bridge the domestic aviation has decreased, both in terms of number of flights and total jet fuel use, and total emissions. For railways the gradual shift towards electrification explains the lowering trend in diesel fuel use and emissions for this transport sector.

For CH_4 the most important sectors are industry (1A2f), residential (1A4b), agriculture/forestry/fisheries (1A4c) and navigation (1A3d), with minor emissions from railways (1A3c), civil aviation (1A3a) and military (other: 1A5).

The reasons for high CH_4 emissions in the first two sectors are the use of LPG trucks in the industry and the relatively large amount of gasoline used in the residential sector. Also the appearance of more gasoline fuelled private boats in navigation has caused a significant increase in the emissions from this sector.

For N_2O the emission trend in sub-sectors is the same as for fuel use and CO_2 emissions.

As for road transport CO_2 alone brings far the most of the CO_2 emission equivalents for other mobile sources. Sorted by size the largest contributors in 2002 are agriculture/forestry/fisheries (1A4c), industry (1A2f), navigation (1A3d), railways (1A3c), civil aviation (1A3a), military (other: 1A5) and residential (1A4b).

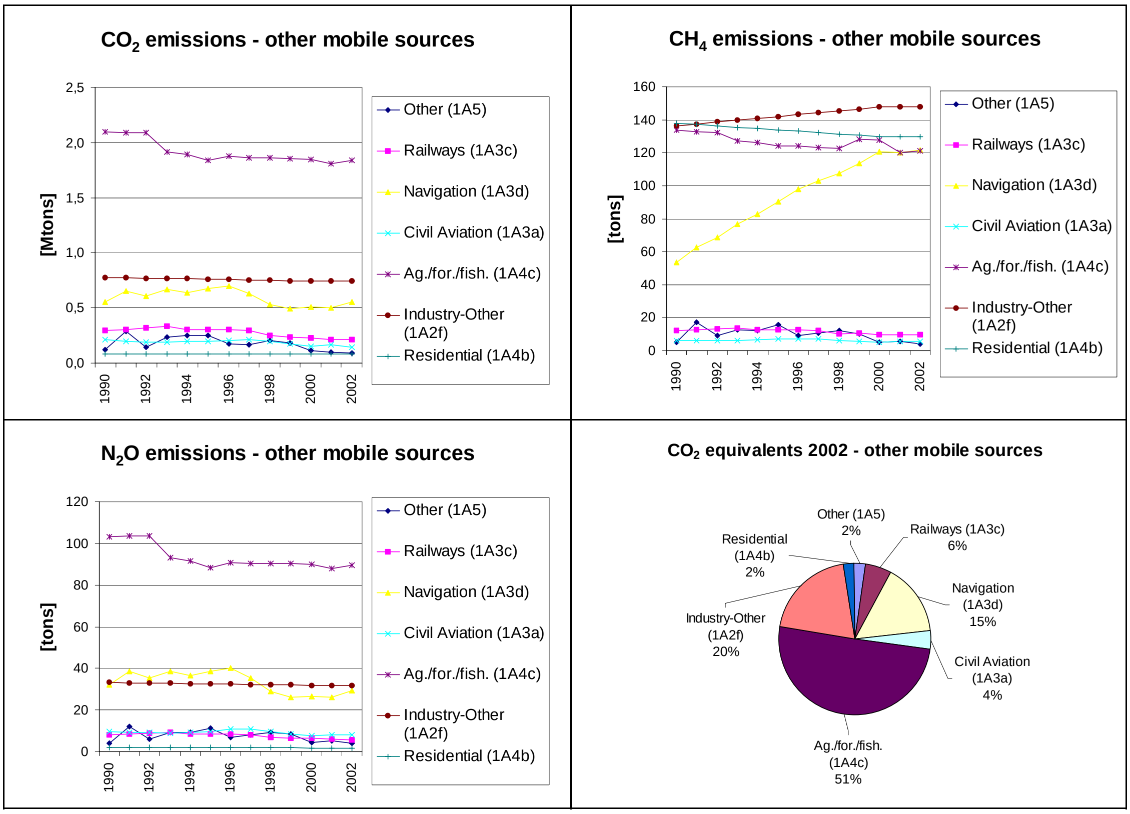


Figure 3.16 Emissions (other mobile sources) 1990-2002 and CO_2 equivalents in 2002

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.

3.3.2.1 Methodology and references for Road Transport

For road transport the Tier 1 and Tier 2 approaches are used in parallel to make annual estimates of the Danish emissions as described in the IPCC guidelines (Penman et al. (2000). The actual calculations are made with the European COPERT III model (Ntziachristos et al. 2000). In COPERT III fuel use 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 fleet classification all present and future vehicles in the Danish traffic are grouped into vehicle layers. This is a sub-division of all vehicle classes into groups of vehicles with the same average fuel use and emission behaviour. An overview of the different layers with years of implementation is given in annex 3.B.1.

Table 3.18 Model vehicle classes, trip speeds and mileage split.

Vehicle classe	Fuel type	Engine size/weight	Trip speed			Mileage [%]		
			Urban	Rural	Highway	Urban	Rural	Highway
PC	Gasoline	< 1.4 l.	40	70	100	35	46	19
PC	Gasoline	1.4 – 2 l.	40	70	100	35	46	19
PC	Gasoline	> 2 l.	40	70	100	35	46	19
PC	Diesel	< 2 l.	40	70	100	35	46	19
PC	Diesel	> 2 l.	40	70	100	35	46	19
PC	LPG		40	70	100	35	46	19
PC	2-stroke		40	70	100	35	46	19
LDV	Gasoline		40	65	80	35	50	15
LDV	Diesel		40	65	80	35	50	15
Trucks	Gasoline		35	60	80	32	47	21
Trucks	Diesel	3.5 – 7.5 tonnes	35	60	80	32	47	21
Trucks	Diesel	7.5 – 16 tonnes	35	60	80	32	47	21
Trucks	Diesel	16 – 32 tonnes	35	60	80	19	45	36
Trucks	Diesel	> 32 tonnes	35	60	80	19	45	36
Urban buses	Diesel		30	50	70	51	41	8
Coaches	Diesel		35	60	80	32	47	21
Mopeds	Gasoline		30	30	-	81	19	0
Motorcycles	Gasoline	2 stroke	40	70	100	47	39	14
Motorcycles	Gasoline	< 250 cc.	40	70	100	47	39	14
Motorcycles	Gasoline	250 – 750 cc.	40	70	100	47	39	14
Motorcycles	Gasoline	> 750 cc.	40	70	100	47	39	14

Information of the vehicle stock and annual mileage is obtained from the Danish Road Directorate. This covers data for the number of vehicles, annual mileage, mileage split between urban, rural and highway driving and the respective average speeds.

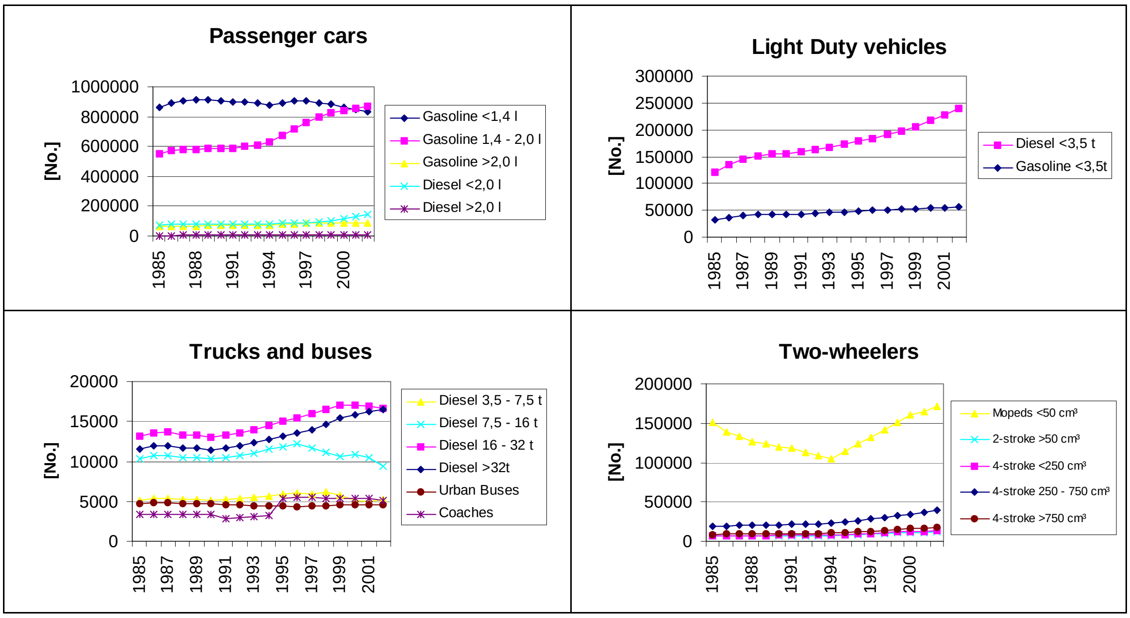


Figure 3.17 Number of vehicles in sub-classes in 1985-2002

The number of vehicles and annual mileages respectively, are provided per first registration year for all vehicle sub-classes. Subsequently the vehicle numbers are summed up in layers, j, for each year, y, by using the correspondance between layers and first registration year, i:

$$N_{j,y} = \sum_{i=FYear(j)}^{LYear(j)} N_{i,y} \quad (1)$$

Weighted annual mileages per layer are calculated as the sum of all mileage driven per first registration year divided with the total number of vehicles in the specific layer.

$$M_{j,y} = \frac{\sum_{i=FYear(j)}^{LYear(j)} N_{i,y} \cdot M_{i,y}}{\sum_{i=FYear(j)}^{LYear(j)} N_{i,y}} \quad (2)$$

Both vehicle numbers and weighted annual mileages per layer are shown in annex 3.B.1.

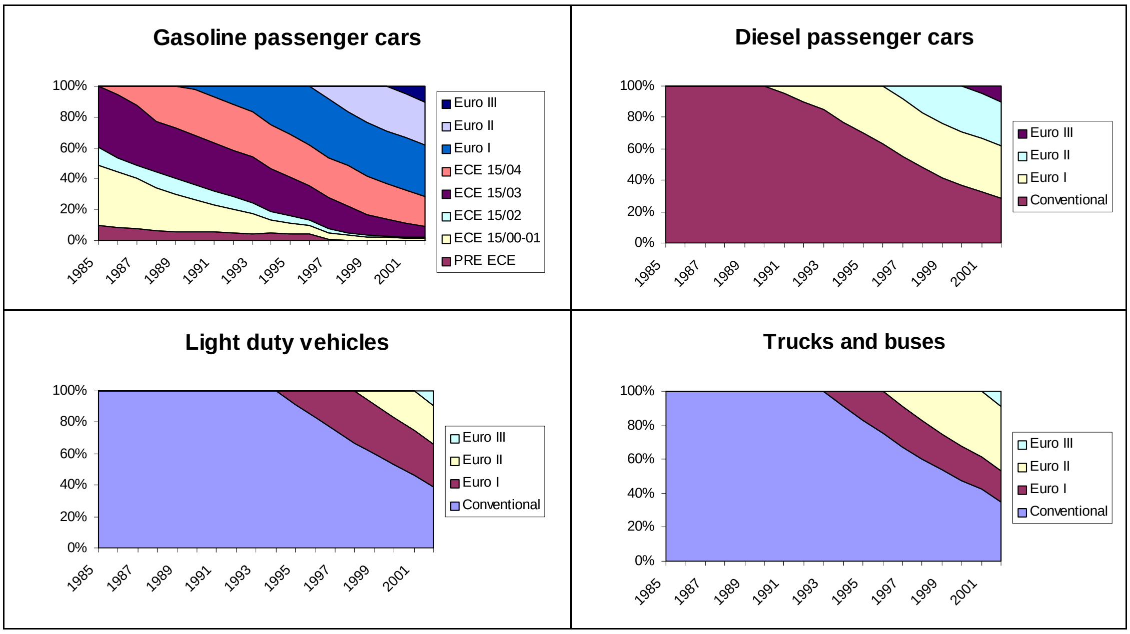


Figure 3.18 Layer distribution of vehicle numbers per vehicle type in 1985-2002

Trip speed dependent fuel use and emission factors are taken from the COPERT model using trip speeds as shown in Table 3.18. The factors are listed in Annex 3.B.2. For new layers not represented by actual data, the emission factors are scaled according to reduction factors, see Ntziachristos et al. (2000) or Illerup et al. (2003).

Deterioration factors

For three-way catalyst cars the emissions of NO_x and 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 forecast year the deterioration factors are calculated per first registration year by using deterioration coefficients and cut-off mileages, as given in Ntziachristos et al. (2000) or Illerup et al. (2002) 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/h, respectively.

Firstly the deterioration factors are calculated for the correspondent trip speeds of 19 and 63 km h-1 in each case determined by the total cumulated mileage less than or exceeding the cut-off mileage. The formulas 3 and 4 show the calculations for the "Urban driving Cycle":

$$UDF = U_A \cdot MTC + U_B \text{, MTC} < U_{MAX} \quad (3)$$

$$UDF = U_A \cdot U_{MAX} + U_B \text{, MTC} >= U_{MAX} \quad (4)$$

Where UDF is the urban deterioration factors, UA and UB the urban deterioration coefficients, MTC = total cumulated mileage, U_{MAX} urban cut-off mileage.

In the case of trip speeds below 19 km h-1 the deterioration factor, DF, equals UDF, whereas for trip speeds exceeding 63 km h-1 DF=EUDF. For trip speeds between 19 and 63 km h-1 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 the vehicle numbers and annual mileages per first registration year:

$$DF_{j,y} = \frac{\sum_{i=FYear(j)}^{LYear(j)} DF_{i,y} \cdot N_{i,y} \cdot M_{i,y}}{\sum_{i=FYear(j)}^{LYear(j)} DF_{i,y} \cdot N_{i,y}} \quad (5)$$

Where DF is the deterioration factor.

Emissions and fuel use for hot engines

Emissions and fuel use results for operationally hot engines are calculated for each year and layer and road type. The procedure is to combine fuel use and emission factors (and deterioration factors for catalyst vehicles), number of vehicles annual mileage numbers and their road type shares given in Table 3.18. 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 use/emission, EF = fuel use/emission factor, S = road type share, k = road type.

For catalyst vehicles the calculations 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 use for cold engines

Extra emissions of SO_2, NO_x and NMVOC (as well as CO, PM, CH_4, CO_2 and FC) from cold start are simulated separately. In the model each trip is associated with an amount of cold start emission and is assumed to take place under urban driving conditions. The number of trips are distributed evenly in months. Firstly 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. Lastly 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 and are equivalent for gasoline fuelled conventional passenger cars and vans and for diesel passenger cars and vans, respectively, see Ntziachristos et al. (2000). 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 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 time periods for future EURO standards. Correspondingly the β-factor for gasoline vehicles is step-wise reduced for EURO II onwards.

For catalyst vehicles the cold extra emissions are found from:

$$CE_{j,y} = \beta_{red} \cdot \beta_{EUROI} \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr_{EUROI} - 1) \quad (9)$$

Where β_{red} = the β reduction factor.

Evaporative emissions from gasoline vehicles

For each year evaporative emissions of hydrocarbons are simulated in the forecast model as hot and warm running loss, hot and warm soak, and diurnal emissions. All emission types are influenced by RVP (Reid Vapour Pressure) and ambient temperature. The emission factors are shown in Ntziachristos et al. (2000).

Running loss emissions originate from vapour generated in the fuel tank during operation. The distinction between hot and warm running loss emissions depend on the engine temperature. In the model hot and warm running loss occur for hot and cold engines, respectively. The emissions are calculated as the annual mileage – broken down on cold and hot mileage totals using the β-factor - times respective emission factors. For vehicles equipped with evaporation control (catalyst cars) the emission factors are only one tenth of the uncontrolled factors used by conventional gasoline vehicles.

$$R_{j,y} = N_{j,y} \cdot M_{j,y} \cdot ((1-\beta) \cdot HR + \beta \cdot WR) \quad (10)$$

Where R is the running loss emissions and HR and WR the hot and warm running loss emission factors, respectively.

In the model hot and warm soak emissions for carburettor vehicles also occurs 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:

$$S_{j,y}{}^{C} = N_{j,y} \cdot \frac{M_{j,y}}{l_{trip}} \cdot ((1-\beta) \cdot HS + \beta \cdot WS) \quad (11)$$

Where S^C is the soak emissions, l_{trip} = the average trip length and HS and WS is 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 per 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 and diurnal emissions.

Fuel use balance

The calculated fuel use in the model must equal the statistical fuel sale totals from the Danish Energy Agency (DEA) according to the UNFCCC emissions reporting format. 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.

For gasoline vehicles all mileage numbers are equally scaled in order to obtain a gasoline fuel equilibrium. For diesel fuel the balance is made by adjusting the mileage for light and heavy-duty vehicles and buses, given that the mileage and fuel consumption factors for these vehicles are regarded as the most uncertain parameters in the diesel engine emission simulations.

The final fuel use and emission factors are shown in annex 3.B.3 for 1990-2002. The total fuel use and emissions are shown in annex 3.B.4 per vehicle category and as grand totals for 1990-2002. In annex 3.B.5 fuel use and emission factors and total emissions are given in CollectER format for 1990 and 2002.

3.3.2.2 Methodologies and references for other mobile sources

The off road sector is divided into several sub-sectors; sea transport, fishery, air traffic, railways, military and the working machinery and materiel in the industry, forestry, agriculture and household and gardening sectors. The emission calculations are made using the Tier 2 method for air traffic and off road working machinery and equipment, while for the remaining sectors the Tier 1 method is used.

Activity data

The activity data for air traffic consist of air traffic statistics provided by the Danish Civil Aviation Agency (CAA-DK) and Copenhagen Airport. For 2001 onwards records are given per flight by CAA-DK as data for aircraft type and origin and destination airports. Prior to 2001 detailed LTO/aircraft type statistics are provided by Copenhagen Airport (for this airport only), while CAA-DK has given information of total take off numbers for other Danish airports. Fuel statistics for jet fuel use and aviation gasoline are obtained from the DEA.

For off road working machinery and equipment the number of different types of machines, their load factors, engine sizes and annual working hours are taken from the Danish EPA (1992 and 1993). Fuel use statistics for diesel, gasoline and LPG are obtained from the DEA in relevant sectors.

The activity data for military, railways, sea transport and fishery consist of fuel use information provided by the DEA. For sea transport the basis is fuel sold in Danish ports and the traffic is defined as either national or international depending on the destination of the vessels in question as prescribed by the IPCC guidelines.

For all sectors fuel use figures are given in annex 3.B.5 for the years 1990 and 2002.

Emission factors

For military ground material and railways aggregated emission factors for gasoline and diesel are derived from the road traffic emission simulations made with the COPERT model. The emission factors for the remaining sectors come from the EMEP/CORINAIR guidebook, see CORINAIR (1999). For all sectors emission factors are given in annex 3.B.5 for the years 1990 and 2002.

Calculation method

For military, railways, national sea traffic and fishing the emissions are estimated with the Tier 1 method using fuel related emission factors and fuel use from the DEA.

For aviation the estimates are made separately for Landing and Take Offs (LTOs < 3000 ft) and cruise (> 3000 ft). From 2001 the estimates are made on a city-pair level by combining activity data and emission factors and subsequently group the emission results into domestic and international totals. In a final step a fuel balance is made. The fuel ratio between model estimates and statistical sales is used to modify the model results of cruise fuel use and emissions according to the domestic and international cruise shares.

Prior to 2001 the calculation scheme is firstly to estimate each year's fuel use and emissions for LTO. Secondly the total cruise fuel use is found year by year as the statistical fuel use total minus the calculated fuel use for LTO. Lastly the cruise fuel use is split into domestic and international parts 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).

Off road working machines and equipment are grouped in the sectors: Inland waterways, agriculture, forestry, industry and household and gardening. In general the fuel use and emissions are calculated by combining information of the number of different machine types and their respective load factors, engine sizes, annual working hours, and fuel use and emission factors.

The simulations take into account the implementation of a two stage emission legislation directive depending on engine size for relevant types of diesel fuelled machinery. Stage I and II of the directive becomes effective for new machinery in use in 1999-2001 and 1999-2003 respectively.

The amount of fuel sold for non-road machinery cannot be derived explicitly from national fuel sale statistics, and hence it is not possible to make a fuel balance in order to achieve a fuel use equilibrium. Instead, the non-road fuel use amount is estimated directly from the reported activity data by EPA (1992 and 2003) and from EMEP/CORINAIR fuel use factors.

For diesel, the calculated fuel use is partly covered by the fuel use amount in the DEA sectors agriculture and forestry, market gardening and building and construction. The remaining diesel fuel amount is taken from the industry sector. It should be noted that the part of diesel fuel in industry not being used by non-road machinery is included in the sector "Combustion in manufacturing industry" (0301) and "Non-industrial combustion plants" (0203) in the Danish emission inventory. The estimated fuel use for gasoline and LPG is maintained by adjusting the amount of fuel used in the simulations for road traffic and household.

The fuel use for small boats and pleasure crafts is derived in the same way as for non-road machinery. The estimated figures are subsequently subtracted from the fishery sector (diesel) and road transport (gasoline).

The calculated emissions for other mobile sources are shown per sector in annex 3.B.5 for the years 1990 and 2002.

3.3.3 Uncertainties and time series consistency

Uncertainty estimates are made for road transport and other mobile sources using the guidelines and emission factor uncertainties formulated by Penman et al. (2000). The uncertainty factors for activity are based on own judgement. The calculations are shown in annex 3.B.6.

Tabel 3.19 Emission uncertainties in 2002 and trend uncertainties 1990-2002.

Category	Fuel type	Activity data Uncertainty	Emission factor Uncertainty		
			CO_2	CH_4	N_2O
		%	%	%	%
Civil Aviation	Aviation Gasoline	0	5	100	1000
	Jet Kerosene	0	5	100	1000
Road Transportation	Gasoline	0	5	40	50
	Diesel Oil	2	5	40	50
Railways	Diesel Oil	2	5	100	1000
Navigation	Residual Oil	2	5	100	1000
	Gas/Diesel Oil	0	5	100	1000
Agriculture	Diesel Oil	20	5	100	1000
	Gasoline	20	5	100	1000
Forestry	Diesel Oil	20	5	100	1000
	Gasoline	20	5	100	1000
Industry	Diesel Oil	20	5	100	1000
	Gasoline	20	5	100	1000
	LPG	20	5	100	1000
Household and gardening	Gasoline	20	5	100	1000
Overall uncertainty in 2002			3,6	32,2	56,0
Trend uncertainty			3,5	3,8	193,2

As regards time series consistency background flight data cannot be made available on a city-pair level from 2000 and backward. However, aided by LTO/aircraft statistics for these years, and the use of proper assumptions a sound level of consistency is obtained anyhow in this part of the transport inventory.

The time series of emissions for the mobile equipment 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 directly provide fuel use information for working equipment and machinery in these sectors.

For 1990 and 2000 background activity data (stock and operation) exist, but for the years in between 1990 and 2000 and for the years beyond 2000 there is a data gap which is difficult to fill in at present being. At current, estimates for intermediate years and years beyond 2000 are produced by interpolation and using 2000 data, respectively (in both situations a new technology penetration rate is assumed)

3.3.4 Quality assurance/quality control (QA/QC)

For road transport and air traffic the Tier 1 and Tier 2 methods are used independently to provide a quality control of the emission estimations. Firstly the bottom up approach (Tier 2) is used as described in the sections 1.1 to 1.5. Secondly the estimates are modified according to a fuel balance using the statistical sale figures respectively for road transportation and civil aviation fuel in Denmark (Tier 1), as described in the sections 1 and 2. The usage of the Tier 1 method ensures that all fuel for road transport and civil aviation is accounted for in the estimations.

For non-road machinery and working equipment the Tier 2 method determines the amount of fuel used. The subsequent adjustment of fuel totals to be used in the estimates for other sectors (section 2.3) ensure that no double counting of emissions is made.

For the remaining transport sectors the Tier 1 method ensure that all fuel is accounted for in the emission estimations.

As a part of the general QA/QC work all time series of emissions in the CRF and SNAP source categories are examined and considerate changes are checked and explained. Moreover a comparison is made to the previous year's estimate, and any major changes are verified. As a last point a data transfer control is made from SNAP source categories to aggregated CRF source categories.

3.3.5 Recalculations

- Road transport: An updated COPERT III run was made for the year 1999 to include the deterioration effect for catalyst vehicles and more accurate Danish cold start parameters. The Danish inventory for non-exhaust particulate emissions (tyre and brake wear and road abrasion) has been revised according to the new EMEP/CORINAIR guidebook methodology chapter.
- Railways: Updated NO_x, NMVOC, CH_4, CO and PM emission factors for diesel are used in a time series from 1985 to 2002 based on real emission measurements carried out by the Danish Railways. For gasoline the minor amount of fuel used by railways is transferred to road transport in the years 1987, 1989-1993 and 1995-2002.
- Inland waterways: A change is made for diesel fuel use in relation to Danish energy statistics based on consultations with the Danish Energy Authority and the Technological Institute of Denmark. Now the estimated amount of diesel fuel use from 1985-2002 is taken directly from the fishery sector in the statistics.
- Fishery: A part of this sector's diesel fuel use is transferred to ”Inland waterways” for the years 1985-2002 (see description ”Inland waterways”).
- International navigation: The Danish Energy Authority has estimated a fuel use for the year 1985, which has been included in the Danish inventory.
- Air traffic: Small changes in emission factors are made for the years 2001 and 2002. Now helicopters are included in background flight data and in addition minor changes are made to the real aircraft type - representative aircraft type relation.
- Agriculture/Forestry/Industry/Household and gardening: A change is made for diesel fuel use in relation to Danish energy statistics based on consultations with the Danish Energy Authority and the Technological Institute of Denmark. Consequently a correction is made to the sectors ”0203: Plants in agriculture, forestry and aquaculture” and ”0301: Combustion in boilers, gas turbines and stationary” in order to obtain a fuel balance.

In response to the review comments of last year's NIR report, a recalculation of the 1999 CH_4 emission factors was made (first point of recalculation list). A more thorough description of the general CH_4 emission factor development gives that the factors are much higher for urban driving than for rural and highway driving. Another characteristic is that the emission factors for EURO I gasoline cars (introduced in 1990) are somewhat higher than the ones for conventional gasoline cars. For EURO II and III catalyst cars (introduced in 1997 and 2001, respectively) the emission factors are lower than conventional gasoline factors.

3.3.6 Improvements

It will continuously be aspired to fulfil the requirements from IPCC of good practice in inventory making for transport. Some time this year a note will be made for transport going through the different issues of choices relating to methods (methods used, emission factors, activity data, completeness, time series consistency, uncertainty assessment), reporting and documentation, and inventory quality assurance/quality control.

The outcome of this transport-related note might result in some changes to the inventory in the future.

3.3.7 Bunkers

In the Danish emission inventories presented in CRF, the distinction between domestic and international emissions from aviation and navigation is made in accordance with the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. In principle this means that fuel sold (and associated emissions) for flights/sea transportations 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.

For aviation the emissions associated with flights inside the Kingdom of Denmark are counted as domestic. The flights from Denmark to Greenland and the Faroe Islands are classified as domestic flights in the inventory background data, and in the real world almost no fuel is bunkered in Greenland/Faroe Islands by other flights than those going to Denmark.

The domestic/international fuel split (and associated emissions) for navigation is not determined with the same precision as for aviation. In this way no special effort has been made to investigate how the fuel quantities sold in Denmark and on the Faroe Islands are classified for vessels going to Greenland/Faroe Islands. For Greenland all marine fuel sales are treated as domestic. However it is considered that this uncertain fuel amount only contribute with a small part of the total fuel sold for navigation purposes in the Kingdom of Denmark.

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3.4 Additional information, CRF sector 1A Fuel combustion

3.4.1 Reference approach, feedstocks and non-energy use of fuels

In addition to the sector specific CO_2 emission inventories (the national approach) the CO_2 emission is also estimated using the reference approach described in the IPCC Reference Manual (IPCC 1996).

Data for import, export and stock change used in the reference approach originates from the annual "basic data" table prepared by the Danish Energy Authority and published on their home page (DEA 2003b). A fuel correspondence list is enclosed in Annex 3.A. White spirit is included in the fuel category naphtha. 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 1996). The country specific emission factors are not used in the reference approach because it is used for verification.

CRF includes a comparison of the national approach and the reference approach estimates. To make results comparable, the CO_2 emission from the plastic part of municipal waste incineration is added in the reference approach. Further consumption for non-energy purposes is subtracted in the reference approach, because non-energy use of fuels is not included in the Danish national approach yet.

Three fuels are used for non-energy purposes: lube oil, bitumen and white spirit. The total consumption for non-energy purposes is relatively low – 10,9 PJ in 2002.

In 2002 fuel consumption rates of the two approaches differ 0,05% and the CO_2 emission differ 0,24%. In 1990-2002 the fuel consumption difference is within 1,96% and the CO_2 emission difference is within 1,92% and thus less the required ±2%.

Comparison of national approach and reference approach is shown in Figure 3.19.

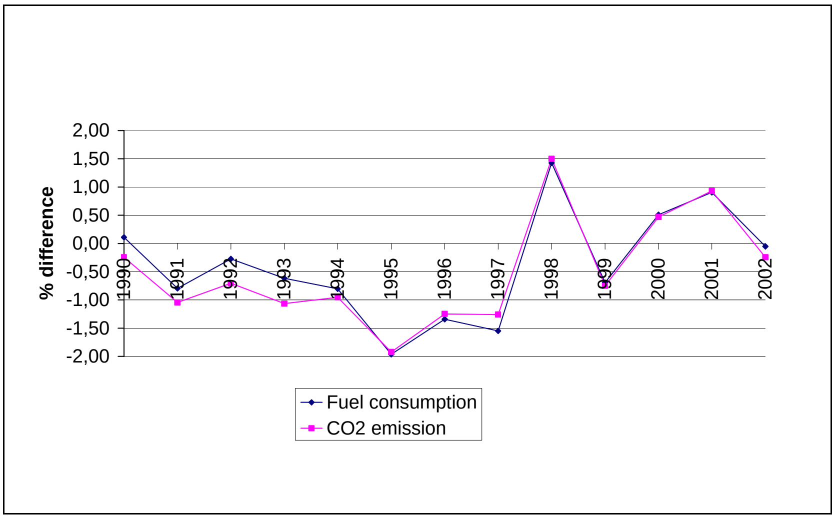

Figure 3.19 Comparison of reference approach and national approach

3.5 Fugitive emissions (CRF sector 1B)

3.5.1 Source category description

3.5.1.1 Fugitive emission from solid fuels, CRF sector 1B1c

Coal mining is not occurring in Denmark, but power plants use a considerable amount of coal. CH_4 emission from storage and handling of coal is included in the Danish inventory.

3.5.1.2 Fugitive emissions from natural gas, transmission and distribution (CRF sector 1B2b)

In the year 2002 the length of transmission pipelines including offshore pipeline is 1439 km. The length of distribution pipelines is 18120 km (cast iron 0 km, steel 2185 km, plastics 15935 km). Two natural gas storages are in operation in Denmark. In 2002 the gas input was 530 Mm^3 and the withdrawal was 542 Mm^3. Emission from gas storage is included in transmission.

3.5.1.3 Flaring, gas (CRF sector 1B2c, Flaring ii)

Off shore flaring of natural gas is the main source in this sector. Flaring in gas treatment and gas storage plants is however also included in the sector.

3.5.2 Methodological issues

3.5.2.1 Fugitive emission from solid fuels, CRF sector 1B1c

The CH_4 emission inventory is based on the tier 1 of the IPCC Reference Manual (IPCC 1996). The CH_4 emission occurring in Denmark is assumed to be half the post-mining emission.

Coal import refers to the official Danish energy statistics (DEA 2003b). In inventories for 1990-1999 country of origin of the imported coal and the underground fraction in each country is taken into account. The emission factor from 1999 has been applied for the 2000-2002 inventories.

Coal import and emission factors are shown in Table 3.20.

Table 3.20 Coal import and CH_4 emission factor, coal storage and handling

Year	Coal import [Mg coal import]	Emission factor 1) [g/Mg coal import]
1990	10255000	336
1991	12810000	310
1992	11942000	327
1993	10467000	458
1994	11772000	477
1995	13009000	485
1996	13134000	485
1997	13474000	485
1998	8071000	430
1999	7117000	474
2000	6415000	474
2001	6924000	474
2002	6262000	474

1) ½ of total post mining emission factor

3.5.2.2 Fugitive emissions from natural gas, transmission and distribution (CRF sector 1B2b)

Inventories of CH_4 emission from gas transmission and distribution is based on annual environmental reports from the Danish gas transmission company, DONG and on a Danish emission inventory for the years 1999-2002 reported by the Danish gas sector (transmission and distribution companies) (Karll 2003). The inventories estimated by the Danish gas sector are based on the work carried out by Marcogas and the International Gas Union (IGU).

In the 1990-1999 inventories fugitive CH_4 emissions from storage facilities and the gas treatment plant are included in the emission factor for transmission. In the 2000-2002 emission inventories transmission, gas storage and gas treatment are registered separately and added.

Gas transmission data are shown in Table 3.21. Emissions from gas storage facilities and venting in the gas treatment plant is shown in Table 3.22. Gas distribution data are shown in Table 3.23.

Table 3.21 CH_4 emission from natural gas transmission

TRANSMISSION		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Transmission rate Mm^3	1)	2739	3496	3616	3992	4321	4689	5705	6956	6641	6795	7079	7289	7287
CH_4 emission Mg	2)		310	93	186	151	536	183	235	156	191	86	157	78
CH_4 IEF kg/Mm^3	3)	88,62	88,62	25,65	46,64	34,98	114,27	36,00	33,78	23,49	28,11	12,15	21,54	10,70

1) In 1990-1997 transmission rates refers to Danish energy statistics, in 1998 transmission rate refers to the annual environmental report of DONG, in 1999-2002 emissions refers to DONG/Danish Gas Technology Centre (Karll 2003)
2) In 1991-95 CH4 emissions are based on the annual environmental report from DONG for the year 1995. In 1996-99 the CH4 emission refers to the annual environmental reports from DONG for the years 1996-99. In 2000-2002 the CH4 emission refers to DONG/Danish Gas Technology Centre (Karll 2003)
3) IEF=Emission/transmission_rate. In 1990 the IEF is assumed to be the same as in 1991

Table 3.22 Additional fugitive CH_4 emissions from natural gas storage facilities and venting in gas treatment plant

<table>
<tr><th></th><th>2000</th><th>2001</th><th>2002</th></tr>
<tr><td>Gas treatment plant</td><td>7,55 Mg</td><td>0 Mg</td><td rowspan="2">67</td></tr>
<tr><td>Gas storage facilities</td><td>76,48 Mg</td><td>72,68 Mg</td></tr>
</table>

Table 3.23 CH_4 emission from natural gas distribution

DISTRIBUTION		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Distribution rate Mm^3	1)	1574	1814	1921	2185	2362	2758	3254	3276	3403	3297	3181	3675	3420
CH_4 emission Mg	2)										43	49	56	38,9
CH_4 IEF kg/Mm^3	3)	14,56	14,56	14,56	14,56	14,56	14,56	14,56	14,56	14,56	13,04	15,40	15,24	11,37

1) In 1999-2002 distribution rates refers to DONG / Danish Gas Technology Centre / Danish gas distribution companies (Karll 2003), 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
2) Danish Gas Technology Centre / DONG/ Danish gas distribution companies (Karll 2003)
3) In the years 1999-2002 IEF=CH_4 emission / distribution rate. In 1990-1998 an average IEF of 1999-2001 is assumed.

3.5.2.3 Flaring, gas (CRF sector 1B2c, Flaring ii)

Emissions from off shore flaring are estimated based on data for fuel consumption from the Danish energy statistics (DEA 2003b) and emission factors for flaring. The emissions from flaring in gas treatment and gas storage plants are estimated based on annual environmental reports of the plants.

The fuel consumption rates are shown in Table 3.24. Flaring rates in gas treatment and gas storage plants are not available until 1995.

The emission factors for off shore flaring are shown in Table 3.25. The CO_2 emission factor follows the same time series as natural gas combusted in stationary combustion plants. All other emission factors are constant in 1990-2002.

The time series for CO_2 emission from gas flaring fluctuates due to fluctuation of off shore flaring rates as shown in figure 3.20.

Table 3.24 Natural gas flaring rate (DEA 2003b)

Year	Flaring, off shore [TJ]	Gas treatment and gas storage [TJ]
1990	4218	-
1991	8692	-
1992	8977	-
1993	7819	-
1994	7709	-
1995	5964	43
1996	6595	30
1997	9629	35
1998	7053	29
1999	15509	32
2000	10023	29
2001	10806	36
2002	8901	44

Table 3.25 Emission factors for off shore flaring of natural gas

Pollutant	Emission factor	
CO_2	57,28	kg/GJ
CH_4	161,5	g/GJ
N_2O	1	g/GJ
SO_2	0,3	g/GJ
NO_x	308	g/GJ
NMVOC	87,2	g/GJ
CO	200	g/GJ

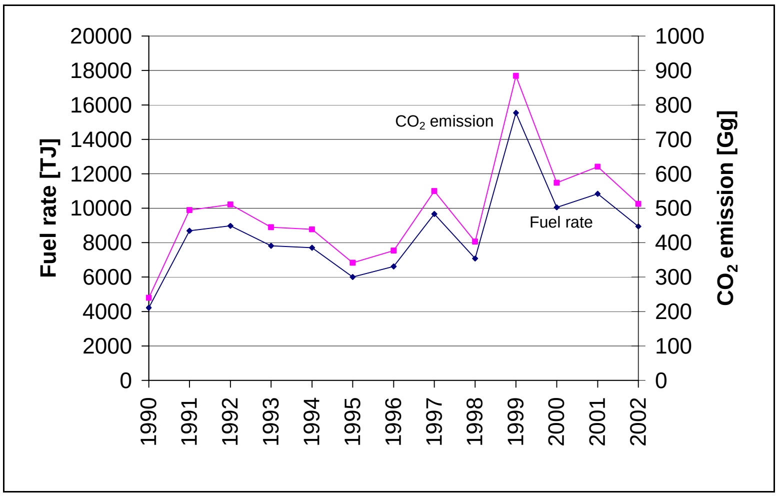

Figure 3.20 time series for gas flaring and CO_2 emission in sector 1B2c ii Flaring, gas

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

Oil Refineries – Petroleum products processing: In the production process at the refineries a part of the volatile hydrocarbons (VOC) is emitted to the atmosphere. It is assumed that CH_4 accounts for

1 % and NMVOC for 99% of the emissions. The VOC emissions from petroleum refinery processes cover non-combustion emissions from feed stock handling/storage, petroleum products processing, product storage/handling and flaring. SO_2 is also emitted from the non-combustion processes and includes emissions from products processing and sulphur recovery plants. The emission calculations are based on information form the Danish refineries and the Energy statistic.

Table 3.26 Oil Refineries. Processed crude oil, emissions and emission factors

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Crude oil (1000 Mg)	7263	7798	8232	8356	8910	9802	10522	7910	7906	8106	8406	8284	8045
CH4 emission (Mg)	37	39	42	43	57	48	62	45	45	45	50	44	43
CH4 emission factor (g/Mg)	5	5	5	5	6	5	6	6	6	6	6	5	5
NMVOC emission (Mg)	3667	3937	4203	4219	5855	4546	5875	4547	4558	4558	4983	4338	4302
NMVOC emission factor (g/Mg)	505	505	511	505	657	464	558	575	577	562	593	524	535

3.5.3 Uncertainties and time-series consistency

Estimation of uncertainty is based on the Tier 1 methodology in IPCC Good Practice Guidance. Results of the uncertainty estimates are shown in Table 3.27.

Table 3.27 Uncertainty, CRF sector 1B Fugitive emissions

Pollutant	Uncertainty of emission inventory [%]	Uncertainty of emission trend [%]
CO_2	16	47
CH_4	98	90
N_2O	52	47
GHG	**23**	**60**

The activity rate uncertainty for fugitive emissions from solid fuels (coal import) is assumed to be 2% referring to GPG. The uncertainty of the post mining emission factor is assumed to be 200% also referring to GPG.

Uncertainty of activity rates for oil and gas activities is 15% referring to GPG. The uncertainty of emissions factors for CO_2 is the uncertainty of emissions factors for flaring. This emission factor uncertainty is 5% (GPG). Uncertainties of CH_4 and N_2O emission factors are both assumed to be 50%.

Table 3.28 Uncertainty of activity rates and emission factors

	Uncertainty Activity rate	Uncertainty Emission factor
CO_2	15	5
CH_4, solid fuel	2	200
CH_4, oil and gas	15	50
N_2O	15	50

3.5.4 Source-specific QA/QC and verification

No source-specific QA/QC and verification is performed.

3.5.5 Source-specific recalculations

3.5.5.1 Fugitive emission from solid fuels, CRF sector 1B1c

No recalculation has been carried out since last year.

3.5.5.2 Fugitive emissions from natural gas, transmission and distribution (CRF sector 1B2b)

Last year the emission from transmission and distribution of natural gas was unintentionally added in the CRF sector *1B2bii Transmission*. This year transmission and distribution is reported separately in CRF. The total emission is not changed. The activity data reported last year was misleading and have been corrected.

3.5.5.3 Flaring, gas (CRF sector 1B2c, Flaring ii)

No recalculation has been carried out since last year.

3.5.6 Source-specific planned improvements

No improvements are planned in this sector.

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4 Industrial processes

4.1 Overview of the sector

The aim of this chapter is to present industrial emissions of greenhouse gases not related to generation of energy. An overview of the identified sources is presented in Table 4.1 with an indication of the contribution to the industrial part of the emission of greenhouse gases in 2002. The emissions are extracted from the CRF tables and presented rounded.

Table 4.1 Overview of industrial greenhouse gas sources (2002).

Process	Code	Substance ton	Emission ton CO_2-eq.	%	Comment
Cement	2A		1,451,771	47.06%	Key-source (2.1% of the total emission of greenhouse gases)
Nitric acid	2B	N_2O: 2,497	774,070	25.09%	Key-source (1.1%)
Refrigeration	2F	HFCs+PFCs	520,860	16.88%	Key-source (1.0% when including foam blowing)
Foam blowing	2F	HFCs	160,040	5.19%	
Lime (quicklime)	2A		96,359	3.12%	0.2% when including production of bricks and tiles
Bricks and tiles	2A		27,384	0.89%	
Other	2F	PFCs+ SF_6: 0.51	15,689	0.51%	
Container glass	2A		14,640	0.47%	
Aerosols / Metered dose inhalers	2F	HFCs	9,870	0.32%	
Electrical equipment	2F	SF_6: 0.4	9,560	0.31%	
Catalysts / fertilisers	2B		3,121	0.10%	
Glass wool	2A		1,629	0.05%	
Steelwork	2C				Production was stopped in 2002; in 2001 the CO_2-emission was estimated to be 46,677 ton
Expanded clay products	2A		-	-	Will be included
Quicklime for sugar production	2A		-	-	Will be included
Iron foundries; coke as reducing agent	2C		-	-	Potential contribution will be investigated
			3,084,993[1]	100.00%	

1. CRF, table 10/5 sums up to 3,084.87 kt CO_2-eq.; the difference may be explained by different rounding.

The sub-sector *Mineral products* (2A) constitute 52%, *Chemical industry* (2B) constitute 25%, and *Consumption of halocarbons and SF_6* (2F) constitute 23% of the industrial emissions of greenhouse gasses. The total emission of greenhouse gases (excl. LUCF) in Denmark is estimated to 68.5 Mt

CO_2-eq. of which the industrial processes contribute with 3.1 Mt CO_2-eq. (4.5%). The key-sources constitute 1-2% of the total emission of greenhouse gases. The trends in greenhouse gases are presented in Table 4.2 and they will be discussed sector by sector below. The emissions are extracted from the CRF tables and presented rounded.

Table 4.2 Survey of greenhouse gases from industrial processes in different sub-sectors from 1990-2002 (kt).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
CO_2													
A. Mineral Products	1021	1194	1313	1326	1326	1326	1402	1569	1571	1490	1526	1551	1592
B. Chemical Industry	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.9	1.4	1.8	2.7	3.1	3.1
C. Metal Production	28	28	28	31	34	39	35	35	42	43	41	47	0
N_2O													
B. Chemical Industry	3.4	3.1	2.7	2.6	2.6	2.9	2.7	2.7	2.6	3.1	3.2	2.9	2.5
HFCs (Gg CO_2 eq.)													
F. Consumption of Halocarbons and SF_6	0.0	0.0	3.4	93.9	135	218	330	324	411	503	605	647	672
PFCs (Gg CO_2 eq.)													
F. Consumption of Halocarbons and SF_6	0.0	0.0	0.0	0.0	0.1	0.5	1.7	4.1	9.1	12.5	17.9	22.1	22.2
SF_6 (Gg CO_2 eq.)													
F. Consumption of Halocarbons and SF_6	44.5	63.5	89.1	101	122	107	61.0	73.1	59.5	65.4	59.2	30.4	21.6

CH_4 will probably be emitted from some of the sources leading to emission of CO_2; this emission will be investigated and included in the next inventory.

Note that for the F-gases (HFCs, PFCs and SF_6) the inventories - as can be seen from the CRF tables - might not constitute full coverage of emissions for 1990-1994. For these gases 1995 is considered as the base year.

The present inventory has been improved to cover especially nitric acid production and a part of the metal industry (steelwork) as response to the last review report from UNFCCC (FCCC/WEB/IRI(3)/2003/DKN). Activity data has been included in the CRF tables for "Other production", where breweries results in emission of NMVOC but no N_2O.

A number of improvements have been planned as e.g. inclusion of iron foundries (as suggested in the review report), use of limestone in production of sugar, and manufacturing of products of expanded clay.

As regards other sources pointed out by the reviewers, please refer to the notation keys in the CRF-tables for details regarding industries not present in Denmark as e.g. ammonia production, adipic acid production, production of primary metals (e.g. aluminium and iron) etc.

4.2 Mineral products (2A)

4.2.1 Source category description

The sub-sector *Mineral products* (2A) covers the following processes:

- Production of cement (SNAP 040612)
- Production of lime (quicklime) (SNAP 040614)
- Production of bricks and tiles (SNAP 040614)
- Production of container glass/glass wool (SNAP 040613)
- Production of products from expanded clay (SNAP 040614)

Production of cement is identified as a key-source; see *Annex 1: Key sources*. CO_2-emissions from expanded clay products are not included in the present NIR.

The time-series for emission of CO_2 from *Mineral products* (2A) are presented in Table 4.3. The emissions are extracted from the CRF tables and presented rounded.

Table 4.3 Time-series for emission of CO_2 (kt) from *Mineral products*.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1. Production of Cement	882	1088	1192	1206	1192	1204	1282	1441	1452	1365	1406	1432	1452
2. Production of Lime and Bricks	123	91	106	106	119	108	106	114	103	107	105	104	124
7. Other[1]	16	16	15	14	15	14	14	14	15	18	16	16	16
Total	1021	1194	1313	1326	1326	1326	1402	1569	1571	1490	1526	1551	1592

1. Production of container glass and glass wool.

The increase in CO_2-emission is most significant for production of cement. From 1990 to 2002 the CO_2-emission has increased from 1021 to 1592 kt CO_2 i.e. 56%. The increase can be explained by the increase in the annual production. The emission factor has only changed slightly as the distribution between types of cement especially grey/white cement has been almost constant from 1990-2002.

4.2.2 Methodological issues

The CO_2-emission from production of cement has been estimated from the annual production of cement expressed as TCE (total cement equivalents[3]) and an emission factor from the company (Aalborg Portland, 2003). The emission factor has been estimated by the company from loss of ig-

[3] TCE (total cement equivalent) express the total amount of cement produced for sale and the theoretical amount of cement from the produced amount of clinkers for sale.

nition determined for the different kinds of clinkers produced combined with produced amount of grey and white cements. 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 not in accordance with the IPCC-guideline (IPCC (1999) p. 3.10ff) that requires information on production of different types of clinker and corresponding emission factors.

The CO_2-emission from production of burnt lime (quicklime) has been estimated from the annual production of burnt lime as measured by Statistics Denmark and an emission factor (0.785 kg CO_2/kg CaO) as recommended by IPCC (IPCC (1996), vol. 3, p. 2.8). Hydrated lime (slaked lime) has not been included in the present estimate and the emission factor has not been corrected for potential content of impurities in the final product (e.g. SiO_2 etc.).

The CO_2-emission from production of bricks and tiles has been estimated from information of annual production measured by Statistics Denmark corrected for amount of yellow bricks and tiles. This amount is unknown and therefore assumed to be 50%. 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 emission factor (0.44 kg CO_2/kg $CaCO_3$) is based on stoichiometric determination.

For further details on the CO_2-estimation from production of burnt lime and from production of bricks which constitutes a combined activity in the CRF sector activities, refer to Annex 3.C.

The CO_2-emission from production of container glass/glass wool has been estimated from production statistics published in environmental reports from the producers and emission factors based on release of CO_2 from specific raw materials (stoichiometric determination).

4.2.3 Uncertainties and time-series consistency

The time-series are presented in Table 4.3. The methodology applied for the years 1990-2002 is considered to be consistent, as the emission factor has been determined by the same approach for all years. The emission factor has only changed slightly as the distribution between types of cement especially grey/white cement has been almost constant from 1990-2002.

For 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 either based on stoichiometric relations or at a standard assumption of $CaCO_2$-content of clay used for bricks.

No source-specific uncertainties have been determined for this sub-sector.

4.2.4 Source-specific QA/QC and verification

The information obtained from specific companies has been compared with default emission factors given in the IPCC guidelines to ensure that they are plausible and in the proper order of magnitude. The data treatment and transfer from the database to the CRF tables has been controlled as described in the general section on quality assurance/quality control.

4.2.5 Source specific recalculations

No source specific recalculations have been performed regarding emissions from production of mineral products. However, a minor change has been introduced for production of cement, as the activity data for 1998-2001 has been changed to include production of cement clinker for final manufacturing elsewhere. The trend and the size of the recalculation can be found in the table in section 10.3.

4.2.6 Source-specific planned improvements

Regarding production of cement a dialogue with the company will be continued with the aim to get more detailed information on production statistics (i.e. production of different types of clinker) and corresponding emission factors.

The statistics for production of burnt lime will be improved to include hydrated lime and the emission factor will be corrected for impurities in the final product.

Production statistics for glass and glass wool as well as information on consumption of raw materials will be completed for 1990-1995.

The emission of CO_2 from products of expanded clay is not included for the moment however this source will be investigated and included in the next NIR.

4.3 Chemical industry (2B)

4.3.1 Source category description

The sub-sector *Chemical industry* (2B) cover the following processes:

- Production of nitric acid/fertiliser (SNAP 040402/040407)
- Production of catalysts/fertilisers (SNAP 040416/040407)

Production of nitric acid is identified as a key-source.

The time series for emission of CO_2 and N_2O from *Chemical industry* (2B) are presented in Table 4.4.

The emissions are extracted from the CRF tables and presented rounded.

Table 4.4 Time-series for emission of GHG from *Chemical industry* (kt CO_2-eq.).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
2. Nitric acid production (N_2O)	1043	955	844	795	807	904	834	848	807	950	1004	885	774
5. Other[1] (CO_2)	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.9	1.4	1.8	2.7	3.1	3.1
Total	1045	957	845	797	808	906	836	850	808	952	1006	888	777

1. Production of catalysts/fertilisers.

The emission of N_2O from nitric acid production is the most considerable source of GHG from chemical industry. The trend for N_2O from 1990 to 2002 shows a decrease from 3.4 to 2.5 kt i.e. -26%. However, the activity and the corresponding emission show considerable fluctuations in the considered period.

From 1996 to 2002 the emission of CO_2 has increased from 1.7 to 3.1 kt i.e. 82% due to increase in activity.

4.3.2 Methodological issues

The N_2O-emission from production of nitric acid/fertiliser is based on measurement for 2002. For the previous years the N_2O-emission has been estimated from annual production statistics from the company and an emission factor based on the measured 2002 emission.

The CO_2-emission from production of catalysts/fertiliser is based in information in the environmental report from the company. In the environmental report the company has estimated the amount of CO_2 from the process and the amount from energy conversion. For the years 1990-1995 the production as well as the CO_2-emission has been assumed to be the same as in 1996.

4.3.3 Uncertainties and time-series consistency

The time-series are presented in Table 4.4. The applied methodology regarding N_2O is considered to be consistent. The activity data is based on information from the specific company and the applied emission factor has been constant from 1990 to 2001 and based on measurements in 2002. The production equipment has not been changed during the period.

The consistency of the methodology applied for determination can not be assessed from the available information as the specific company has given a general distribution of CO_2 from energy conversion and processes.

No source-specific uncertainties have been determined for this sub-sector.

4.3.4 Source-specific QA/QC and verification

The information obtained from specific companies has been compared with default emission factors given in the IPCC guidelines to ensure that they are plausible and in the proper order of magnitude. The data treatment and transfer from the database to the CRF tables has been controlled as described in the general section on quality assurance/quality control.

4.3.5 Source specific recalculations

N_2O emissions from nitric acid production have been included for the time-series 1990-2002. The potential of this source as N2O emitter was pointed out in the review report.

4.3.6 Source-specific planned improvements

The applied emission factor for N_2O from production of nitric acid is based on measurement from one year and this factor will be improved or validated before preparation of the next NIR.

The emission of CO_2 from production of catalysts/fertilisers will be validated be further contact to the company to get further detail on processes leading to generation of CO_2. The production statistics as well as emission of CO_2 will be completed for 1990-1995.

4.4 Metal production (2C)

4.4.1 Source category description

The sub-sector *Metal production* (2C) cover the following process:

- Steelwork (SNAP 040207)

• Iron foundries (SNAP 030303/0402)

CO_2-emissions from iron foundries are not included in the present NIR.

The time-serie for emission of CO_2 from *Metal production* (2C) is presented in Table 4.5. The emissions are extracted from the CRF tables and presented rounded.

Table 4.5 Time-serie for emission of CO_2 (kt) from *Metal production* .

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1. Iron and steel production	28	28	28	31	34	39	35	35	42	43	41	47	NO/ NE[1]

1. The activity has been stopped in the first half of 2002 to bankruptcy and therefore information for 2002 is not available.

From 1990 to 2001 the CO_2-emission has increased from 28 to 47 kt i.e. 68%. The increase in CO_2-emission is similar to the increase in the activity as the consumption of metallurgical coke per produced amount of steel sheets and bars has nearly has been constant during the period.

4.4.2 Methodological issues

The CO_2-emission from consumption of metallurgical coke at steelwork has been estimated from the annual production of steel sheets and steel bars combined with consumption of metallurgical coke per produced amount. 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 (3.6 ton CO_2/ton metallurgical coke) is based on values in the IPCC-guideline (IPCC (1996), vol. 3, p. 2.26). 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-serie - see Table 4.5 - is considered to be consistent as the same methodology has been applied for the whole period. The activity i.e. produced amount of steel sheets and bars as well as consumption of metallurgical coke has been published in environmental reports. The emission factor (consumption of metallurgical coke per ton of product) has been almost constant from 1994 to 2001. For the remaining years the same emission factor has been applied. In 2002 the production has been stopped.

No source-specific uncertainties have been determined for this sub-sector.

4.4.4 Source specific recalculations

CO2 emissions from steelworks have been included for the time-series 1990-2001. The possibility of this source was pointed out in the review report.

4.4.5 Source-specific QA/QC and verification

The data treatment and transfer from the database to the CRF tables has been controlled as described in the general section on quality assurance/quality control.

4.4.6 Source-specific planned improvements

Production statistics and information on consumption of raw materials will be completed for 1990-1993. The mass balance (i.e. produced amounts of steel bars and steel sheets as well as consumption of metallurgical coke) for the steelwork will be improved/verified.

The emission of CO_2 from iron foundries is not included for the moment however this source will be investigated and included in the next NIR.

4.5 Production of Halocarbons and SF_6 (2E)

There is no production of Halocarbons and SF_6 in Denmark.

4.6 Metal Production (2C) and Consumption of Halocarbons and SF_6 (2F)

4.6.1 Source category description

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:

- 2C: SF6 used in Magnesium Foundries SNAP 040304 SF6
- 2F: Refrigeration SNAP 060502 HFC32, 125, 134a, 152a, 143a, PFC (C_3F_8)
- 2F: Foam blowing SNAP 060504 HFC134a, 152a
- 2F: Aerosols/Metered dose inhalers SNAP 060506 HFC134a
- 2F: Production of electrical equipment SNAP 060507 SF_6
- 2F: Other processes SNAP 060508 SF_6, PFC (C_3F_8)

A quantitative overview is given below for each of these source categories and each F-gases showing their emissions in tons through the times series. The data are extracted from the CRF tables that are part of this submission and presented data are rounded. It must be noticed that the inventories for the years 1990-1993(1994) might not in fully cover emissions from these gases. The choice of Denmark for the base year for these gases is 1995.

Table 4.6 Consumption of SF_6 used in Magnesium foundries.

2C	SF6 Used in Magnesium Foundries (t)												
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
SF6	1,30	1,30	1,30	1,50	1,90	1,50	0,40	0,60	0,70	0,70	0,89	NO	NO

Table 4.7 Consumption HFCs and PFCs in refrigeration and air condition equipment.

2F	Refrigeration (t)												
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
HFC 32	NE	NE	NE	NE	NE	0,1	0,8	1,8	2,7	3,8	5,7	7,33	8,4
HFC125	NE	NE	NE	NE	0,2	2,6	9,5	15,8	21,8	31,7	43,1	45,05	48,5
HFC134a	NE	NE	0,3	2,6	10,3	14,3	16,3	34,2	45,9	94,3	111,5	127,57	151,3
HFC152a	NE	NE	NE	NE	NE	0,0	0,0	0,1	0,4	0,5	0,6	0,58	0,5
HFC143a	NE	NE	NE	NE	0,2	2,4	8,6	13,7	19,3	29,1	39,6	40,09	43,2
PFC (C3F8)	NE	NE	NE	NE	0,0	0,1	0,2	0,6	1,3	1,8	2,3	2,64	2,7

Table 4.8 Consumption of HFCs in foam blowing.

2F	Foam blowing (t)												
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
HFC 32	NE	NE	NE	NE	NE	NO	NO	NO	NO	NO	NO	3,7	0,0
HFC125	NE	NE	NE	NE	NE	NO	NO	NO	NO	NO	NO	3,7	0,0
HFC134a	NE	NE	2,0	66,4	87,1	135,8	187,5	138,2	164,1	125,0	127,4	131,94	121,8
HFC152a	NE	NE	3,0	30,0	46,0	43,4	32,2	15,2	9,3	37,7	16,2	12,82	12,5

Table 4.9 Consumption of HFCs in aerosols/metered dose inhalers.

2F	Aerosols (t)												
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
HFC134a	NO	NO	NO	NO	NO	NO	NO	NO	0,6	8,1	12,9	9,24	7,6

Table 4.10 Consumption of SF_6 in electrical equipment.

2F	Electrical Equipment (t)												
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
SF6	0,06	0,11	0,11	0,12	0,14	0,16	0,18	0,38	0,27	0,48	0,47	0,53	0,40

Table 4.11 Consumption of PFCs and SF_6 in other processes.

2F	Other (t)												
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
SF6	0,50	1,25	2,32	2,61	3,07	2,83	1,97	2,08	1,52	1,55	1,12	0,75	0,51
PFC (C3F8)	NO	NO	NO	NO	NO	NO	NO	NO	0,00	0,00	0,27	0,52	0,50

The emission of SF_6 has been decreasing recent years due to no activity on Magnesium Foundry exists any longer and due to decrease in the use in electric equipment. Also a decrease in "other", which for SF_6 is used in window plate production use, laboratory use and use in running shoes is occurring.

The emission of HFCs has decreased for the use as a refrigerant and in foam blowing. There is a stagnant tendency 2001-2002. The F-gases are since 1. March 2001 regulated in two ways. For some types of use there is a ban to use the gases in new installations and for other types of use there is taxation. These regulations seem to have the influence that emissions are stagnant.

The table below quantifies 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 2002.

Table 4.12 Time-series for emission of HFCs, PFCs and SF_6.

GREEN-HOUSE GAS EMISSIONS	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
	CO_2 equivalent (Gg)												
HFCs	0,00	0,00	3,44	93,93	134,53	217,73	329,30	323,75	411,20	502,98	604,64	647,32	672,10
PFCs	0,00	0,00	0,00	0,00	0,05	0,50	1,66	4,12	9,10	12,48	17,89	22,13	22,17
SF_6	44,45	63,50	89,15	101,17	122,06	107,36	60,99	73,09	59,46	65,39	59,25	30,43	21,63

The decrease in SF_6 emission has brought its emissions in CO_2 eqv. down to the level of PFC. Seen together and for all uses the by far most dominant group is HFCs. In this grouping the HFCs constitute a key source both with regard to the key source level and trend analysis. In the level analysis the group of HFCs are number 18 out of 21 key sources and they contribute in 2002 to 1.0% of the National total.

4.6.2 Methodological issues

The data for emissions of HFCs, PFCs, and SF_6 has been obtained in continuation of 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 takes into account the substances in stock form. This is in accordance with the IPCC-guideline (IPCC (1996), vol. 3, p. 2.43ff).

The following sources of information has 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

Data is primarily based on respondents from enterprises and importers resulting from a questionnaire survey.

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
- Determining 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 wherever possible carried out for individual substances, even though the consumption of certain HFCs has been very limited, This has been done 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

The substances have in the survey been accounted for 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 following relations has been used.

Table 4.13 Time-series for emission of HFCs, PFCs and SF_6.

Pure HFCs / HFC Mixtures	HFC-32	HFC-125	HFC-134a	HFC-143a	HFC-152a
HFC-401a					13%
HFC-402a		60%			
HFC-404a		44%	4%	52%	
HFC-407a	23%	25%	52%		
HFC-410a		7%		46%	
HFC-507a		50%		50%	

The survey on the F-gases is reported yearly by the Danish Environmental Protection Agency and the data are kept and calculations performed in spreadsheets. The latest report is available in English as Danish Environmental Protection Agency (2004a).

4.6.3 Uncertainties and time-series consistency

The time-series for emission of Halocarbons and SF_6 are presented in section 1.2.1 where it was also mentioned that fully consistency in the time-series as regards coverage of the sources is achieved from 1994 (1995). For the whole time-series the same model are used for the data presented in this submission and model parameters are not changed during the time-series.

The uncertainty varies from substance to substance. Uncertainty is greatest for HFC-134a due to a widespread application in products that are imported and exported. The greatest uncertainty in the areas of application is expected to arise from consumption of HFC-404a and HFC-134a in commercial refrigerators and mobile refrigerators. The uncertainty on year to year data is influenced by the uncertainty on the rates at which the substances are released, which results in significant differences in the emission determinations in the short term (approx. five years), differences that balances in the long term.

4.6.4 Source-specific QA/QC and verification

A very comprehensive QC procedure on the data in the model for the whole time-series has for this submission been carried out in connection to the process which provided (1) data for the CRF background Tables 2(II).F. for the years (1993)-2002 and (2) provided 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 done according to their trade names. Conversion was made to the HFCs 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.

4.6.5 Source-specific recalculations

Revisions of the methodology for F-gases emissions were made in spring 2003. However, the full revision was in the April 15, 2003 submissions only made for year 2001. In this submission the full revision for the whole time-series 1990-2002 as regards emissions of F-gases is introduced. This means in this submission recalculated emissions for the years 1990-2000. Further, as explained above data has now been provided to the background Tables 2(II).F. for the years (1993)-2002. This was also a result of a recommendation of the review team. Finally, potential emissions for F-gases in Table 2(I)s2 has been revised also according to the new methodology.

4.6.6 Source-specific planned improvements

It is planned to improve uncertainty estimates and QA/QC procedures.

5 Solvents and other product use (CRF: 3 SNAP: 06)

5.1 The present NMVOC inventory

Use of solvents is an important source of evaporation of NMVOC and contributed in 2001 with approximately 31 % of the total NMVOC emission. The most important sectors for industrial use of solvents are: Car repairing and treatment, chemical industry, paint application in iron and steel industry, paint manufacturing, the plastic industry, the foodstuff industry, preservation of wood and the printing industry. For these sectors the Government and the industries agreed to reduce the emissions of NMVOC by 40 % from 1988 to 2000. The reduction targets for each trade was estimated by trades and companies.

As a part of an agreement between the Danish Industry and the Danish Environmental Protection Agency the emissions from various industries have been reported to the Danish EPA. The reporting is not annual and linear interpolation is used between the reporting years.

In the Danish inventory emission estimates for solvent use are made for paint application (SNAP category 0601) in the sectors: construction and buildings, domestic use, boat building and wood. Chemical product manufacturing and processing includes: polyester processing, polyurethane processing, polystyrene foam processing, paint manufacturing, glues manufacturing and other product manufacturing and processing (SNAP category 0603). The use of solvents in "Other use of solvents and related activities" (SNAP category 0604) takes places in the sectors: printing industry, fat, edible and non edible oil extraction, application of glues and adhesives, underseal treatment and conservation of vehicles, domestic solvent use and other uses (Reference: Report from the Danish EPA, 1995, no. 50, VOC reduction plants (in Danish). The emission trends are given in table 5.1.

It is important to notice that not all the use of solvents are included in this agreement and no activity data has been available. A work is going on to improve the emission estimates and in section 5.1 a brief description of the new methodology is given.

5.2 The new methodology regarding Solvents

The emissions of Non-Methane Volatile Organic Carbon (NMVOC) from industrial and household use in Denmark has been assessed. Until now the NMVOC inventory in Denmark has been based on questionnaires and interviews with different industries, regarding emissions from specific activities, such as lacquering, painting impregnation etc. However, this approach implies large uncertainties due to the diverse nature of many solvent using processes. For example, it is inaccurate to use emission factors derived from one printwork in an analogue printwork, since the type and combination of inks may vary considerably. Furthermore the employment of abatement techniques will result in loss of validity of estimated emission factors.

A new approach has been introduced, focusing on single chemicals instead of activities. This will lead to a clearer picture of the influence from each specific chemical, which will enable 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. Mass balances are simple and functional methods for calculating the use and emissions of chemicals

$$use = production + import - export - destruction/disposal - hold\ up \quad \text{(Eq. 1)}$$

$$emission = use * emission\ factor \quad \text{(Eq. 2)}$$

where "hold up" is the difference in the amount in stock in the beginning and at the end of the year of inventory.

A mass balance can be made for single substances or groups of substances, and the total amount of emitted chemical is obtained by summing up the individual contributions. It is important to perform an in-depth investigation in order to include all relevant emissions from the large amount of chemicals. The method for a single chemical approach is shown in Figure 5.1.

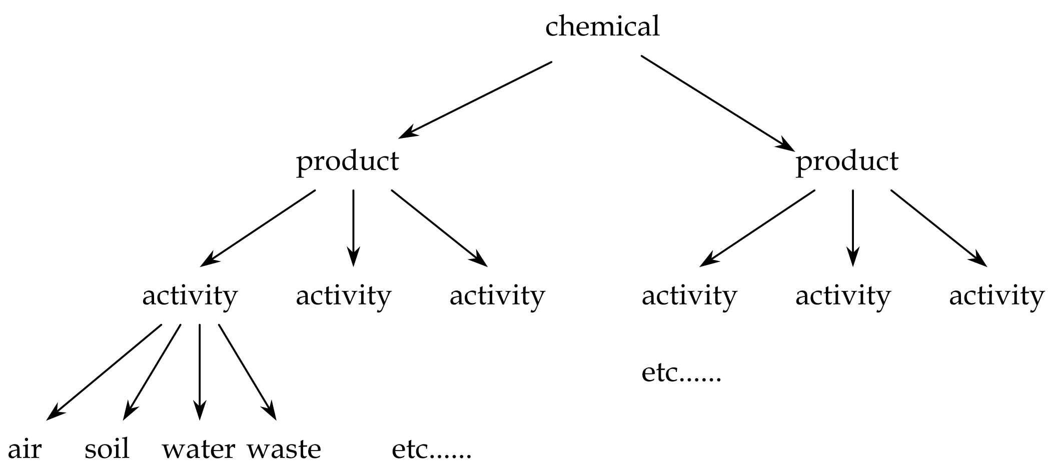


Figure 5.1 Methodological flow in a chemical based emission inventory.

The tasks in a chemical focused approach are

1) Definition of chemicals to be included
2) Quantification of use amounts from Eq. 1
3) Quantification of emission factors for each chemical

In principle all chemicals that can be classified as NMVOC must be included in the analysis, which implies that it is essential to have an explicit definition of NMVOC. The definition of NMVOC is, however, not consistent; In the EMEP-guidelines for calculation and reporting of emissions, NMVOC are defined as "all hydrocarbons and hydrocarbons where hydrogen atoms are partly or fully replaced by other atoms, e.g. S, N, O, halogens) which are volatile under ambient air conditions, excluding CO, CO_2, CH_4, CFCs and halons". The amount of chemicals that fulfil these criteria is large, and a list of 650 single chemicals and a few chemical groups described in "National Atmospheric Emission Inventory", is used. It is probable that the major part will be insignificant in a mass balance, but it is not correct to exclude any chemicals before a more detailed investigation has been made.

Production, import and export figures are extracted from Statistics Denmark, from which a list of 427 single chemicals, a few groups and products is generated. For each of these a *use* amount in tonnes pr. year (from 1995 to 2003) is calculated. It is found that that 44 different NMVOC comprise over 95 % of the total use, and it is these 44 chemicals that are investigated further.

The *use* amounts are distributed according to the SNAP coding, defined in EMEP/CORINAIR Emission Inventory Guidebook, Group 6: Solvent and other product use. In the Nordic SPIN (Substances in Preparations in Nordic Countries) database information is available in a NACE coding system, on industrial use categories and products specified for individual chemicals. In order to perform a spatial disaggregation, by relating the chemicals to specific products and/or activities, the SNAP codes are coupled with NACE codes.

Emission factors, cf. Eq. 2, are obtained from regulators or the industry and can be provided on a site by site basis, or as a single total for whole sectors.

Outputs from the inventory are

- a list where the 44 most predominant NMVOCs are ranked according to emissions to air,
- specification of emissions from industrial sectors and from households,
- contribution from each NMVOC 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.

Table 5.1 Use of solvents. NMVOC emissions for various sectors (Reference: Report from the Danish EPA, 1995, no. 50, VOC reduction plants (in Danish)) Reference: Danish EPA, 1995, Report no. 50, VOC reduction plants (in Danish)

		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
0601	**Paint application**	0												
060101	Paint application : manufacture of automobiles													
060102	Paint application : car repairing	0	0	0	0	0	0	0	0	0	0			
060103	Paint application : construction and buildings	9452	9497	9542	9586	9631	9676	9721	9766	9810	9855	9900	9900	9900
060104	Paint application : domestic use (except 06.01.07	9452	9497	9542	9586	9631	9676	9721	9766	9810	9855	9900	9900	9900
060105	Paint application : coil coating													
060106	Paint application : boat building	0	0	0	0	0	0	0	0	0	0			
060107	Paint application : wood	6500	6192	5884	5576	5276	4960	4652	4344	4036	3728	3420	3420	3420
060108	Other industrial paint application	0	0	0	0	0	0	0	0	0	0			
060109	Other non industrial paint application													
0603	**Chemical products manufacturing or processing**													
060301	Polyester processing	470	478	486	494	502	510	518	526	534	542	550	550	550
060302	Polyvinylchloride processing													
060303	Polyurethane processing	3	3	3	3	3	3	3	4	4	4	4	4	4
060304	Polystyrene foam processing (c)	920	919	918	917	916	915	913	913	912	911	910	910	910
060305	Rubber processing													
060306	Pharmaceutical products manufacturing													
060307	Paints manufacturing	300	298	296	294	292	290	288	286	284	282	280	280	280
060308	Inks manufacturing													
060309	Glues manufacturing	24	23	22	20	19	18	17	16	14	13	12	12	12
0603010	Asphalt blowing													
0603011	Adhesive, magnetic tapes, films and photographs													
060314	Other	930	877	823	770	716	663	610	556	503	449	396	396	396
0604	**Other use of solvents and related activities**													
060401	Glass wool enduction													
060402	Mineral wool enduction													
060403	Printing industry	1575	1462	1349	1235	1122	1009	896	783	669	556	443	443	443
060404	Fat, edible and non edible oil extraction	1920	1893	1866	1839	1812	1785	1758	1731	1704	1777	1650	1650	1650
060405	Application of glues and adhesives	2700	2580	2460	2340	2220	2100	1980	1860	1740	1620	1500	1500	1500
060406	Preservation of wood	0	0	0	0	0	0	0	0	0	0			
060407	Underseal treatment and conservation of vehicles	1400	1345	1290	1290	1180	1125	1070	1015	960	905	850	850	850
060408	Domestic solvent use (other than paint application	6653	6807	6961	7115	7269	7423	7576	7730	7884	8038	8192	8192	8192
060409	Vehicles dewaxing													
060411	Domestic use of pharmaceutical products (k)													
060412	Other (preservation of seeds,...)	0	0	0	1696	0	0	0	0	0	0			

6 The emission of greenhouse gasses from the agricultural sector (CRF Sector 4)

The emission of greenhouse gases from the agricultural activities includes CH_4 emission from enteric fermentation and manure management and N_2O emission from manure management and agricultural soils. The emissions are reported in CRF – table 4.A, 4.B(a), 4.B(b) and 4.D. Furthermore the emission of Non-methane volatile organic compounds (NMVOC) from agricultural soil is given in table 4s2.

Emission from rice production, burning of savannas and crop residues does not occur in Denmark, which are the reason why table 4.C, 4.E and 4.F has not been completed. Burning of plant residue has been prohibited since 1989 and may only take place in connection with cultivation of seed grass. It is assumed that the emission is insignificant and hence not included in the emission inventory.

6.1 Overview

In 2002 given in CO_2 equivalents the agricultural sector without LULUCF contributes with 15% of the overall greenhouse gas emission (GHG). Next to the energy sector the agricultural sector is the largest source of GHG emission in Denmark. The major part of the emission is related to the livestock production, which in Denmark is dominated by the production of cattle and pigs. In 2002 the N_2O emission contributed with 63% of the total GHG emission and CH_4 with the remaining 37%.

From 1990 to 2002 the emissions have decreased from 12.8 Gg CO_2-eqv. to 10.1 Gg CO_2-equ., which corresponds to a 21%-reduction (Table 6.1). In 2003 the GHG emission were recalculated. The reestimated emission is lower than previous reported, but the reduction from 1990 to 2002 is at the same level. Further explanation is given in Chapter 6.8.

Table 6.1 Emission of GHG in the agricultural sector in Denmark 1990 – 2002 (CRF)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
						Gg CO_2 – eqv.							
N_2O	8 983	8 828	8 527	8 316	8 102	7 903	7 561	7 483	7 454	7 013	6 760	6 625	6 370
CH_4	3 842	3 874	3 883	3 968	3 934	3 931	3 953	3 863	3 907	3 786	3 804	3 845	3 764
Total	12 826	12 702	12 411	12 285	12 036	11 834	11 514	11 346	11 360	10 800	10 564	10 470	10 134

Figure 6.1 shows the distribution of greenhouse gas emission from the main sources. The decreased emission can be associated with a decrease of N_2O emission from agricultural soils due an offensive National environmental policy during the last twenty years. The environmental policy has introduced a series of measures to prevent loss of nitrogen from the agriculture to the aquatic environment. The measures includes improved utilisation of nitrogen in husbandry manure, ban on manure application in autumn and winter, increased area with winter green fields to catch nitrogen, a maximum number of animals per hectare and a maximum nitrogen application rates to agricultural crops. The result is a decrease in the N-excretion and emission per produced animal, which has reduced the overall emission of GHG.

From 1990 to 2002 there is no reduction in the estimated CH_4 emission. The emission from enteric fermentation has decreased caused by a fall in the number of cattle. But, on the other hand, the emission from manure management has increased due to the change to more slurry based stable systems, which has a higher emission factor. By coincidence this decrease and this increase have a size as to balance, so the trend for CH_4 emissions from 1990 to 2002 is about zero.

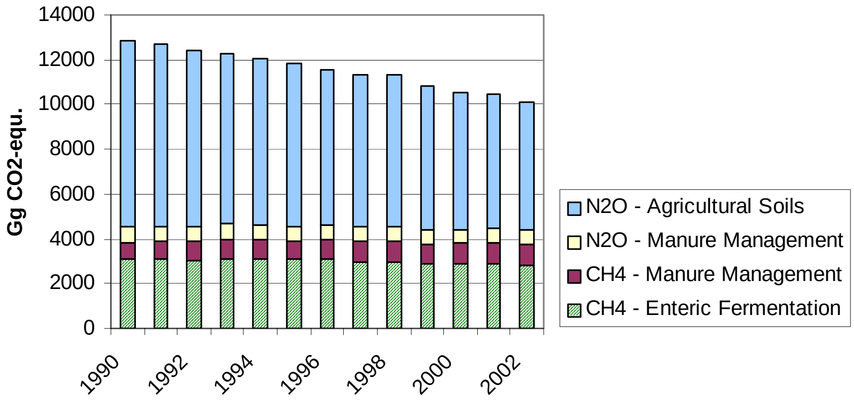


Figure 6.1 Danish greenhouse gas emission 1990 - 2002

6.1.1 References – sources of information

The calculations of the emissions are based on methods described in the IPCC Guideline (IPCC, 1996) and Good Practice Guidance (IPCC, 2000).

Activity data and emission factors are collected and discussed in corporation with specialists and researchers at different institutes such as the Danish Institute of Agricultural Sciences, Statistics Denmark, the Danish Agricultural Advisory Centre, the Danish Plant Directorate and the Danish Environmental Protection Agency. It means that both the data and the methods will be evaluated continuously according to the latest knowledge and information.

Table 6.2 List of institutes involved

References	Abbreviation	Data / information
National Environmental Research Institute	NERI	- reporting - data collecting
Statistics Denmark - Agricultural Statistic (www.dst.dk)	DS	- No. of animal - milk yield - slaughtering data - land use - crop production
Danish Institute of Agricultural Sciences	DIAS	- N-excretion - feeding situation - growth - N-fixed crops - crop residue - N-leaching/runoff - NH_3 emissions factor
The Danish Agricultural Advisory Centre	AAC	- stable type - grassing situation - manure application time and methods
Danish Environmental Protection Agency	EPA	- sewage sludge used as fertiliser - industrial waste used as fertiliser
The Danish Plant Directorate	PD	- organic farming - synthetic fertiliser (contribution and type)

The emission estimates are calculated in a comprehensive agricultural model complex (DIEMA) covering ammonia, CH_4, N_2O and CO_2. Ammonia, CH_4 and N_2O are implemented in a great detail. The submodule covering LULUCF and CO_2 will be implemented in 2004. An overview of DIEMA is given in figure 6.2.

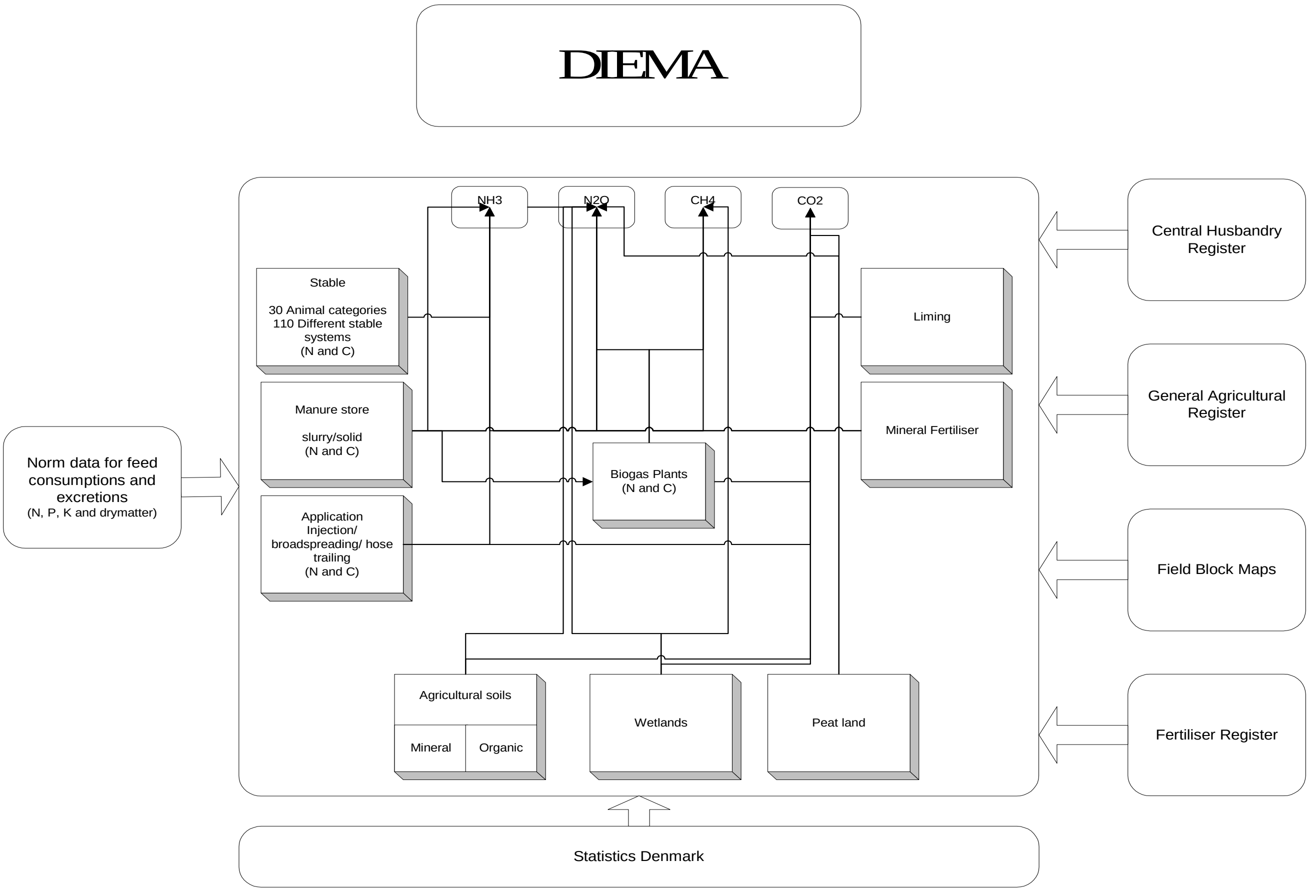


Figure 6.2 DIEMA – Danish Integrated Emission Model for Agriculture

The Danish standards related to feeding consumption, manure type in different stable type, nitrogen content in manure etc. are described and published by the Danish Institute of Agricultural Sciences (Poulsen *et al*. 2001). These standards are updated annually. In 1998 these standards was published in English (Poulsen and Kristensen 1998). The main part of the emission of GHG from the agricultural sector is related to the livestock production. DIEMA is using about 30 livestock categories depending on type of livestock and weight class. Each category is subdivided according to stable type and manure type. The emission is calculated from each category.

6.1.2 Key source identification

Most of the agricultural emission sources can be considered as key sources both at level and trend niveau. The most important keysource is N_2O emission from agricultural soils, which contribute with 8% of the total national GHG emission.

Table 6.3 Key source identification from the agricultural sector 2002 (Annex 1)

CRF table	Compounds	Emission source	Key source identification
4.A	CH_4	Enteric fermentation	Level/trend
4.B(a)	CH_4	Manure management	Level
4.B(b)	N_2O	Manure management	Level
4.C	CH_4	Rice cultivation	Not occurrence
4.D	N_2O	Direct N_2O emission from nitrogen used in agriculture	Level/trend
4.D	N_2O	Direct N_2O emission from agricultural soils	Level/trend
4.E	CH_4/N_2O	Burning of savannas	Not occurrence
4.F	CH_4/N_2O	Field burning of agricultural residues	Not occurrence

6.2 CH_4 emission from Enteric Fermentation - Table 4.A

6.2.1 Description

The majority of the CH_4 emission origins from enteric fermentation. 28% of the Danish GHG emission from agricultural activities originates from enteric fermentation (CRF table 4.). The emission is primarily related to the ruminants and in Denmark particular from the production of cattle, which in 2002 contribute with 86% of the emission. The emission from the pig production is the second largest source and contributes with 10% of total (figure 6.3).

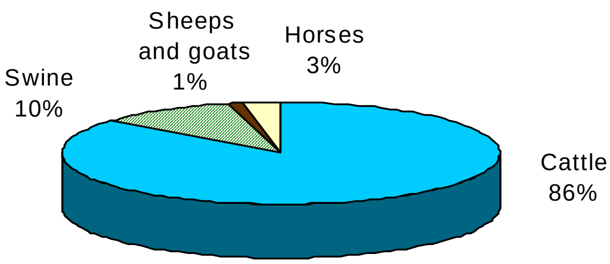


Figure 6.3 Emission from enteric fermentation 2002

6.2.2 Methodological issues

6.2.2.1 Implied emission factor

The implied emission factor for all animal categories is based on a Tier 2 approach. The feeding consumption for all animal categories is based on the Danish norm figures (Poulsen *et al*. 2001). The norm data are based on actual efficacy feeding controls or actual feeding plans at farm level collected by DAAC or DIAS. For cattle approximately 20% of the herd is included and for pigs app. 35% of all pigs are included. The data are given in Danish feeding units or kg feed stuff and converted to Mega Joule (MJ). Default values for the methane conversion rate (Y_m) given by IPCC are used. In CRF table 4.A. in category "Non-dairy Cattle" 6% is mentioned, however, 4% is used for estimating the emission from rearing of bull calves. In the CRF food intake for some categories is given per produced unit and therefore not comparable with the default values given in IPCC. In the next CRF this will be converted to an average daily feed per head.

In Table 6.4 is shown the implied emission factor for cattle and pigs. Due to changed data for feeding consumption and stable type distribution the implied emission factor may vary between the years. The category "Non-Dairy Cattle" includes calves, heifer, bulls and suckler cows and the implied emission factor is a weighted average of these different subcategories. The category "Swine" (pigs) includes sows, piglets and slaughtering pigs.

The increasing emission factor for dairy cattle is a result of an increasing milk yield in average from 6200 litre per cow per year in 1990 to 7500 litre per cow per year in 2002 (Statistics Denmark). The emission factor for "Non-Dairy cattle" is due to different numbers in the different subcategories and changed feeding data. The implied emission factor for pigs is almost at the same level as in 1990. Improved fodder efficacy for slaughtering pigs has result in lower implied emission factor for slaughtering pigs, but on the other hand there has been an increase in fodder consumption for sows due to more piglets per sow.

The enteric emission from poultry and fur farming is seen as non-significant.

Table 6.4 Implied emission factor – Enteric Fermentation 1990 – 2002 (CRF)

		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
CRF - Table 4.A							Kg CH_4/head/yr							
1.a	Dairy Cows	109.48	109.56	109.63	109.71	116.21	116.32	116.39	116.45	117.22	117.20	117.23	117.22	117.95
1.b	Non-Dairy Cattle	33.72	33.95	34.12	34.34	34.24	34.39	34.44	34.79	34.78	35.22	35.42	35.58	35.80
3.	Sheep	17.17	17.17	17.17	17.17	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	13.15	13.15	13.15	13.15	13.15	13.15	13.15	13.15	13.15	13.15
6.	Horses	23.90	23.90	23.90	23.90	23.90	23.90	23.90	23.90	23.90	23.90	23.90	23.90	23.90
8.	Swine	1.07	1.10	1.12	1.10	1.10	1.07	1.11	1.10	1.10	1.13	1.11	1.07	1.08
9.	Poultry	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
10.	Other -fur farming	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE

6.2.2.2 Activity data

The numbers of animals are given in the Agricultural Statistic (Statistics Denmark). For slaughtering pigs and poultry is used the production level (produced numbers) instead of the number given in the census. This to improve the emission estimates. Only farms larger than 5 hectares are included in the annual census. An approximate number of sheep, poultry and horses on these smallholdings are added to the number in the Agricultural Statistics in agreement with DAAC. The largest difference is found for horses. In the Agricultural census the number is estimated 40000 horses. The total number of horses in 2002 - including horses placed on small farms and riding schools are approximately 153000.

Buffalo, camels and llamas, mules and donkeys do not occur in Denmark.

6.2.3 Uncertainties and time-series

The uncertainty of CH_4 emission from enteric fermentation is estimated to 20%, which corresponds to the uncertainty given in IPCC using Tier 2 approach. The uncertainty for the livestock production is relative small and estimated to 0.9% for cattle and pigs by Statistics Denmark. The uncertainties of the emission factor depends on the variations in fodder consumption, energy content in fodder and the methane conventions factor, which are estimated to 20%.

In table 6.5 is given the development in number of animal (from the census) from 1990 to 2002 and in table 6.6 is given the total emission from enteric fermentation. The emission from enteric fermentation is decreased by 10% from 1990 to 2002, which is primarily related to a decrease in the number of cattle from 753000 dairy cattle in 1990 to 610000 in 2002. The number of pigs has increased from 9.5 mio. in 1990 to 12.7 mio. in 2002, but the increase has only minor importance on the emission of CH_4 from enteric fermentation.

Table 6.5 Number of animals from 1990 to 2002 (CRF)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
							1000 head						
Dairy Cattle	753	742	712	714	700	702	701	670	669	640	636	623	610
Non-Dairy Cattle	1 486	1 480	1 478	1 481	1 405	1 388	1 393	1 334	1 308	1 247	1 232	1 284	1 187
Sheep	92	107	102	88	80	81	94	78	83	83	81	92	74
Goats	8	9	9	9	9	9	9	10	10	10	10	11	11
Horses	135	137	138	140	141	143	144	146	147	149	150	152	153
Swine	9 497	9 783	10 455	11 568	10 923	11 084	10 842	11 383	12 095	11 626	11 922	12 608	12 732
Poultry	16 249	15 933	19 041	19 898	19 852	19 619	19 888	18 994	18 674	21 010	21 830	21 236	20 580
Other - fur farming	2 264	2 112	2 283	1 537	1 828	1 850	1 918	2 212	2 345	2 089	2 199	2 304	2 422

Table 6.6 Emission of CH_4 from Enteric Fermentation 1990 – 2002 (CRF)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
							Gg CH_4						
Dairy Cattle	82.45	81.25	78.05	78.35	81.29	81.71	81.55	78.06	78.43	75.03	74.50	73.07	71.90
Non-Dairy Cattle	50.11	50.24	50.42	50.87	48.12	47.73	47.96	46.40	45.51	43.92	43.66	45.67	42.47
Sheep	1.58	1.83	1.76	1.52	1.37	1.39	1.62	1.34	1.43	1.42	1.40	1.59	1.27
Goats	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.14	0.14
Horses	3.23	3.26	3.30	3.33	3.37	3.41	3.44	3.48	3.51	3.55	3.59	3.62	3.66
Swine	10.14	10.74	11.74	12.71	12.03	11.91	12.03	12.53	13.28	13.09	13.26	13.52	13.79
Poultry	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Other - fur farming	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Total Gg CH_4	147.61	147.44	145.39	146.89	146.32	146.27	146.72	141.93	142.29	137.13	136.52	137.60	133.23
Total Gg CO_2-eqv.	3 100	3 096	3 053	3 085	3 073	3 072	3 081	2 981	2 988	2 880	2 867	2 890	2 798

6.3 CH_4 and N_2O emission from Manure Management - Table 4.B(a)

6.3.1 Description

The emission of CH_4 and N_2O from manure management is given in table 4.B(a) and 4.B(b). This source contributes with 15% of the total emission from the agricultural sector in 2002 and the major part of the emission originates from the production of cattle and swine.

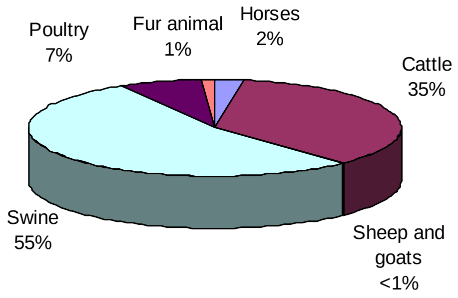


Figure 6.4 Emission of CH_4 and N_2O from manure management in 2002 given in CO_2-eqv.

6.3.2 Methodological issues

6.3.2.1 CH_4 emission

IPCC methodologies Tier 2 approach is used for estimating the CH_4 emission related to manure management. The amount of manure is calculated for each stable type and estimated as: feed consumption minus the digestibility of the feeding stuff for each group of animals plus straw amendments in the different stable types (Poulsen *et al*. 2001). The straw amendments differ between stable type. The feed consumption (Poulsen *et al*. 2001) includes energy for maintenance, pregnancy and growth. Standard ash figures are used. Default values given in IPCC guidelines for the methane production B_o and MCF are used. Background data is given in Annex 3 table A. For liquid systems the MCF in Good Practice Guidance has been changed from 10% to 39% for cold climates. Massé *et al*. (2003) and Husted (1994) has for a climatic condition like Denmarks obtained MCF values around 10% for slurry and hence Denmark continues to use 10% as MCF.

In table 6.7 is shown the development in the implied emission factor from 1990 to 2002. The implied emission factor for dairy cattle has increased as a result of a growing milk yield, but also because of changes in stable type. Old tied-up stables with solid manure have been replaced by loose-holdings with slurry based systems. The MCF for liquid manure is ten times higher than solid manure.

For non-dairy cattle there has been an opposite development where an increasing part of the bull-calves is raised in stables with deep litter.

For pigs there has been the same development as for dairy cows with less solid manure and more slurry based systems.

At present it is not possible to registered the emission from fur farming in table 4.B(a). The CRF format, used for the next reporting gives an opportunity to include emission from other categories – e.g. fur farming.

Table 6.7 Implied emission factor – Manure Management 1990 – 2002 (CRF)

CRF		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Table 4.B(a)									Kg CH_4/head/yr					
1a	Dairy Cattle	13.69	14.11	13.57	13.98	14.50	14.68	15.39	14.33	14.59	14.04	16.38	16.99	17.26
1b	Non-Dairy Cattle	2.20	2.09	2.02	1.95	1.87	1.79	1.76	1.72	1.68	1.70	1.67	1.67	1.62
3	Sheep	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
4	Goats	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
6	Horses	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.74
8	Swine	2.25	2.39	2.51	2.49	2.52	2.48	2.59	2.60	2.61	2.71	2.66	2.57	2.59
9	Poultry	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01
*	Other – fur farming	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE

* The new CRF format gives possibility to implement emission from "other" animal categories. Emission from fur farming will be implemented in the inventory for 2003.

Biogas plants using animal slurry reduce the emission of CH_4 and N_2O (Sommer *et al.* 2001). In 2002 there were 20 common facilities and 50 individual farm facilities. The common facilities account for 88% of the treated slurry in 2002 (DEA, personal comm.). In 2002 about 4%, or 0.64 mio. tonnes of cattle slurry and 0.78 mio. tonnes of pig slurry were treated in biogas plants. The reduction in the CH_4 emission is based on model calculations for an average size biogas plant with a capacity of 550 m^3 per day. For methane a reduction in the emission of methane of 30% for cattle slurry and 50% for pig slurry is obtained (Nielsen *et al*. 2002, Sommer *et al.* 2001). Due to the biogas plants the total emission of CH_4 is reduced with 0.82 Gg CH_4 corresponding to 2% reduction.

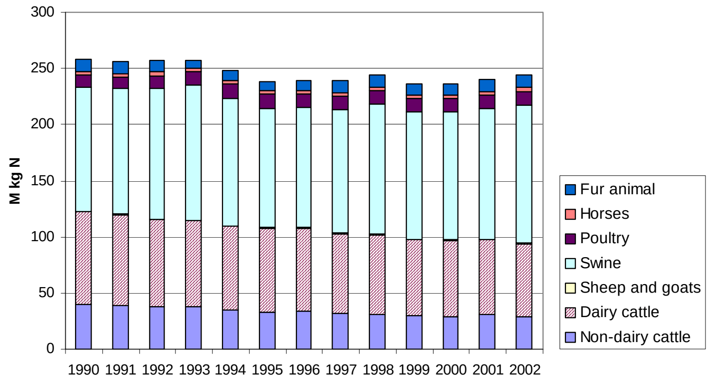
6.3.2.2 N_2O emission

The N_2O emission from manure management is based on the amount of nitrogen in the manure. The IPCC default emission values are applied – i.e. 2.0% of the N-excretion for solid manure, 0.1% for liquid manure and 0.5% from poultry in stable system without bedding. Nitrogen from poultry without bedding contributes less than 1% of the total amount of nitrogen in manure.

The total amount of nitrogen in the manure has decreased by 5% from 1990 to 2002 (table 6.8). The excretion rates in table 6.8, is a weighted value for the different subcategories. Especially the improvement in fodder efficiency for swine has increased the N-excretion per animal. N-excretion from the swine production contributes with a still increasing part of the total N-excretion (figure 6.5).

Table 6.8 Nitrogen excretion rates per head, 1990 – 2002 (CRF)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Table 4.B(b)							Kg N/head/yr						
Animal categories													
Non-dairy cattle	36.57	36.68	36.80	36.92	36.64	36.56	36.62	36.74	36.77	37.00	37.15	37.72	37.77
Dairy cattle	129.49	128.63	127.76	126.89	126.06	125.22	125.09	124.94	124.82	124.60	125.31	124.91	126.70
Sheep*	21.18	21.33	21.47	21.61	21.76	21.90	20.11	18.32	16.53	14.75	16.95	16.95	16.93
Swine	11.62	11.43	11.17	10.40	10.38	9.62	9.89	9.74	9.65	9.83	9.63	9.30	9.71
Poultry	0.65	0.66	0.58	0.59	0.66	0.62	0.60	0.62	0.62	0.57	0.55	0.57	0.59
Horses	48.89	47.77	46.66	45.54	44.42	43.31	43.31	43.31	43.31	43.31	43.31	43.31	43.31
Fur farming	490	4.83	4.80	4.75	4.70	4.65	4.66	4.65	4.64	4.63	4.63	4.62	4.61
								M kg N/yr					
N-excretion, total	293	291	293	293	283	274	275	274	279	270	270	274	277



* Mother sheep including lambs. The category includes goats.

Figure 6.5 The N-excretion distributed on animal categories 1990 – 2002

The reduction of N_2O in relation to the biogas production is not included in the inventory. It is expected this will reduce the emission with 1%. This reduction will be implemented in the emission inventory for 2003.

6.3.3 Uncertainties and time-series

The uncertainty of CH_4 and N_2O emission from manure management is estimated to 10% for the activity data and 500% for the emission factor. The high uncertainty is particular connected to the emission factor for N_2O. The data used for estimating the CH_4 emission is based on Tier 2 approach and reflects the Danish conditions. There is a need for a more accuracy quantifying of the uncertainties based on expert judgement.

As mentioned above the N_2O emission has decreased. Nevertheless, the total emission from manure management in the period from 1990 to 2002 has increased with 10% due to development in the CH_4 emission (table 6.9).

Table 6.9 Emission of N_2O and CH_4 from Manure Management 1990 – 2002 (CRF)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
							Gg N_2O						
N_2O emission													
Liquid manure	0.31	0.31	0.31	0.31	0.30	0.28	0.28	0.28	0.29	0.28	0.29	0.29	0.30
Solid manure	1.90	1.90	1.91	1.91	1.86	1.80	1.80	1.81	1.85	1.79	1.69	1.70	1.65
Total Gg N_2O	2.21	2.20	2.22	2.21	2.15	2.09	2.09	2.10	2.14	2.07	1.98	1.99	1.95
Total Gg CO_2-eqv.	686	683	687	686	668	647	647	649	662	640	613	618	605
CH_4 emission													
Total Gg CH_4	35.35	37.06	39.53	42.07	41.01	40.92	41.52	42.04	43.74	43.16	44.61	45.51	46.01
Total Gg CO_2-eqv.	742	778	830	884	861	859	872	883	919	906	937	956	966
Total Manure Management Gg CO_2-eqv.	1428	1461	1517	1570	1529	1506	1519	1532	1581	1546	1550	1574	1571

6.4 N_2O emission from Agricultural Soils - Table 4.D

6.4.1 Description

The N_2O emission from agricultural soils given in table 4.D, contribute with 57% of the total emission from the agricultural sector in 2002. Figure 6.6 shows the distributions of the different sources. The main part origins as direct emission of which the largest sources are manure and fertiliser applied on agricultural soil. Another large source is the indirect N_2O emission, where emission from nitrogen leaching is essential. The category "Other" includes emission from sewage sludge and sludge from the industry used as fertiliser.

The emission from agricultural soils includes only N_2O emission. In table 4s2 it is also an opportunity to register the CH_4 emission in connection with agricultural soils, however no estimates have been made yet.

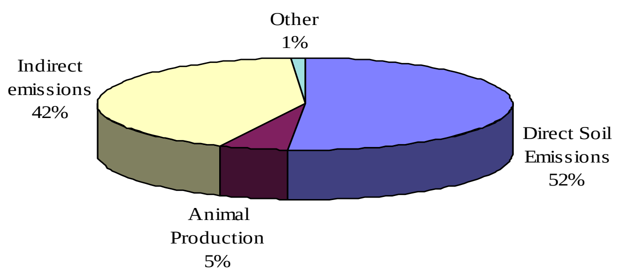


Figure 6.6 N_2O emission from agricultural soils 2002.

6.4.2 Methodological issues

Emissions of N_2O are closely related to the nitrogen balance.

The IPCC Tier 1a methodology is used to calculate the N_2O emission. The emission factors for all sources are based on the default values given in IPCC. National data for the evaporation of ammonia from the ammonia inventory is applied. A survey is given in table 10. The estimated emission from the different subsources is shortly described in the following text.

Table 6.10 Emission factor - N_2O emission from Agricultural Soils 1990 - 2002

Agricultural soils – table 4.D	Ammonia emission	N_2O emission
		kg N_2O -N/kg N
1. Direct Soil Emissions		
Synthetic Fertiliser applied to soils	NH_3 emission = 2%	0.0125
Animal Wastes Applied to Soils	NH_3 emission = (31-25%)	0.0125
N-fixing Crops		0.0125
Crop Residue		0.0125
Cultivation of Histosols		8 kg N_2O-N/ha
2. Animal Production	NH_3 emission = 7%	0.02
3. Indirect Soil Emissions		
Atmospheric Deposition		0.01
Nitrogen Leaching and runoff		0.025
4. Other		
Industrial Waste used as Fertiliser		
Sewage sludge used as Fertiliser		0.0125

6.4.2.1 Direct Emissions

Manure applied to soil

The amount of nitrogen applied on soil is estimated as the N-excretion in the stable minus the emission of ammonia – both are calculated in the ammonia emission inventory. The total N-excretion from 1990 to 2002 is decreased with 6%. Despite the reduction in N-excretion the amount of nitrogen applied on soil is nearly unaltered, which is due to a reduction in the ammonia emission. The percentage of volatile ammonia emission is decreased from 31% in 1990 to 25% in 2002.

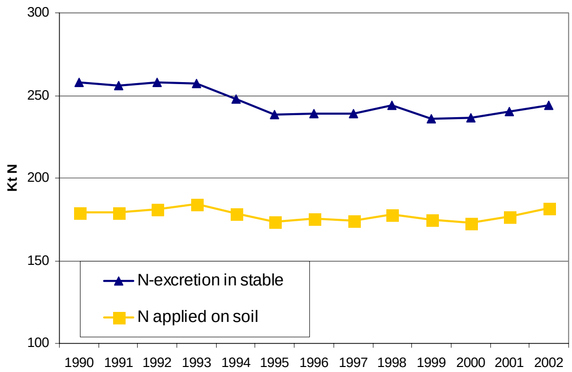


Figure 6.7 Amount of nitrogen excreted and applied on agricultural soil 1990 – 2002

Synthetic fertiliser

Nitrogen applied on soil by used of synthetic fertiliser is based on sale estimates by the Danish Plant Directorate, minus the ammonia emission based on estimate from the DIAS (Sommer *et al.* 1992, 1994 and 1996). The Danish value for the FracGASF is considerably lower i.e. 0.02 than given in IPCC (0.10). This is probably due to a small consumption of urea (<1%), which has high emission factor.

The use of mineral fertiliser includes fertiliser used in parks, golf courses and private gardens. Approximately 1-2 percent of the mineral fertiliser can be related to this use out side the agriculture area.

N-fixing crops

To estimate the emission from N-fixing crops IPCC Tier 1b is applied. The calculated emission is based on nitrogen content, the fraction of dry matter and the content of protein for each harvest crop type. Data for crop yield is based on Statistics Denmark. For nitrogen content in the plants the data is taken from Danish feedstuff tables (Danish Agricultural Advisory Centre). The estimates for the amount of fixed nitrogen in crops is made by a model developed by Danish Institute of Agricultural Science (Kristensen 2003, Høgh-Jensen *et al*. 1998, Kyllingsbæk 2000).

In Table 6.11 is given the background data for estimating the N-fixing. The main part of the emission origins from fields with grass and clover.

Table 6.11. Emission from N-fixing crops 2002

Nitrogen fixing crops			N-fixing		
	Dry matter Fraction	N-Fraction	Variations 1990-2002 kg N/ha	2002 kg N/ha	2002 Kg N fix total
Pulses*	0.85	0.0337	96-179	139	5 572
Lucerne	0.21	0.0064	307-517	449	1 600
Cereals and pulses for green fodder	0.23	0.0061	16-38	23	2 598
Pulses, fodder cabage etc.	0.23	0.0061	0-1	0	50
Peas for canning*	0.85	0.0337	76-139	111	480
Seeds for sowing	NE	NE	181-186**	182	757
Grass and clover field in rotation	0.13	0.0052	41-94	90	19 685
Grass and clover outside rotation	0.13	0.0052	6-11	9	1 515
Aftermath	0.13	0.0052	6-15	6	1 590
Total N-fix					33 846

* Dry matter content for straw is 0.87 and the N-fraction is 0.010.
** Assumed that N-fix for red clover is 200 kg N/ha and 180 kg N/ha for white clover.

Crop Residue

N_2O from crop residues is calculated as the total aboveground amount of crop residues returned to soil. For cereals the aboveground residues are calculated as the amount straw plus stubble and husks. The total amount of straw is given in the annual census and reduced with the amount used for feeding, bedding and biofuel in power plants. In the calculation is straw for feeding and bedding subtracted because these amounts of nitrogen removed and some part later on returned to the soil via manure. Data for stubble and husks are provided by Danish Institute of Agricultural Sciences.

Cultivation of Histosols

It is assumed that 10% of the organic soils are in rotation, which in Denmark is equivalent to 18400 ha. This area has been estimated to the same level all years. At present no knowledge is available to make a better identifications of the histosols. In connection with the implementation of land use in the LULUCF in 2004 new from estimates for histosols will be provided.

6.4.2.2 Animal Production

The amount of nitrogen deposit on grass is based on values from the ammonia inventory. It is assumed that 15% of the nitrogen from dairy cattle in average is excreted on grass. The N-excretion is not differing significantly from 1990 to 2002. An emission factor by 7% is used for all animal categories based on investigation from the Netherlands and United Kingdom (Jarvis *et al*. 1989a, Jarvis *et al*., 1989b and Bussink 1994).

6.4.2.3 Indirect Emissions

Atmospheric Deposition

Atmospheric deposition includes all ammonia emissions sources corresponding to the ammonia emission inventory (Hutchings *et al.* 2001). This mean also emission from crops and from ammonia treated straw is taken into account.

Table 6.12. Ammonia emission 2002 (DIEMA)

Emission of ammonia	2002
	Tonnes NH_3-N
Manure	64 259
Synthetic fertiliser	4 593
Crops	11 108
NH_3 treated straw	774
Sewage sludge and industrial waste	66
Emission total	80 801

Nitrogen leaching and Run-off

Nitrogen leaching and run-off from 1986 to 2003 has been recalculated by DIAS in 2003 in connection with a new action plan on the aquatic environment. The calculation is based on two different model predictions, SKEP/Daisy and N-Les2 (Børgesen and Grant, 2003). The result of these two calculations differs only marginally. The average of these two model predictions is used in the estimated the emission from 1990 to 2002. Since 1990 the use of mineral fertiliser has been reduced with more than 50% and the leaching too.

Figure 6.8 shows the estimated leaching in relation to the nitrogen input from mineral fertiliser, nitrogen in manure and sludge. As it can be seen an average leaching percentage is decreasing from 38% to 34%.

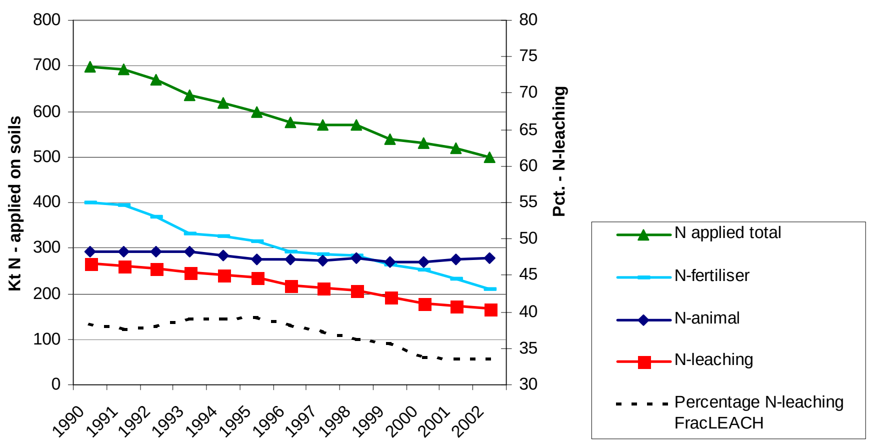


Figure 6.8 Nitrogen applied on agricultural soils and N-leaching from 1990 to 2002

6.4.2.4 Other Emissions

Under the category of "Other" is mentioned nitrogen from industrial waste and sewage sludge used as fertiliser. The amount of nitrogen applied on agricultural soils from these sources is minus the ammonia emission. Information about industrial waste, sewage sludge and the content of nitrogen is given from the Danish Environmental Protection Agency. It is assumed that 1.9% of N-input will volatile as ammonia due to that a great part of N is organically bound in the waste.

6.4.3 Uncertainties and time-series

Uncertainties for the activity data to estimate the emission from agricultural soils are estimated to 20%. The uncertainties are mainly related to estimation of sources from N-leaching. The emission factors for N_2O is based on IPCC default values. These values are connected with high uncertainties as a result of different soil types and climatic conditions. The default values does not necessary correspond the Danish conditions. The estimate of 95% confidence limit range is between 0.25% to 6% as given in IPCC Guidance (2000). Therefore the uncertainties for the emission factor of agricultural soils and manure management are estimated to 500%.

The N_2O emission from agricultural soils has been reduced by 30% from 1990 to 2002. This is mainly due to a decrease in use of synthetic fertiliser and a decrease in N-leaching, as a result of the National environmental policy, where action plans has focused on improvement of the nitrogen utilisation.

Table 6.13 Emission of N_2O from Agricultural Soils 1990 – 2002 (CRF)

CRF – table 4.D	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
							Gg N_2O						
Total N_2O emission	26.76	26.27	25.29	24.61	23.98	23.41	22.30	22.04	21.91	20.56	19.83	19.38	18.60
1. Direct Emissions	13.45	13.22	12.50	12.05	11.76	11.51	11.07	11.12	111.9	10.53	10.31	10.02	9.55
Synthetic Fertiliser	7.69	7.59	7.10	6.39	6.25	6.06	5.58	5.53	5.44	5.05	4.83	4.49	4.05
Animal Waste Applied	3.51	3.52	3.56	3.62	3.50	3.41	3.45	3.42	350	3.43	3.40	3.48	3.58
N-fixing Crops	0.88	0.77	0.65	0.83	0.79	0.73	0.71	0.86	0.95	0.77	0.76	0.71	0.66
Crop Residue	1.13	1.10	0.95	0.98	0.99	1.08	1.10	1.08	1.08	1.05	1.08	1.11	1.03
Cultivation of Histosols	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
2. Animal Production	1.01	1.03	1.03	1.05	1.03	1.04	1.05	1.02	1.01	0.99	0.99	1.01	0.96
3. Indirect Emissions	12.22	11.91	11.63	11.33	11.02	10.68	10.01	9.74	9.53	8.88	8.37	8.14	7.86
Atmospheric Deposition	1.72	1.66	1.64	1.59	1.53	1.45	1.39	1.38	1.40	1.33	1.32	1.31	1.27
N-leaching and Run-of	10.50	10.24	9.99	9.74	9.49	9.23	8.62	8.35	8.13	7.56	7.05	6.84	6.59
4. Other	0.09	0.11	0.13	0.18	0.17	0.18	0.18	0.16	0.17	0.15	0.17	0.21	0.22
Industrial Waste	0.03	0.05	0.06	0.09	0.09	0.09	0.09	0.09	0.10	0.08	0.10	0.14	0.15
Sewage sludge	0.06	0.06	0.07	0.10	0.09	0.09	0.09	0.08	0.07	0.07	0.07	0.07	0.07

6.5 NMVOC emission

Less than 1% of the NMVOC emission origins from the agricultural sector. The method for estimating the emission of NMVOC from agricultural soils is not consistent - the emission needs to be estimated. The emission factor for arable land crops and grassland are 393 g/ha and 2120 g/ha, respectively.

6.6 Uncertainties

Table 14 shows the estimated uncertainty for certain emission sources, which is based on expert judgement (Olesen *et al*. 2001, Gyldenkærne, pers. comm., 2004). The uncertainties for number of animals and hectares grown with different crops are very small. The uncertainty for activity data in connection to enteric fermentation is estimated to 2%, 10% for emission from manure management and 20% for emission from agricultural soils. The uncertainties concerning the emission factors are estimated to 20% for emission from enteric fermentation and 500% for both manure management and agricultural soils, which is mainly related to the N_2O emission.

There is a need to improve the calculation of uncertainties – especially for sources, which contributes significantly to the total emission from the agricultural sector.

Table 6.14 The estimated uncertainty associated with activities and emission factor for CH_4 and N_2O

Source	Emission	Uncertainty[1]		Quantitative estimation of uncertainy[2]	
		Activity data	Emission factor	Activity data	Emission factor
4.A Enteric Fermentation	CH_4	*	*	2%	20%
4.B Manure Mangement				10%	500%
	CH_4 – table 4.B(a)	*	**	10%	30%
	N_2O – table 4.B(b)	*	***	10%	500%
4.D Agricultural Soils	N_2O			20%	500%
1. Direct soil emissions					
1a. Syntehetic Fertilizer		*	***		
1.b Animal waste applied to soils		*	***		
1.c N-fixing crops		*	***		
1.d Crop Residue		*	***		
1.e Cultivation of histosols		**	***		
2. Animal production		*	***		
3. Indirect soil emissions					
3.a Atmospheric deposition		*	***		
3.b Leaching and runoff		**	***		
4. Other					
Sewage sludge and industrial waste used as ferilizer		*	***		
Agricultural soils	NMVOC	*	***		

[1] Olesen et al., 2001

[2] Gyldenkærne pers. comm., 2004 (The uncertainties values is used in a uncertainty estimate for total national emission)

* uncertainty < 20%,

** uncertainty 20-50%

*** uncertainty > 50%

6.7 Quality assurance and quality control - QA/QC

To ensure the consistency in the inventory certain time series has been worked out for both the activity data and emission factor. Considerable variations over the years can reveal miscalculations or changes in methods. These variations is checked and explained or errors have been revised.

Activity data and emission factors are collected and discussed in corporation with specialists and researcher at different institutes and research sections (table 2). As a consequence both the data and methods are evaluated continuously according to the latest knowledge and information.

6.8 Recalculation

In connection with the implementation of a comprehensive emission module (DIEMA) a recalculation of the previous emission has taken place. In the recalculation, the remarks pointed out by the UNFCCCs review team has also been taken into account. The recalculation has lowered the emission level of GHG emission from the agricultural sector by approximately 10% compared to previous emission inventory given in CO_2-eqv. This is mainly due to Changes in the N_2O emission.

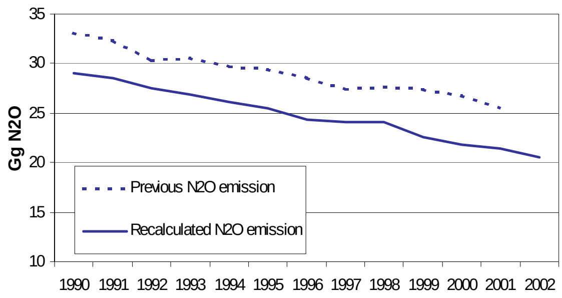
The previous estimated reduction in the GHG emission from 1990 to 2002 is almost unaltered approximately 18-20%.

Table 6.15 Changes in GHG emission in the agricultural sector compared to CRF reported last year

GHG emission	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
							Gg CO_2-eqv.						
Previous emission	14 348	14 096	13 441	13 618	13 174	13 111	12 803	12 354	12 460	12 083	11 868	11 550	
Recalculated emission	12 826	12 702	12 411	12 285	12 036	11 834	11 514	11 346	11 360	10 800	10 564	10 470	10 134
Change Gg CO_2-eqv.	-1 523	-1 394	-1 030	-1 333	-1 139	-1 277	-1 288	-1 008	-1 100	-1 283	-1 304	-1 080	
Change in pct.	-11	-10	-8	-10	-9	-10	-10	-8	-9	-11	-11	-9	

The emission of N_2O is in average for 1990 to 2002 about 15% lower than estimated in previous emission inventory (figure 6.7). The reduction is mainly related to an error in the calculation for crop residues where the nitrogen content in crop residues in the previous inventory was too high. This is now corrected in connection with a change in method from Tier 1a to Tier 1b. Another change, which has influenced the N_2O emission considerably, is an updating of the emission from N-leaching made by DIAS.

In the previous inventory changes in the CH_4 emission only reflects changes in the number of animal and in some cases changes in distribution of subcategories. In the recalculated inventory where Tier 2 is used for all animal categories, the development of the emission furthermore taken changed in fodder- and stable conditions into account. Unlike the previous emission inventory, there is no reduction in the estimated CH_4 emission from 1990 to 2001. The emission from enteric fermentation has decreased caused by a reduction in the number of cattle. But, on the other hand, the emission from manure management has increased due to the change to more slurry based stable systems, which has a higher emission factor, so the trend for CH_4 emissions from 1990 to 2002 is about zero (figure 6.7).



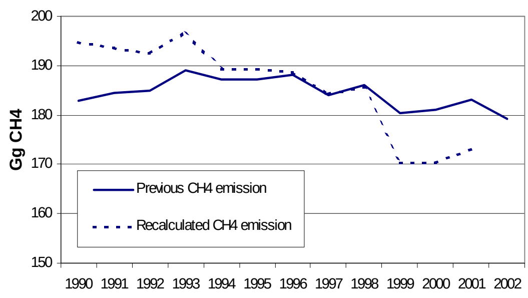


Figure 6.7 Recalculated emissions of CH_4 and N_2O compared to previous emission 1990-2002

Other differences regards to the recalculation between the inventory reported in April 2003 and this inventory can be mentioned:

- The same model based system (DIEMA) used to calculate the ammonia emission from livestock production is also used to estimate the GHG emission. The data used to estimate the N_2O emission is in accordance with the ammonia emission inventory.
- Atmospheric deposition now include ammonia emission from crops, ammonia treated straw and sewage sludge and industrial waste used as fertiliser.
- The review report from UNFCCCs secretariat has pointed an inconsistency regards to the emission factor for N_2O emission from manure management between CRF and NIR. The deviation was due to the ammonia emission, which by a mistake was subtracted. This is now corrected.
- Goats are included in the inventory.
- The emission factor used to calculate the emission from cultivation of histosols is now corrected to 8 kg N_2O-N per ha for all years.
- Reduction in CH_4 as a consequence of biogas treated slurry is now included.
- Recalculation of emission from N-fixing crops are now based on Tier 1b approach.

6.9 Planned improvements

One of the highest priorities for the next emission inventory is implementation of the CO_2 emission from agricultural soils (LULUC). A first estimate for CO_2 emission from liming and cultivation of organogenic soils is estimated (Gyldenkærne and Mikkelsen 2004). But, at present no knowledge is available to estimate the emission in relation to changes in the content of organic matter in agricultural soils, as a consequence of changed in cultivation management. Model development for implementation of LULUC will be finish in 2004 and the results will be implemented in the next inventory.

An another high priority is implementation of a formal QA/QC plan. DIAS will be a major contributor to this.

Furthermore the following issues will be in focus to improve the emission inventory:

- Investigate the possibilities to use national data for N_2O –emissions with priorities on sources, which influence the total emission with a considerably contribute.
- The average daily feed intake given in table 4.A is an expression for the intake per produced unit used to estimate the CH_4 emission from enteric fermentation. This will be changed to an average feed intake per year for each animal category, which are comparably with the default values in IPCC guidelines.
- Include CH_4 emission from manure management from fur animals

- Include reductions of N_2O emission caused to the biogas treated slurry.
- Better uncertainty estimates with priority for emission sources, which have a considerable influence at the total emission.
- Recalculate the NMVOC emissions from agricultural soils.

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7 The Specific methodologies regarding Forestry. CRF Tables 5 and 5A

7.1 Removals by Sinks in Forestry

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7.1.1 Revisions of methodology and other changes since 2003 in relation to reported C sinks in Forestry

Since the submission to UNFCCC in April 2003 only small methodological revisions has been carried out, but this appendix has been amended with more information in response to the latest review.

7.1.1.1 Forests planted before 1990

In this submission, the calculation of net uptake of CO_2 in forests planted before 1990 has been slightly revised. The revision also includes reported net uptake for the years 1990-2001. In previous submissions, the net uptake was calculated using a 10-year average of harvested biomass 1990-1999. Today harvesting data are available for the recent years, so the net uptake is calculated as the 10-year average gross carbon uptake (due to gross increment) minus annual removals due to harvesting. The changes due to the revisions are generally small as the harvested amounts of wood are relatively stable over the period 1990-2002 (see Fig. 1). However, the year 2000 deviates with a low net CO_2 uptake due to the severe storm in Dec. 1999. The windthrow caused by this storm made the harvested amounts of wood in 2000 more than two times higher than in the average year. The storm-felled amount of wood amounted to 3.6 mio. m^3 distributed over about 20000 ha (Larsen and Johannsen, 2002). Gross increment and consequently gross carbon uptake is negatively affected by the windthrow as the age distribution changes towards low productive reforested stands. As in the previous submission, gross carbon uptake in the period 2000-2002 has been adjusted in order to account for this. With the present revision, both gross carbon uptake and carbon loss due to harvesting incorporates the dynamics brought about by the storm damage in Dec. 1999.

In response to the recommendation made by the review team for the 2003 submission, this appendix has included specific figures for gross CO_2 uptake and loss of CO_2 due to harvesting. Net uptake of CO_2 is calculated from these figures. More information has also been included about the increment data from the Forestry Census and the changes in modelling of annual increment for each tree species category. The intention was to improve the transparency regarding the increased uptake reported for forests planted before 1990. In the 2003 submission, reported CO_2 uptake in forests planted before 1990 increased from 916 Gg yr^{-1} to around 3000 Gg yr^{-1}. The revised CO_2 uptake was the result of better data supplied by the most recent Forestry Census. The changes in data and calculations are mentioned in greater detail later in this appendix. In short, the increase in uptake was due to 1) improved modelling of rates of gross increment and 2) use of individual estimates for gross rates of increment and annual harvests to calculate annual net increment. In submissions until 2002, net annual increment was just a roughly suggested figure mentioned in the Forestry Census 1990 (Statistics Denmark, 1994, p 26). This rough estimate of net annual increment was evaluated as being too modest, mainly due to overestimation of total harvests.

7.1.1.2 Afforestation since 1990

Within this category, just one minor revision of the afforestation areas in the years 1999-2001 was done. The Danish Forest and Nature Agency discovered a minor discrepancy in their database on land area of subsidized afforestation projects, and the afforestation areas were consequently slightly reduced. This has had almost no effect on CO_2 uptake in the period 1990-2002.

7.1.1.3 Uncertainty of the reported sinks

In response to the review of the 2003 submission a discussion has been added on the probably high but currently unknown uncertainty for CO_2 uptake in forestry. Uncertainty will be addressed for the inventory data in detail when the first results from the new sample-based National Forest Inventory are available in 2007.

7.1.1.4 Forest inventory data and reference values used in calculations

Standing stocks of wood in 1990 and 2000, and annual increments for the periods 1990-99 and 2000-2002 are all obtained from the Forestry Census of 2000 (Larsen and Johannsen, 2002).

The Forestry Census has been carried out roughly every 10 years and is based on questionnaires to forest owners. Detailed information about the census and the methodology can be found in Larsen and Johannsen (2002), and further documentation is available from Danish Forest and Landscape Research Institute[4]. In short, the estimates of standing volume and volume increments in the Forest Census from 1990 and from 2000 are based on questionnaire information from forest owners on forest area distributed to species and age classes, and information on site productivity. Based on standard yield table functions these input data are used to estimate standing volume and rate of increment for each tree species category.

From 2002, a new sample-based National Forest Inventory has been launched which will replace the Forestry Census. The National Forest Inventory will be complete by 2006, and the first background data for use in the NIR is expected from 2007. This type of forest inventory will be quite similar to inventories used in other countries, e.g. Sweden.

In 1990, the forested area was 411000 ha (= 4110 km^2) or approximately 10% of the land area. The forest area is defined as closed canopy high forest. This means that open woodland and open areas within the forest are not included. Broadleaved tree species made up 35% and coniferous species made up 65% of the forest area. In order to enable comparison with the Forestry Census of 2000, standing stocks of wood in 1990 were recalculated in the new Forestry Census using the same growth models and site indices (Larsen and Johannsen, 2002). The recalculated standing stock of wood was 64.8 mill. m^3 (as opposed to the original estimate of 55.2 mill. m^3) equivalent to 15.77 m^3 per km^2, distributed on 40% broadleaved species and 60% coniferous species. This stock of wood was equivalent to 22425 Gg C or 82225 Gg CO_2.

In 2000, the forested area was 468000 ha or approximately 11% of the land area. The increase in forested area is partly a result of afforestation of former arable land (about 27536 ha) and partly a result of a higher number of respondents in the most recent census. Broadleaved tree species made up 37% and coniferous species made up 63% of the forest area. The standing stock of wood was 77.9 mill. m^3 equivalent to 16.65 m^3 per km^2, distributed on 37% broadleaved species and 63% coniferous species. This stock of wood was equivalent to 26803 Gg C or 98278 Gg CO_2.

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There is no information on applicable expansion factors for Danish conditions. Expansion factors are needed to convert stem volumes for conifers and total aboveground biomass for the broadleaves to total biomass. Therefore, stemwood volumes for conifers are converted to total biomass by an expansion factor of 1.8 based on Schöne and Schulte (1999), and aboveground biomass for broadleaves are converted to total biomass by an expansion factor of 1.2 based on Vande Walle et al. (2001) and Nihlgård and Lindgren (1977). The difference between expansion factors is mainly due to the difference in biomass data for the species categories. The total biomass in m^3 is converted to dry mass by use of tree species-specific wood densities (Moltesen, 1988, see Table 7.1), and carbon content is lastly calculated by using a carbon concentration of 0.5 g C g^{-1} dry mass.

Table 7.1 Wood densities for Danish tree species (Moltesen, 1988).

	Wood denisty (t dry matter/ m^3 fresh volume)
Norway spruce	0.38
Sitka spruce	0.37
Silver fir	0.38
Douglas-fir	0.41
Scots pine	0.43
Mountain pine	0.48
Lodgepole pine	0.37
Larch	0.45
Beech	0.56
Oak	0.57
Ash	0.56
Maple	0.49

The Danish expansion factors and the wood densities result in estimates of C stores that are 46% lower for broadleaves and 20% lower for conifers than when using the IPCC default expansion factor of 1.9 and the volume to dry weight ratios of 0.45 for conifers and 0.65 for broadleaves. The large difference for broadleaves is due to the fact that the reported biomass for broadleaves in the Danish Forestry Census is total aboveground biomass.

The Danish reporting on changes in forest carbon stores only considered the biomass of trees. There is no available systematic information on soil organic carbon for the reporting.

So far, the design of the Danish Forestry Census has not made it possible to quantitatively address *uncertainty* of inventory data used to estimate the reported sink for CO_2 in Danish forests. The uncertainty of the volume and increment estimates in the Forest Census 1990 and 2000 are related to a number of issues: The values of site productivity refer to fully stocked stands, with no border effects and with a given thinning regime. However a number of these issues are uncertain. The stands are not fully stocked as the estimates are based on a 90% stocking but it may be lower. The very fragmented shape of the Danish forest area results in many borders and hence a reduction in the actual productivity on the area as a whole. Furthermore the yield table functions are based on a certain frequency of thinnings which in turn affect the standing volume. With the changing conditions for the forestry sector, these prescriptions are not followed, which in turn may lead to deviations, both positive and negative, from the estimated volume and increment. Further details and alternative estimates can be found in Johannsen (2002) and Dralle et al. (2002).

Other factors also contribute to uncertainty of the reported sinks. As previously mentioned, the lack of national biomass expansion factors or better expansion functions makes the calculation step from biomass to total biomass the most critical in terms of uncertainty. Basic densities of wood from different tree species are better documented and the C concentration is probably the least variable parameter in calculations.

In recognition of the difficulties in analyses of uncertainty, the estimated uptake of CO_2 in the forestry sector must be treated with caution. However, the assessment of uncertainty will improve significantly from 2007 when the new National Forest Inventory can supply the first national estimate of stocks of wood, increment and harvests based on a design with permanent sampling plots and partial replacement. The new design will enable an assessment of uncertainty related to inventory data.

7.1.1.5 Annual CO_2-sequestration in forests planted before 1990.

Net C sequestration in the periods 1990–1999 and 2000-2001 was the result of a net increase in standing stock of the existing forests. Net C sequestration in existing forests is the result of a relatively low and slightly decreasing harvest intensity, especially for conifers, but it is also partly a result of an uneven age class distribution with relatively many young stands.

The estimated gross wood increment for the period 2000–2002 was updated in the most recent questionnaire-based Forestry Census of 2000. Mean annual increments (m^3 ha^{-1}) for the categories of tree species for the periods 1990-1999 and 2000-2009 are provided in the Forestry Census of 2000. For the period 1990-99 a new increment estimate was calculated based on information from the 1990 Forestry Census, since missing information on site productivity now could be replaced by reference values from the State Forests. Further details on the calculation of the estimates can be found in Johannsen (2002).

Annually harvested amounts of wood (Figure 7.1) are obtained from Statistics Denmark (http://www.statistikbanken.dk/). Commercial harvesting was used in calculations for broadleaved species as wood from thinning operations in young stands is sold as fuel wood and therefore appears in the statistics. For conifers, non-commercial thinning operations are more common. In order to account for this, 20% were added to the figures for commercial harvests of coniferous wood.

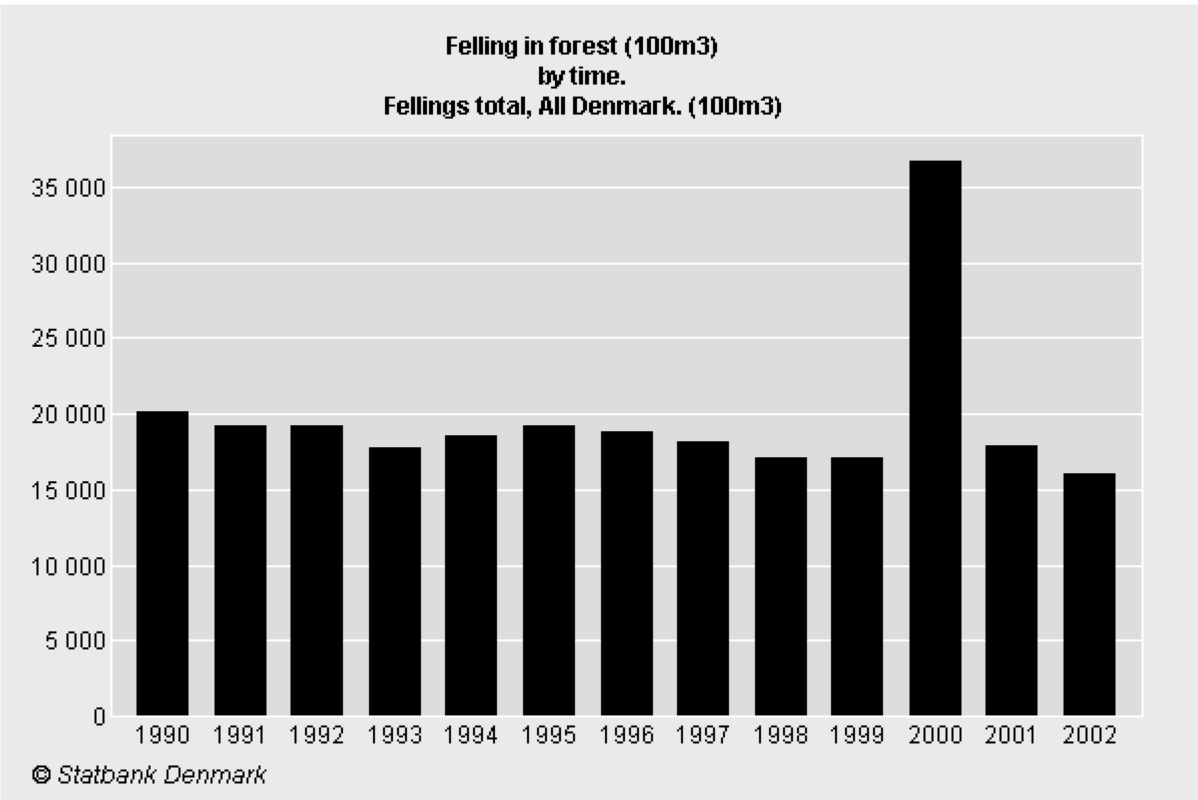

Figure 7.1. Total annual harvests of commercial wood in forests planted before 1990. The peak in 2000 is almost solely due to windthrow of conifers during the storm on Dec. 3, 1999. From http://www.statistikbanken.dk/.

The resulting net annual increment (wood increment minus harvested wood) was around 2.3 mill. m^3 y^{-1} for 1990–1999 and is estimated at around 2.7 mill. m^3 y^{-1} for 2000-2002 (Larsen and Johannsen, 2002). Rates of wood increment are converted to CO_2 uptake by the same method as mentioned above for carbon stocks.

The data on gross uptake of CO_2 due to annual gross increment, annual loss of CO_2 with harvested wood, and the resulting net sink for CO_2 are given in Table 7.2. The resulting net sink for CO_2 in forests existing in 1990 was around 3000 Gg CO_2 yr^{-1} for the period 1990-1999 and somewhat higher (around 3500 Gg CO_2 y^{-1} for the period 2000-2002. In the year 2000 the sink was much lower than in all other years due to the storm in Dec. 1999.

Table 7.2. Data on gross uptake of CO_2, loss of CO_2 due to harvesting (Figure 7.1) and the resulting net annual sink for CO_2 for the period 1990 – 2002 in forests existing before 1990.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Gross uptake of CO_2 Gg yr^{-1})	-5743	-5743	-5743	-5743	-5743	-5743	-5743	-5743	-5743	-5743	-6083	-6083	-6083
Loss of CO_2 in harvested wood (Gg yr^{-1})	2911	2732	2746	2534	2651	2761	2695	2614	2464	2476	5489	2618	2358
Net annual sink for CO_2 (Gg yr^{-1})	-2832	-3012	-2997	-3210	-3092	-2982	-3048	-3129	-3279	-3268	-594	-3465	-3725

In reports to UNFCCC until 2001, the net sink for CO_2 in forests existing in 1990 was reported as 916 Gg CO_2 y^{-1} for the period 1990-1999. The higher sink for CO_2 currently reported for the period 1990-99 is due to the use of more specific data. In submissions before 2001, the applied net annual increment was a rough estimate made in the Forestry Census of 1990. Now, net annual increment is based on specific data for gross increment and annual harvests by tree species category. This change was made in order to make the calculations more transparent. For 2000-2002, the sink for CO_2 was slightly higher than for 1990-1999. This is mainly attributed to the higher number of respondents to the questionnaire, i.e. the included forest area was larger. Annual increment per ha was quite similar for the two periods. The estimated increment in the period 2000-2009 was adjusted in order to account for the forest damage and changed age distribution caused by the storm in Dec. 1999. The loss of increment was estimated at 182,00 m^3 yr^{-1} for the period 2000-2009.

7.1.1.6 CO_2 sequestration by afforestation of former arable land

In 1989 the Danish Government decided to encourage a doubling of the forested area within a tree generation of approximately 80–100 years (Danish Forest and Nature Agency 2000). In order to reach this target, an afforestation rate of roughly 4–5000 ha yr^{-1} is needed, but the afforestation rate has been much lower than needed with an average afforestation rate of 1837 ha yr^{-1} for the period 1990-2002. Afforestation is carried out on soils formerly used for agriculture (cropland). The annually afforested area is specified in Table 7.3. Data on the area afforested 1990-1998 by state forest districts, other public forest owners and private land owners receiving subsidies is based on an evaluation report on afforestation (Danish Forest and Nature Agency, 2000). Area data for the years 1999-2002 are obtained from the records of Danish Forest and Nature Agency. The area afforested by private land owners without subsidies is estimated by subtracting the afforestation categories mentioned above from the total area afforested per year in the period 1990-99 as recorded in the latest Forestry Census (Larsen and Johannsen, 2002). The Forestry Census included

Nordmann's fir plantations for Christmas trees and greenery on arable land as afforestation. These stands made up 40% of the total area afforested 1990-99. The Nordmann's fir plantations were not included in the afforested area used in the Danish LUCF reporting. Firstly, they never become closed forests as the trees are harvested within a ten year rotation, and secondly changes in the market for Christmas trees may force land owners to revert the land use to agriculture after a few years.

The approximate distribution of broadleaved and coniferous tree species is obtained from the Forestry Census of 2000 (Larsen and Johannsen, 2002) for all ownership categories except private landowners receiving subsidies. The tree species distribution for the latter category was obtained from the evaluation report on afforestation (Danish Forest and Nature Agency, 2000).

Full carbon accounting is used in a manner by which C-stock changes are based on area multiplied by uptake. Uptake is calculated using a simple carbon storage model based on the Danish yield tables for Norway spruce (representing conifers) and oak (representing broadleaves) (Møller 1933). The amounts of carbon sequestered in annual cohorts of afforested areas are summed up in the model to give the total carbon storage in a specific year.

Table 7.3 Distribution of afforestation area (ha) on different landowners and tree species. Plantations of Nordmann's fir for Christmas trees and greenery are not included in the afforested area.

Year	State forests	Other publicly owned forests	Private forests with subsidies	Private without subsidies	Total area	Broadleaved	Coniferous
1990	107	12	0	611	730	320	410
1991	300	12	70	611	993	527	466
1992	562	12	70	611	1255	721	534
1993	450	149	70	611	1280	738	542
1994	553	149	178	611	1491	912	579
1995	396	141	178	611	1326	790	536
1996	407	146	212	611	1376	833	543
1997	414	267	968	611	2260	1614	646
1998	146	101	547	611	1405	912	493
1999	358	150	3314	611	4433	3622	811
2000	196	150	1764	611	2721	2092	629
2001	175	158	1181	611	2125	1552	573
2002	200	81	1600	611	2492	1959	533

Wood volumes are converted to carbon stores by the same method as mentioned for carbon stocks in 1990 except that a higher expansion factor of 2 is used for both species categories. The higher expansion factor is used in recognition of the age-dependency of expansion factors. The stem biomass represents a much lower proportion of the total biomass for age classes 1-10, thus a higher expansion factor is needed. However, studies in other countries indicate that an expansion factor of 2 clearly underestimates the total biomass for age classes 1-10 (Schöne and Schulte, 1999). As there are no Danish expansion functions including age, it was chosen to use an expansion factor of 2 as a conservative estimate so far. Here is clearly an area for improvement.

Decomposition rates for the various slash components are included in the model. Carbon storage in wood products may be included in the accounting by use of a module with turnover rates for the various wood products. This option was not included in the calculations of the figures presented here. For more information see Danish Energy Agency (2000).

The following carbon pools were included for afforestation stands: whole tree biomass (including roots), and slash. Based on studies of soils in a chronosequence of afforested stands, no significant changes in soil organic matter was expected to take place during the first 30 years following afforestation (Vesterdal et al., 2002). However, yet unpublished results from an EU project (http://www.fsl.dk/afforest/) indicates that this may not be the case following afforestation at other soil types. But there is currently no systematic data available to explore this further. The yield tables used for calculation of carbon stores are valid for yield class 2 (on a scale decreasing from 1 to 4). There is made no distinction between growth rates on different soil types.

The annual CO_2 uptake and the cumulated CO_2 uptake and afforested area since 1990 are given in Table 7.4. As shown in the table, annual sequestration of CO_2 in forests established since 1990 has gradually increased to 73 Gg CO_2 in 2001, for further details see the Annex. 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.

Table 7.4 Annual CO_2 uptake, cumulated CO_2 uptake and cumulated afforested area (ha) due to afforestation activities 1990–2002.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Annual CO_2 uptake (Gg yr^{-1})	0	-1	-3	-5	-8	-10	-16	-24	-34	-43	-59	-74	-88
Cumulated CO_2 uptake (Gg)	0	-1	-4	-10	-17	-28	-44	-68	-102	-145	-204	-278	-365
Cumulated afforestation area (ha)	730	1723	2978	4258	5749	7075	8451	10711	12116	16549	19270	21395	23887

During the Kyoto commitment period 2008–2012 (5 years), it is estimated that the Danish afforestation activities will result in sequestration of 384 Gg C equivalent to 1408 Gg CO_2. This amount of C results from the afforestation of 49100 ha of former arable land over the period 1990–2012. The sink capacity is based on a conservative estimate of around 2500 ha of land afforested annually 2003-2012, but it is possible that other instruments in addition to subsidisation will make it possible to increase the rate of afforestation and eventually the sequestration of CO_2.

7.1.1.7 Total contribution of forestry

Table 7.5 gives the figures reported in this NIR distributed to the categories *afforestation* and *forests existing prior to 1990*. Afforestation currently contributes little to the total uptake in forestry, but the annual uptake increases as stands enter the stage of maximum rate of increment and as the afforestation area gradually increases.

Table 7.5 CO_2 stores and annual uptake in forests in Gg, 1990–2002. Uptake due to changes in forest biomass stocks in forests planted before 1990 and due to afforestation of former arable land since 1990.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
CO_2 store in all forests	82225										98278		
Total CO_2 uptake in forests	-2832	-3013	-3000	-3215	-3100	-2992	-3064	-3153	-3313	-3311	-653	-3539	-3813
CO_2 uptake in forests existing before 1990	-2832	-3012	-2997	-3210	-3092	-2982	-3048	-3129	-3279	-3268	-594	-3465	-3725
CO_2 uptake due to afforestation since	0	-1	-3	-5	-8	-10	-16	-24	-34	-43	-59	-74	-88

7.1.1.8 Output of Excel model used for calculation of the amounts of CO_2 sequestered due to afforestation since 1990.

		Afforestation area, ha				Total CO2 uptake		CO2 uptake per cumulated area		
Planting year	Years after establish-ment	Broad-leaves	Conifers	Total	Cumu-lated area since 1990	Annual Gg/yr	Cumu-lated Gg	Annual CO2 uptake, t/ha	Annual C uptake, t/ha	Running average CO2 uptake since 1990 Gg/ha
1990	0	320	410	730	730	0	0	0.0	0.00	0.00
1991	1	527	466	993	1723	1	1	0.7	0.20	0.73
1992	2	721	534	1255	2978	3	4	1.0	0.28	0.72
1993	3	738	542	1280	4258	5	10	1.2	0.34	0.75
1994	4	912	579	1491	5749	8	17	1.3	0.36	0.75
1995	5	790	536	1326	7075	10	28	1.5	0.40	0.78
1996	6	833	543	1376	8451	16	44	1.9	0.53	0.87
1997	7	1614	646	2260	10711	24	68	2.2	0.61	0.90
1998	8	912	493	1405	12116	34	102	2.8	0.77	1.05
1999	9	3622	811	4433	16549	43	145	2.6	0.71	0.97
2000	10	2092	629	2721	19270	59	204	3.1	0.83	1.06
2001	11	1552	573	2125	21395	74	277	3.4	0.94	1.18
2002	12	1959	533	2492	23887	88	365	3.7	1.00	1.27

The carbon increment model behind the output tables.

Carbon increment models based on oak and spruce, yield class 2

Based on yield tables in Møller (1933)

		Broadleaves, oak yield class 2				Conifers, Norway spruce yield class 2				
		With products		Without products		With products		Without products		
Year	Age	Increment t CO2/ha/yr	Storage t CO2/ha	Increment t CO2/ha/yr	Storage t CO2/ha	Increment t CO2/ha/yr	Storage t CO2/ha	Increment t CO2/ha/yr	Storage t CO2/ha	Stored wood for bioenergy t CO2/ha
1990	0	0	0	0	0	0	0	0	0	
1991	1	2	2	2	2	1	1	1	1	0
1992	2	2	4	2	4	1	3	1	3	0
1993	3	2	6	2	6	1	4	1	4	0
1994	4	2	9	2	9	1	6	1	6	0
1995	5	2	11	2	11	1	7	1	7	0
1996	6	6	17	6	17	7	14	7	14	0
1997	7	6	24	6	24	7	21	7	21	0
1998	8	6	30	6	30	7	28	7	28	0
1999	9	6	36	6	36	7	35	7	35	0
2000	10	6	43	6	43	7	41	7	41	0
2001	11	9	51	9	51	12	54	12	54	0
2002	12	9	60	9	60	12	66	12	66	0

Tables used to calculate total uptake of CO_2 based on annual cohorts of broadleaved and coniferous stands.

Summation table for cohorts of areas afforested with broadleaves (t CO2)

	Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
	Area	320	527	721	738	912	790	833	1614	912	3622	2092	1552	1959
Year	Age													
1990	0	0												
1991	1	685	0											
1992	2	685	1128	0										
1993	3	685	1128	1543	0									
1994	4	685	1128	1543	1579	0								
1995	5	685	1128	1543	1579	1952	0							
1996	6	2054	1128	1543	1579	1952	1691	0						
1997	7	2054	3383	1543	1579	1952	1691	1783	0					
1998	8	2054	3383	4629	1579	1952	1691	1783	3454	0				
1999	9	2054	3383	4629	4738	1952	1691	1783	3454	1952	0			
2000	10	2054	3383	4629	4738	5855	1691	1783	3454	1952	7751	0		
2001	11	2739	3383	4629	4738	5855	5072	1783	3454	1952	7751	4477	0	
2002	12	2739	4511	4629	4738	5855	5072	5348	3454	1952	7751	4477	3321	0

Summation table for cohorts of areas afforested with conifers (t CO2)

	Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
	Area (ha)	410	466	534	542	579	536	543	646	493	811	629	573	533
Year	Age (yr)													
1990	0	0												
1991	1	566	0											
1992	2	566	643	0										
1993	3	566	643	737	0									
1994	4	566	643	737	748	0								
1995	5	566	643	737	748	799	0							
1996	6	2829	643	737	748	799	740	0						
1997	7	2829	3215	737	748	799	740	749	0					
1998	8	2829	3215	3685	748	799	740	749	891	0				
1999	9	2829	3215	3685	3740	799	740	749	891	680	0			
2000	10	2829	3215	3685	3740	3995	740	749	891	680	1119	0		
2001	11	5092	3215	3685	3740	3995	3698	749	891	680	1119	868	0	
2002	12	5092	5788	3685	3740	3995	3698	3747	891	680	1119	868	791	0

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8 Waste (CRF sector 6)

8.1 Overview of the sector

The source in focus in this sector is the CRF source category 6 is *6.A Solid Waste disposal on Land* and its CH_4 emissions. This source is considered dominant in the sector.

As regards the CRF source category *6.B. Waste-water Handling* the CH_4-emission is considered of negligible importance due to aerobic waste water systems. Also N_2O emission is considered of minor importance. Refer to section 8.3.6.

For the CRF source category *6.C. Waste Incineration* the emissions are included in the energy sector since all waste incinerated in Denmark are used in energy production.

For the source sector *6.D. Other* no activities and emissions are considered.

The CH_4-emission from solid waste disposal on land constitutes a key source category in the key source level analysis. As regards the key source trend analyses it is not a key source since it is number 20 in the list where 18 are keys. In year 2002 it contributes 1.6% to the National total (without LULUCF) and is the seventh most contributing source in the list of 21 key sources in the key source analysis performed in this report (Refer Annex 1).

A quantitative overview of the source category is shown in Table 8.1 below with the amounts of land filled waste, the annual CH_4-emissions from the waste, the CH_4 collected as biogas and used for energy production and the resulting emissions for the years 1990-2002. The amount of waste and the resulting CH_4-emission are to be found as well in the CRF tables of this submission.

The amount of waste deposited has decreased markedly for the time-series. This is a result action plans of the government, the "Action plan for Waste and Recycling 1993-1997" and "Waste 21 1998-2004". The latter plan had inter alia the goal of all waste to recycle 64%, incinerate 24% and deposit 12%. The goal for deposited waste was met in 2000. Further, in 1996 was introduced a municipal obligation to assign combustible waste to incineration.

The decrease of the emission through the time-series is markedly, but much less than the decrease in amount deposited. This is due to the time involved in the processes generating the CH_4, which reflected in the model used for emission calculation.

Table 8.1

Year	Waste	Annual emission	Biogas collected	Annual net emission	
	kt	kt CH4	kt CH4	kt CH4	kt CO2-eqv.
1990	3175,1	64,0	1,7	62,4	1309,8
1991	3032,3	65,3	1,7	63,7	1337,4
1992	2889,6	66,5	1,7	64,8	1361,1
1993	2746,8	67,4	2,8	64,7	1358,1
1994	2604,0	68,2	2,8	65,5	1374,6
1995	1957,0	68,7	6,0	62,7	1316,2
1996	2507,0	68,8	6,6	62,2	1306,1
1997	2083,0	68,6	9,4	59,2	1243,3
1998	1859,0	68,5	10,4	58,1	1220,4
1999	1467,0	68,2	9,9	58,2	1222,9
2000	1482,0	67,8	10,3	57,5	1206,6
2001	1300,0	66,6	10,0	56,6	1188,2
2002	1174,0	65,1	11,2	53,9	1131,3

The amount of gas being collected has increased due to an increase in the installations using the gas in energy production.

8.2 Solid Waste disposal on Land (CRF 6.A)

8.2.1 Source category description

Disposal of waste takes place in Denmark on 135 registered sites (2002). The organic part of the waste deposited at these sites generates CH_4 gas, some of which is collected and used as biogas in energy producing installations at 25 sites (2002).

8.2.2 Methodology

The data used for the amounts of municipal solid waste deposited at solid waste disposal sites, is according to official registration performed by the Danish Environmental Protection Agency in the so-called ISAG database (the latest report on the registration up to year 2002 is Danish Environmental Protection Agency (2004b). CH_4 emissions from Solid Waste Disposal Sites are based on a model suited to the Danish conditions. The model is based on a IPCC Tier 2 approach. The model is unchanged since the NIR2003. In Annex 3.E of this report details on the Methodology on CH_4-emission from solid deposited waste are given.

8.2.3 Uncertainty and time-series consistency

The activity data for is time-series is consistent in the sense that the source for the data for the whole time-series is the registered amount of waste. A registration that has been done since the start of the 1990th in order to measure the effects of action plans.

The consistency of the emission factor comes as a result of the same model run for the whole time-series. The time lag in the model is the same for the whole time-series and is within the interval recommended for a first order decay model in the IPCC guidelines.

For consideration of consistency, refer to the Table 8.1

Uncertainty might come from the use of the same waste composition for the whole times-series. This is a possible item for further analyses

8.2.4 QA/QC and verification

It is a QC-procedure as regards data handling etc when the results of the runs of the model as regards CH_4-emissions are compared/adjusted to the CH_4-emissions in the CRF-tables.

8.2.5 Source specific recalculations

Recalculations have been performed since the April 15 2003 submission. The whole time-series previously submitted was recalculated for two reasons.

For 1996-2001 the emission estimates changed due to adjustments of the waste amounts used in the model. Adjustments of emission are up to 10%.

For 1990-1995 minor corrections of the emission factors were made to make full agreement between activities and emissions reported in the CRF and the First Order Decay model used for the CH_4 emission estimates. Adjustments of emissions are at maximum 1%.

These recalculations were announced in the NIR2003 and noticed by the review team. Further the review team noted that data for the sectoral background Tables of the CRF was not provided. Please refer to those tables for the CRF of this submission where such an improvement has now been made. Further the general improvement of the use of Notation Keys also has been implemented in this sector.

8.2.6 Source specific planned improvements

As regards the recommendation made by the review team to conduct uncertainty analysis it is planned to do so. Further, the consequence of a change in composition of waste during the time-series will be considered.

8.3 Further, source specific planned improvements

The waste water handling sector will be analysed for Denmark in order to estimate and document the CH_4- and N_2O-emissions, which especially for CH_4 is believed to be of only minor importance.

9 Other (CRF sector 7)

Not relevant for Denmark.

10 Recalculations and improvements

10.1 Explanations and justifications for recalculations

The explanations and justifications for recalculations included in this submission and performed since the submission April 15, 2003 are given in the sector chapters, refer to:

Energy:	
• Stationary Combustion	Section 3.2.5
• Transport	Section 3.3.5
• Fugitive emissions	Section 3.5.5
Industry	
• Mineral Products	Section 4.2.5
• Chemical Industry	Section 4.3.5
• Metal Production	Section 4.4.5
• Consumption of F-gases	Section 4.5.5
Agriculture	Section 6.8
LULUCF	Chapter 7
Waste	Section 8.2.5

10.2 Implications for emission levels

For the **National Total CO_2 Equivalent Emissions without Land-Use Change and Forestry** the general impact of the recalculations performed is small. All the differences for this national total for the time-series as taken from the recalculation tables of the CRF tables for 1990-2001 are negative reflecting that this submissions represents slightly smaller National total emissions than previously submitted. The differences vary between a maximum negative difference of 0,86% (1991) and minimum negative difference of 0.14% (2001). Refer to Table 10.1 below.

For the **National Total CO_2 Equivalent Emissions with Land-Use Change and Forestry** also the general impact of the recalculations is small, although they are bigger than without LULUCF due to recalculations in the LULUCF Sector. The differences vary between a maximum negative difference of 3.51% (1991) and maximum positive difference of 3.85% (2000). These extreme differences refer to recalculated estimates with major changes in the forestry sector for those years. Refer to Chapter 7.

Table 10.1 Recalculations performed year 2004 for inventories 1990-2001. National totals with and without LUCF. The percentage difference for National Totals between this and April 15, 2003 submission

	1990			1991		
	Previous submission	Latest submission	Difference	Previous submission	Latest submission	Difference
	CO2 equivalent (Gg)		(%)	CO2 equivalent (Gg)		(%)
Total CO2 Equivalent Emissions with Land-Use Change and Forestry	66.098,59	65.917,86	-0,27	79.239,18	76.458,40	-3,51
Total CO2 Equivalent Emissions without Land-Use Change and Fores	69.216,59	68.749,86	-0,67	80.157,18	79.471,40	-0,86

1992			1993			1994			1995		
Previous submission	Latest submission	Difference	Previous submission	Latest submission	Difference	Previous submission	Latest submission	Difference	Previous submission	Latest submission	Difference
CO2 equivalent (Gg)		(%)	CO2 equivalent (Gg)		(%)	CO2 equivalent (Gg)		(%)	CO2 equivalent (Gg)		(%)
70.337,63	70.258,84	-0,11	73.086,16	72.410,00	-0,93	76.913,31	76.573,07	-0,44	74.207,17	73.963,41	-0,33
73.458,63	73.258,84	-0,27	76.209,16	75.625,00	-0,77	80.039,31	79.673,07	-0,46	77.335,17	76.955,41	-0,49

1996			1997			1998			1999		
Previous submission	Latest submission	Difference	Previous submission	Latest submission	Difference	Previous submission	Latest submission	Difference	Previous submission	Latest submission	Difference
CO2 equivalent (Gg)		(%)	CO2 equivalent (Gg)		(%)	CO2 equivalent (Gg)		(%)	CO2 equivalent (Gg)		(%)
87.644,33	87.214,31	-0,49	77.802,70	77.519,91	-0,36	72.645,31	72.344,39	-0,41	69.588,76	69.241,31	-0,50
90.778,33	90.278,31	-0,55	80.944,70	80.672,91	-0,34	75.797,31	75.657,39	-0,18	72.749,76	72.552,31	-0,27

2000			2001		
Previous submission	Latest submission	Difference	Previous submission	Latest submission	Difference
CO2 equivalent (Gg)		(%)	CO2 equivalent (Gg)		(%)
64.664,04	67.155,16	3,85	65.879,20	65.774,30	-0,16
68.181,04	67.808,16	-0,55	69.410,20	69.313,30	-0,14

10.3 Implications trends, including time series consistency

In the considerations leading to performed recalculations the consistency of the time series back to 1990 ((1993) 1995 for F-gases) is a high priority. As a consequence activity data, emission factors and methodologies are carefully chosen to represent the emissions for the time series correctly. In situations where activity data and/or emission factors for single years have been corrected and leading to a recalculation it is often considerations of the time-series that led to the correction.

It was mentioned in section 10.2 that for the **National Total CO_2 Equivalent Emissions without Land-Use Change and Forestry** the general impact of the recalculations performed is small and that the changes for the whole time-series is between -0.14 and -0.86. Therefor the implications of the recalculations on the trend 1990-2002 of this National Total are small.

However, the small changes on the National Total are an aggregated result of considerable recalculations in different sectors leading to both negative and positive differences comparing this submission with the previous. The result of all recalculations performed is shown in the table below. The differences between this and the previous submission are for all greenhouse gases reported shown in the unit of CO_2-equivalents. Memo items are not shown. The table is made on CRF source categories where recalculations have been performed. Also the difference on the level of National Total without LULUCF is shown, so the contributions for the source categories to the national result on differences can be directly considered in absolute (CO_2-eqv.) values. The table is made out of the recalculation tables in the CRF-tables.

It can be seen from the table that the biggest and major recalculations has taken place for N_2O for Agriculture (4.B. manure management and 4.D. soils) and for N_2O for Industrial processes (2.B. Chemical Industry). These recalculations are explained in the sector chapters. The recalculated sources mentioned are key sources. By coincidence these major recalculations are for Agriculture negative at a size rather close to the positive recalculation for Industry. Especially this is the case for 1990-1997. So the impact on nation total is small for these biggest recalculations.

Next to the biggest recalculations (although included in the table LULUCF is not considered here, refer to chapter 7) are in size the recalculations for CO_2 for Energy (1.A.2. Manufacturing Industries and Construction) with a negative difference for the whole time-series and for CO_2 for Energy (1.A.4. Other sectors) with a positive difference. These recalculations are numerically of comparable size, though 1.A.2. being somewhat bigger. Further, adding to this other smaller negative differences for the Energy Sector leads to a negative difference for CO_2 for the Energy Sector as a whole except for 2001.

Further recalculation of importance in size for the whole series are for CH_4 for Agriculture (4.A. Enteric Fermentation and 4.B. Manure Management). For both these activities the differences are negative for 1990-1994. For 1999-2001 the differences are positive. The net result for CH_4 from Agriculture for 1998-2001 is positive differences and for 1990-1997 negative.

For details on the trend etc of the recalculation performed in the Agricultural Sector refer to section 6.8.

In conclusion the recalculations performed has for some single activities and sectors (Agriculture and Industry) substantial importance for the whole time-series 1990-2001. For the National total the recalculations is rather small and negative, since the single activities recalculated by coincidence to some extend equal out.

Table. Recalculation performed year 2004 for 1990-2001. Differences (CO2-eqv) between this and the April 2003 submission. Memo items not shown

GREENHOUSE GAS SOURCE AND SINK CATEGORIES		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
		CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2
1.A.	Fuel Combustion Activities	-43,3	-130,6	-57,4	-65,9	-73,2	-55,9	-77,0	-87,0	-0,5	25,0	-30,5	8,0
1.A.1.	Energy Industries	-25,3	-32,4	-31,4	-45,7	-34,8	-35,2	-35,9	-38,5	-33,6	-44,2	-50,6	2,0
1.A.2.	Manufacturing Industries and Construction	-221,9	-210,9	-228,0	-229,2	-139,5	-241,0	-238,3	-213,1	-129,5	-147,6	-83,2	-149,2
1.A.3.	Transport	10,9	-59,9	24,1	33,7	41,6	48,1	53,4	58,1	66,0	70,5	73,5	71,8
1.A.4.	Other Sectors	193,0	172,7	177,9	175,3	59,5	172,1	143,8	106,5	96,6	146,3	29,7	83,4
1.B.	Fugitive Emissions from Fuels	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-0,1	0,0
1.B.2.	Oil and Natural Gas	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-0,1	0,0
2.A.	Mineral Products	15,5	16,1	12,4	15,0	8,5	15,0	13,9	29,5	134,5	88,4	73,4	87,0
2.B.	Chemical Industry	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,9	1,4	1,8	2,7	3,1
2.C.	Metal Production	28,4	28,5	28,5	31,0	33,5	38,6	35,2	35,0	42,2	43,0	40,7	46,7
2.G.	Other	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
5.A.	Changes in Forest and Other Woody Biomass Stocks	286,0	-2095,0	121,0	-92,0	26,0	136,0	70,0	-11,0	-161,0	-150,0	2864,0	-8,0
		CH4	CH4	CH4	CH4	CH4	CH4	CH4	CH4	CH4	CH4	CH4	CH4
1.A.	Fuel Combustion Activities	3,8	-48,4	-1,4	6,3	1,9	11,0	19,3	-21,0	9,4	-33,8	-42,0	-49,4
1.A.1.	Energy Industries	-2,6	-5,1	-9,3	-3,4	1,4	9,4	6,0	-24,9	-38,1	-38,9	-40,1	-44,2
1.A.2.	Manufacturing Industries and Construction	-0,9	0,9	-1,0	-0,8	-6,8	-6,9	-0,5	-2,1	-1,7	-2,7	-3,3	-3,5
1.A.3.	Transport	-0,3	-1,9	-0,1	0,1	0,3	0,4	0,5	0,6	0,8	-8,5	1,0	1,0
1.A.4.	Other Sectors	7,6	-42,4	8,9	10,4	7,1	8,1	13,2	5,4	48,4	16,3	0,4	-2,8
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	0,0
1.B.	Fugitive Emissions from Fuels	0,0	-168,4	0,0	0,0	-1,2	0,0	0,0	0,0	0,0	0,3	0,0	0,0
1.B.2.	Oil and Natural Gas	0,0	-170,4	0,0	0,0	-1,2	0,0	0,0	0,0	0,0	0,3	0,0	0,0
4.A.	Enteric Fermentation	-88,8	-25,4	-62,1	-69,5	31,1	31,6	44,4	42,7	47,5	151,9	152,4	142,2
4.B.	Manure Management	-157,7	-124,5	-96,7	-94,9	-71,4	-77,5	-51,8	-47,5	-38,3	56,3	76,0	71,3
6.A.	Solid Waste Disposal on Land	-0,6	-0,3	0,3	-0,6	-0,9	-0,5	2,0	2,2	57,0	113,2	9,6	20,4
		N2O	N2O	N2O	N2O	N2O	N2O	N2O	N2O	N2O	N2O	N2O	N2O
1.A.	Fuel Combustion Activities	5,9	11,4	3,2	1,6	2,1	1,8	1,5	-1,3	-6,4	0,0	-15,0	-17,5
1.A.1.	Energy Industries	0,6	3,7	-2,0	-4,0	-3,4	-4,2	-5,3	-8,0	-12,0	-16,0	-18,6	-19,8
1.A.2.	Manufacturing Industries and Construction	0,5	0,7	0,4	0,4	1,3	0,7	1,7	2,1	1,7	0,9	1,3	0,5
1.A.3.	Transport	0,2	-2,2	0,3	0,3	0,4	0,4	0,4	0,5	0,5	7,2	0,6	0,6
1.A.4.	Other Sectors	4,6	9,6	4,6	4,8	3,8	4,9	4,7	4,1	3,4	7,8	1,8	1,2
1.A.5.	Other	0,0	-0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,0
2.B.	Chemical Industry	1042,9	954,8	843,6	794,9	806,5	903,8	834,3	848,2	806,5	950,2	1003,5	885,3
4.B.	Manure Management	224,5	214,2	206,6	190,2	173,1	160,4	159,9	199,8	196,6	184,5	172,8	176,7
4.D.	Agricultural Soils [(2)]	-1500,5	-1416,4	-1078,2	-1358,7	-1271,5	-1391,3	-1440,7	-1202,8	-1305,6	-1676,0	-1705,7	-1470,6
		HFCs	HFCs	HFCs	HFCs	HFCs	HFCs	HFCs	HFCs	HFCs	HFCs	HFCs	HFCs
2.F.	Consumption of Halocarbons and SF_6	0,0	0,0	-0,2	-1,7	-6,5	-18,1	-41,5	-68,4	-78,2	-94,9	-100,4	0,0
		PFCs	PFCs	PFCs	PFCs	PFCs	PFCs	PFCs	PFCs	PFCs	PFCs	PFCs	PFCs
2.F.	Consumption of Halocarbons and SF_6	0,0	0,0	0,0	0,0	-0,1	-0,4	-1,3	-3,1	-5,9	-7,4	-10,4	0,0
		SF6	SF6	SF6	SF6	SF6	SF6	SF6	SF6	SF6	SF6	SF6	SF6
2.F.	Consumption of Halocarbons and SF_6	1,4	1,4	0,0	-21,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Total CO_2 Equivalent Emissions without LULUCF		-466,7	-685,8	-199,8	-584,2	-366,2	-379,8	-500,0	-271,8	-139,9	-197,5	-372,9	-96,9

10.4 Recalculations, including in response to the review process, and planned improvement to the inventory (e.g. institutional arrangements, inventory preparations)

The review process and the review report have been very valuable for the improvements made and the recalculations performed. The final outcome of the review process is the review report available as http://unfccc.int/program/mis/ghg/countrep/denrep03.pdf

In the review process comments were made to a draft version of the review report. These are unpublished but can be made available upon request.

In general the reviewers has pointed out lacks of the use of notation keys in the CRF tables. The insertion of notation keys has for this submission been considerable improved for all sectors.

For the *Energy Sector* as regards *Stationary Combustion* the response to the review report is given in the Energy Chapter, section 3.2.5. last paragraph and in section 3.2.6. The main message here is that no recalculation has taken place as a result of the comments made by the reviewers, but the documentation has been improved to clarify subjects questioned by the reviewers. The plans for future improvements are given in section 3.2.6, where the most important plans are a disaggregation of the fuel consumption in the Industrial Sector and updating of energy statistics. For the *Energy Sector* as regards *Transport* a response to the review team is given in Energy Chapter, section 3.3.5. last paragraph and outline of plans are given in sector 3.3.6. For *Energy, fugitive emissions* the recalculations carried out are noted in section 3.5.5. In connection to the Energy Sector the review team notes that the inventories for Greenland and Faro Islands are not disaggregated. This note has been discussed and the plan is now to include those emissions under "other" in the relevant CRF source categories. It is important to mention that the emissions for Greenland and Faro Islands are very small as compared to Denmark.

For the *Industrial Sector* the review team recommended a number of potential sources to be considered, e.g. N_2O emissions from Nitric acid production. The resources in the sector have been strengthened. N_2O emission from Nitric Acid production has been estimated for 1990-2002. For more details on the response to the recommendation by the review team refer to section 4.1. For F-gases a full introduction of recalculated emission estimates as a result of a revision of the model used was announced to the reviewers. This has now been done, the changes are minor, refer to the table in section 10.3. Further, the reviewers noted inconsistencies as regards background information on the potential emission of F-gases in the CRF-tables. These emissions have been changed.

For the *Agricultural Sector* all of the comments of the review team have been carefully considered and action been taken. Details on the response and implementation can be seen in section 6.8. In general the inconsistencies pointed out by the reviewers have been removed and the plans for improvements announced to the reviewers have been implemented. For the further plans in the sector one of the highest priority plan is to include CO_2 from Agricultural soils. For further details and plans refer to section 6.9.

For the *LULUCF Sector* the note made by the review team to describe the methodology more transparently has been carefully considered in preparing the sector Chapter 7. This chapter also includes some considerations on uncertainty. Further, notation keys has been inserted in the CRF tables.

For the *Waste Sector* and CH_4 from solid disposal on land small inconsistencies existed between activities and emission factors in the CRF and in FOD model used. The review team noted this.

The inconsistencies are now removed. As a part of the general improvement of the use of notation keys, this has also been done in this sector, including that the review team point on the use of "IE" in Table 6.A. The review team suggested to compare the model used with IPCC default methodology. It is the plan to depending on resources to do so. As regards the recommendation made by the review team to conduct uncertainty analysis it is also planned to do so. The review team had question to waste water-handling system as regards CH_4 and N_2O emissions. The plan is to analyse this in order to estimate and document the CH_4- and N_2O-emissions, which especially for CH_4 is believed to be of only minor importance.

In **conclusion** considerations have been made of all of the review reports suggestions, comments, recommendations and corrections. Improvements in inventories on items pointed out by reviewers were to be made in a rather short timeframe and so much as possible was done. The time frame is set from the time from receiving the draft review report November 11, 2003 and from receiving the final report February 12, 2004 and until March 31 2004 were the final inventories was to be delivered to the European Commission. For items pointed out by the reviewers and not reflected in this inventory submission in this NIR has been put remarks, extended explanations and announcement of plans for improvements.

As regards planned improvement to the inventory as concerns institutional arrangements, inventory preparations no major changes are foreseen. A strengthening on timely delivery of data from other institutions will be carried out and considerations will be made to have data delivered data for some sources missing.