PROJECTION OF GREENHOUSE GASES 2013-2035

Scientific Report from DCE – Danish Centre for Environment and Energy No. 129 2014

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Ole-Kenneth Nielsen
Marlene S. Plejdrup
Morten Winther
Katja Hjelgaard
Malene Nielsen
Patrik Fauser,
Mette H. Mikkelsen
Rikke Albrektsen
Steen Gyldenkærne
Marianne Thomsen

Aarhus University, Department of Environmental Science

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UNIVERSITY
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Data sheet

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Authors: Ole-Kenneth Nielsen, Marlene S. Plejdrup, Morten Winther, Katja Hjelgaard, Malene Nielsen, Patrik Fauser, Mette H. Mikkelsen, Rikke Albrektsen, Steen Gyldenkærne, Marianne Thomsen

Institution: Aarhus University - Department of Environmental Science

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Abstract: This report contains a description of models, background data and projections of CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 for Denmark. The emissions are projected to 2035 using a scenario combined with the expected results of a few individual policy measures. Official Danish forecasts of activity rates are used in the models for those sectors for which forecasts are available, i.e. the latest official forecast from the Danish Energy Agency. The emission factors refer to international guidelines and some are country-specific and refer to Danish legislation, Danish research reports or calculations based on emission data from a considerable number of industrial plants. The projection models are based on the same structure and method as the Danish emission inventories in order to ensure consistency.

Keywords: Greenhouse gases, projections, emissions, CO_2, CH_4, N_2O, HFCs, PFCs, SF_6

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Contents

List of abbreviations

CH_4	Methane
CHP	Combined Heat and Power
CHR	Central Husbandry Register
CO_2	Carbon dioxide
COPERT	COmputer Programme to calculate Emissions from Road Transport
CORINAIR	CORe INventory on AIR emissions
CRF	Common Reporting Format
DCA	Danish Centre for food and Agriculture
DCE	Danish Centre for Environment and energy
DEA	Danish Energy Agency
DEPA	Danish Environmental Protection Agency
DSt	Statistics Denmark
EEA	European Environment Agency
EIONET	European Environment Information and Observation Network
EMEP	European Monitoring and Evaluation Programme
ENVS	Department of Environmental Science, Aarhus University
EU ETS	European Union Emission Trading Scheme
FSE	Full Scale Equivalent
GHG	Greenhouse gas
GWP	Global Warming Potential
HFCs	Hydrofluorocarbons
IDA	Integrated Database model for Agricultural emissions
IEF	Implied Emission Factor
IPCC	Intergovernmental Panel on Climate Change
LPG	Liquefied Petroleum Gas
LTO	Landing and Take Off
LULUCF	Land Use, Land-Use Change and Forestry
MCF	Methane Conversion Factor
MSW	Municipal Solid Waste
N_2O	Nitrous oxide
NFI	National Forest Inventory
NIR	National Inventory Report
PFCs	Perfluorocarbons
SF_6	Sulphur hexafluoride
SNAP	Selected Nomenclature for Air Pollution
SWDS	Solid Waste Disposal Sites
UNFCCC	United Nations Framework Convention on Climate Change
WWTP	WasteWater Treatment Plant

Preface

This report contains a description of models and background data for projection of Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6) for Denmark. The emissions are projected to 2035 using a basic scenario, which includes the estimated effects of policies and measures implemented by September 2012 on Denmark's greenhouse gas (GHG) emissions ('with existing measures' projections).

DCE – Danish Centre for Environment and Energy, Aarhus University, has carried out the work. The project has been financed by the Danish Energy Agency (DEA).

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Department of Geosciences and Natural Resource Management, Copenhagen University, for cooperation in the preparation of the Danish GHG inventory where the department is responsible for the forest category.

Summary

This report contains a description of the models, background data and projections of the greenhouse gases (GHG) carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) for Denmark. The emissions are projected to 2035 using a scenario, which includes the estimated effects of policies and measures implemented by September 2014 on Denmark's GHG emissions ('with existing measures' projections). The official Danish forecasts, e.g. the latest official forecast from the Danish Energy Agency (DEA), are used to provide activity rates (2013-2025) in the models for those sectors for which these forecasts are available. For the years 2026-2035 the emissions are projected by DCE based on the best available knowledge, but is not based on an official energy projection. The estimates for these years are therefore not part of the official projection by the Danish Energy Agency. The emission factors refer to international guidelines or are country-specific and refer to Danish legislation, Danish research reports or calculations based on emission data from a considerable number of industrial plants in Denmark. The projection models are generally based on the same structure and methodology as the Danish emission inventories in order to ensure consistency. Emissions are not corrected for electricity trade, and it should be pointed out that there is a substantial uncertainty regarding the projection of electricity import/export, which may have a significant effect on the projected emissions.

The main sectors in 2013 are Energy Industries (34 %), Transport (23 %), Agriculture (19 %) and Other Sectors (10 %). For the latter sector the most important sources are fuel combustion in the residential sector. GHG emissions show a decreasing trend in the projection period from 2013 to 2035, with decreasing emissions from 2013 to 2025 and almost constant emissions from 2025 to 2035. In general, the emission share for the Energy Industries sector can be seen to be decreasing for the years 2013-2027 followed by an increase in the years 2028-2035, the emission share for the Agriculture is increasing, while emissions from the remaining sectors show a decreasing trend over the projection period. The total emissions in 2013 are estimated to be 53.4 million tonnes CO_2 equivalents and 39.8 million tonnes in 2035, corresponding to a decrease of 25 %. From 1990 to 2013 the emissions are estimated to decrease 22 %.

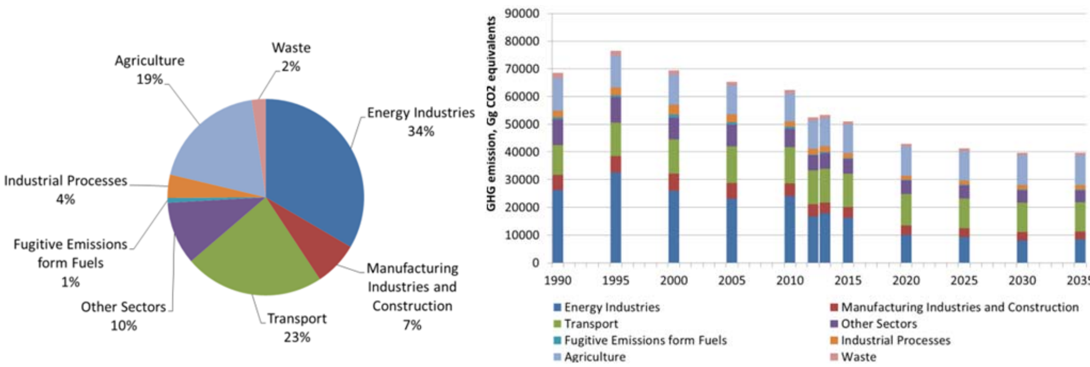


Figure S.1 Total GHG emissions in CO_2 equivalents. Distribution according to main sectors in 2013 and time series for 1990 to 2035.

Stationary combustion

Stationary combustion includes Energy industries, Manufacturing industries and construction and Other sectors. Other sectors include combustion in commercial/institutional, residential and agricultural plants. The GHG emissions in 2013 from the main source, which is public power and heat production (63 %), are estimated to decrease significantly in the period from 2013 to 2028 (67 %) due to a partial shift in fuel type from coal to wood and municipal waste. From 2029 to 2035 the emission is projected to be almost constant. Also, for residential combustion plants and combustion in manufacturing plants a significant decrease in emissions is projected; the emissions decrease by 45 % and 30 % from 2013 to 2035 respectively. The emissions from the other sectors remain almost constant over the period except for energy use in the offshore industry (oil and gas extraction), where the emissions are increasing by 164 % from 1990 to 2012 and projected to increase by 54 % from 2013 to 2035.

Fugitive emissions from fuels

The greenhouse gas emissions from the sector "Fugitive emissions from fuels" show large fluctuations in the historical years 1990-2012, due to emissions from exploration, which occur only in some years with varying amounts of oil and gas flared. Emissions from exploration are not included in the projection, as no projected activity data are available. Emissions are estimated to decrease in the projection period 2013-2035 by 27 %. The decrease mainly owe to expected decrease of offshore flaring in the oil and natural gas extraction. Emissions from extraction of oil and natural gas are estimated to decline over the period 2011-2035 due to the expectation of a decrease of extracted amounts of natural gas. Emissions of greenhouse gases from other sources are estimated to be constant or nearly constant over the projection period.

Industrial processes and product use

The GHG emission from industrial processes and product use increased during the nineties, reaching a maximum in 2000. Closure of a nitric acid/fertiliser plant in 2004 has resulted in a considerable decrease in the GHG emission. The most significant sources of GHG emission in 2013 is cement production (49 %) and use of substitutes (f-gases) for ozone depleting substances (ODS) (35 %). The corresponding shares in 2035 are expected to be 80 % and 4 %, respectively. Consumption of limestone and the emission of CO_2 from flue gas cleaning are assumed to follow the consumption of coal and waste for generation of heat and power. The GHG emission from this sector will continue to be strongly dependent on the cement production at Denmark’s one cement plant.

Transport and other mobile sources

Road transport is the main source of GHG emissions in 2013 (67 %) and emissions from this source are expected to decrease by 13 % from 2013 to 2035 due to a forecasted reduction in traffic. The emission shares for the remaining mobile sources (e.g. domestic aviation, national navigation, railways and non-road machinery in industry, households and agriculture) are small compared with road transport. Non-road machinery in industry contributes with 16 % of the GHG emission in 2013 and this share is expected to stay at 16 % in 2035.

Agriculture

The main sources in 2013 are enteric fermentation (36 %), agricultural soils (36 %) and manure management (26 %). The corresponding shares in 2035 are expected to be 41 %, 33 % and 24 %, respectively. From 1990 to 2012, the emission of GHGs in the agricultural sector decreased by 15 %. In the projection years 2013 to 2035 the emissions are expected to increase by 7 %. The reduction in the historical years can mainly be explained by improved utilisation of nitrogen in manure, a significant reduction in the use of fertiliser and a reduced emission from N-leaching. These are consequences of an active environmental policy in this area. Measures in the form of technologies to reduce ammonia emissions in stables and expansion of biogas production are considered in the projections, but emissions are estimated to increase due to an expected increase of the number of animals.

Waste

The total GHG emission from the waste sector has been decreasing in the years 1990 to 2013 by 35 %. The decreasing trend is expected to continue with a decrease of 24 % from 2013 to 2035. In 2013, GHG emission from solid waste disposal is predicted to contribute 66 % of the emission from the sector as a whole. A decrease of 55 % is expected for this source in the years 2013 to 2035, due to less waste deposition on landfills. An almost constant level for emissions from wastewater is expected for the period considered. GHG emissions from wastewater handling in 2013 contribute with 13 %. Emissions from biological treatment of solid waste contribute 19 % in 2013 and 41 % in 2035.

LULUCF

For all land categories except Forest Land is assumed an overall emission of around 4 500 Gg CO_2 eqv. per year in 2013, decreasing to 4 100 Gg CO_2 eqv. per year in 2035. The main drivers for this decrease is a reduction in the area with organic soil in agricultural crop production and an expected decrease in the emission from agricultural mineral soils as they are expected to approach an equilibrium state with the annual organic matter input to and the annual degradation of the organic matter in the mineral soils.

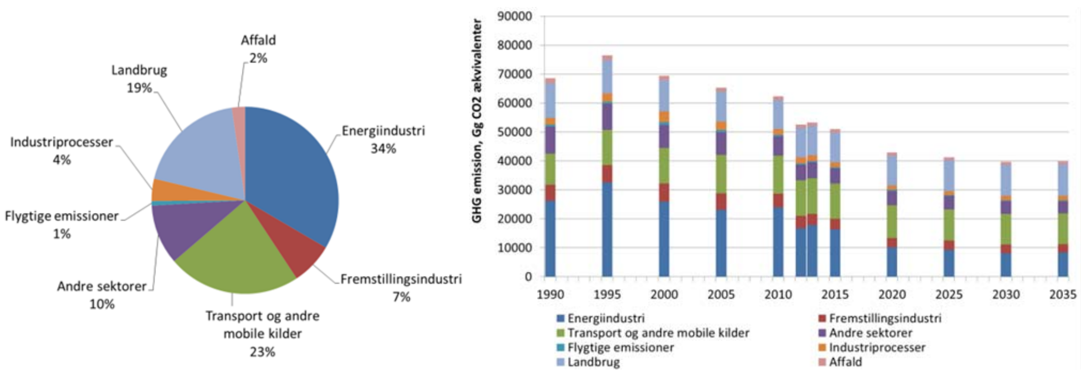
Major changes have been made in the emission inventory for the LULUCF (Land Use, Land Use Change and Forestry) sector. The emission factors have been updated and new sources such as N_2O from mineral soils in cropland, CH_4 sources in Forests, Grassland and Wetlands, movement of liming from LULUCF to Agriculture etc. has been introduced. All these changes have changed the overall emission from the LULUCF sector from being a net sink of 851 Gg CO_2 eqv. to a net source of 491 Gg CO_2-eqv. (excl. liming) compared to the reported emission for 2012 in the annual 2014 submission to UNCCC. The largest changes are found in the emission factors for organic soils which have increased. In total the expected emission from Cropland is expected to increase with 22 % and from Grassland with 83 % compared with 2012.

It has not been possible to get updated forest data and the projection does therefore not include living biomass, dead organic matter and the organic soils in the forest. It does however include emissions from the expected land use conversions of mineral soils and loss of living biomass in the converted area. Based on the evidence from historical data this has little influence on the overall carbon stock changes in forest.

Sammenfatning

Denne rapport indeholder en beskrivelse af modeller, baggrundsdata og fremskrivninger af de danske emissioner af drivhusgasser kuldioxid (CO_2), metan (CH_4), lattergas (N_2O), de fluorerede drivhusgasser HFC'ere, PFC'ere, svovlhexafluorid (SF_6). Emissionerne er fremskrevet til 2035 på baggrund af et scenarie, som medtager de estimerede effekter på Danmarks drivhusgasudledninger af virkemidler iværksat indtil september 2014 (såkaldt "med eksisterende virkemidler" fremskrivning). I modellerne er der, for de sektorer hvor det er muligt, anvendt officielle danske fremskrivninger af aktivitetsdata, f.eks. er den seneste officielle energifremskrivning fra Energistyrelsen (2013-2025) anvendt. For perioden 2026-2035 er emissionerne fremskrevet af DCE baseret på bedste tilgængelige viden, men er ikke baseret på en officiel energifremskrivning. Estimaterne for disse år er derfor ikke en del af Energistyrelsens officielle fremskrivning. Emissionsfaktorerne refererer enten til internationale vejledninger, dansk lovgivning, danske rapporter eller er baseret på målinger på danske anlæg. Fremskrivningsmodellerne bygger på samme struktur og metoder, som er anvendt for de danske emissionsopgørelser, hvilket sikrer at historiske og fremskrevne emissionsopgørelser er konsistente. Data for emissioner er ikke korrigeret for elhandel, og der gøres opmærksom på, at der er betydelig usikkerhed omkring import/eksport af el i fremskrivningen, som kan have væsentlig betydning for opgørelsen af emissioner.

De vigtigste sektorer i forhold til emission af drivhusgas i 2013 forventes at være energiproduktion og -konvertering (34 %), transport (23 %), landbrug (19 %), og andre sektorer (10 %). For "andre sektorer" er den vigtigste kilde husholdninger (Figur R.1). Fremskrivningerne af drivhusgasemissionerne viser en faldende tendens i prognoseperioden fra 2013 til 2035 med faldende emissioner i perioden 2013-2025 efterfulgt af et mere konstant niveau i perioden 2025-2035. Generelt falder emissionsandelen for energisektoren, mens emissionsandelen for landbrugssektoren stiger. De totale emissioner er beregnet til 53,4 millioner tons CO_2-ækvivalenter i 2013 og til 39,8 millioner tons i 2035 svarende til et fald på 25 %. Fra 1990 til 2013 er emissionerne beregnet til at falde med ca. 22 %.



Figur R.1 Totale drivhusgasemissioner i CO_2-ækvivalenter fordelt på hovedsektorer for 2013 og tidsserier fra 1990 til 2035.

Stationær forbrænding

Stationær forbrænding omfatter Energiindustri (konvertering og olie/gas produktion), Fremstillingsindustri og Andre sektorer. Andre sektorer dækker over handel/service, husholdninger samt landbrug/gartneri. Drivhusgasemissionen fra kraft- og kraftvarmeværker, som er den største kilde i 2013 (63 %), er beregnet til at ville falde markant i perioden 2013 til 2028 (67 %) grundet et delvis brændselsskift fra kul til træ og affald. For 2029 til 2035 vil emissionen være nogenlunde konstant. Emissionerne fra husholdningers og fremstillingsindustriers forbrændingsanlæg falder ifølge fremskrivningen også i perioden 2013 til 2035 (henholdsvis 45 % og 30 %). Drivhusgasemissionerne fra andre sektorer vil være næsten konstante i hele perioden med undtagelse af off-shore-sektoren, hvor emissioner fra anvendelse af energi til udvinding af olie og gas stiger med 164 % fra 1990 til 2012 og med 54 % fra 2013 til 2035.

Flygtige emissioner

Emissionen af drivhusgasser fra sektoren "Emissioner af flygtige forbindelser fra brændsler" udviser store fluktuationer i de historiske år 1990-2012, som følge af varierende omfang af efterforsknings- og vurderingsboringer (E/V-boringer). Emissioner fra E/V-boringer indgår ikke i fremskrivningen, da der ikke foreligger fremskrevne aktivitetsdata. Emissionerne fra de øvrige flygtige kilder forventes at falde med 27 % i perioden 2013-2035. Den største del af faldet skyldes faldende flaring ved udvinding, som følge af forventningen om en faldende produktion af naturgas. Emissionerne af drivhusgasser fra de øvrige kilder forventes at være konstante eller nærkonstante i fremskrivningsperioden.

Industriprocesser og anvendelse af produkter

Emissionen af drivhusgasser fra industrielle processer og anvendelse af produkter er steget op gennem halvfemserne med maksimum i 2000. Ophør af produktion af salpetersyre/kunstgødning i 2004 har resulteret i en betydelig reduktion af drivhusgasemissionen. De væsentligste kilder er cementproduktion, som bidrager med mere end 49 % i 2013, og anvendelse af substitutter (f-gasser) for ozonnedbrydende stoffer (ODS), der bidrager med 35 %. Forbrug af kalk og derved emission af CO_2 fra røggasrensning antages at følge forbruget af kul og affald i kraftvarmeanlæg. Drivhusgasemissionen fra industrielle processer forventes også i fremtiden at være meget afhængig af cementproduktionen.

Transport og andre mobile kilder

Vejtransport er den største emissionskilde for drivhusgasser i 2013 (67 %), og emissionerne fra denne kilde forventes at falde med 13 % fra 2013 til 2035 bl.a. som følge af et fald i det forventede trafikarbejde. Den samlede emission for andre mobile kilder er lave sammenlignet med vejtransport. Nonroad maskiner i industrien udgør 16 % af emissionen i 2013, og andelen forventes også at udgøre 16 % i 2035.

Landbrug

Den største kilde i 2013 er emissioner fra dyrenes fordøjelse (36 %), landbrugsjorde (36 %) og gødningshåndtering (26 %). De tilsvarende andele i 2035 forventes at være hhv. 41 %, 33 % og 24 %. Fra 1990 til 2012 er emissionen fra landbrugssektoren faldet med 15 %. I fremskrivningsperioden 2013-2035 forventes emissionerne af stige med 7 %. Årsagen til faldet i de historiske år er en forbedring i udnyttelsen af kvælstof i husdyrgødningen, og hermed et markant fald i anvendelsen af handelsgødning samt lavere emission fra kvælstofudvaskning. I fremskrivningen er der taget højde for teknologiske tiltag i form af ammoniakreducerende teknologi i stald og en øget vækst i biogasanlæg, men emissionerne er estimeret til at stige pga. en forventet stigning i antallet af dyr.

Affald

Affaldssektorens samlede drivhusgasemissioner er faldet med 35 % i perioden 1990 til 2013. Den faldende trend forventes at fortsætte med et fald på 24 % fra 2013 til 2035. I 2013 udgør drivhusgasemissionen fra lossepladser 66 % af den totale emission fra affaldssektoren. Et fald på 55 % er forventet for denne kilde i perioden 2013 til 2035. Dette skyldes, at mindre affald bliver deponeret og at tidligere deponeret affald har afgivet meget af CH_4-potentialet. I 2013 udgør spildevandshåndtering 13 % af sektorens samlede emission. Emissionerne fra biologisk behandling af affald udgør 19 % i 2013 og 41 % i 2035.

LULUCF

For alle kategorier undtagen Skov forventes en samlet emission på omkring 4.500 Gg CO_2-ækvivalenter i 2013, faldende til 4.100 Gg CO_2-ækvivalenter i 2035. De væsentligste årsager til faldet er en reduktion af arealet af organiske landbrugsjorde, samt et forventet fald i emissionen fra mineralske landbrugsjorde, da disse nærmer sig en ligevægtstilstand mellem den årlige tilgang af organisk materiale og den årlige nedbrydning af mineraljordenes indhold af organisk materiale.

Der er udført en række væsentlige ændringer for LULUCF-sektoren (Land Use, Land Use Change and Forestry). Emissionsfaktorerne er opdateret, der er inddraget nye kilder som N_2O fra dyrkede mineraljorde, CH_4 fra skov, græsarealer og vådområder, emissioner fra kalkning er flyttet til landbrugssektoren mm. Disse ændringer har betydet, at LULUCF sektoren i 2012 er beregnet til at udgøre en kilde på 491 Gg CO_2-ækvivalenter, mens LULUCF-sektoren i den seneste rapportering i 2014 til UNFCCC samlet set bidrog med et optag på 851 Gg CO_2-ækvivalenter. Den største ændring er en stigning i emissionsfaktorerne for organiske jorde. Samlet set forventes emissionerne fra landbrugsjorde og fra græsarealer at stige med hhv. 22 % og 83 % i forhold til 2012, jf. de opdaterede metoder.

Det har ikke været muligt at få opdaterede skov-data, og derfor inkluderer fremskrivningen ikke levende biomasse, dødt organisk materiale samt organiske jorde i skove. Der indgår dog emissioner fra forventede ændring af arealanvendelsen for mineraljorde samt tab af levende biomasse for de ændrede arealer. Sammenlignet med de historiske data har dette kun lille betydning for den samlede kulstofbalance i skove.

1 Introduction

In the Danish Environmental Protection Agency's project 'Projection models 2010' a range of sector-related partial models were developed to enable projection of the emissions of SO_2, NO_x, NMVOC and NH_3 forward to 2010 (Illerup et al., 2002). Subsequently, the project "Projection of GHG emissions 2005 to 2030" was carried out in order to extend the projection models to include the GHGs CO_2, CH_4, N_2O as well as HFCs, PFCs and SF_6, and project the emissions for these gases to 2030 (Illerup et al., 2007). This was further updated in the project "Projection of greenhouse gas emissions 2007 to 2025" (Nielsen et al., 2008), "Projection of Greenhouse Gas Emissions 2009 to 2030" (Nielsen et al., 2010), "Projection of Greenhouse Gas Emissions 2010 to 2030" (Nielsen et al., 2011) and "Projection of greenhouse gas emissions 2011 to 2035" (Nielsen et al., 2013). The purpose of the present project, "Projection of greenhouse gas emissions 2013 to 2035" has been to update the emission projections for all sectors based on the latest national energy projections, other relevant activity data and emission factors.

1.1 Obligations

In relation to the Kyoto Protocol, the EU has committed itself to reduce emissions of GHGs for the period 2008-2012 by 8 % (on average) compared to the level in the so-called base year: 1990 for CO_2, CH_4, and N_2O and either 1990 or 1995 for industrial GHGs (HFCs, PFCs and SF_6). Under the Kyoto Protocol, Denmark has committed itself to a reduction of 21 % as a part of the Burden Sharing agreement within the EU. On the basis of the GHG inventory submission in 2006 and Denmark's choice of 1995 as the base year for industrial GHGs, Denmark's total GHG emissions in the base year amount to 69,323 ktonnes CO_2 equivalents. Calculated as 79 % of the base year Denmark's assigned amount under the Burden Sharing Agreement amounts to 273,827 ktonnes CO_2 equivalents in total or on average 54,765 ktonnes CO_2 equivalents per year in the period 2008-2012.

Since 1990 Denmark has implemented policies and measures aiming at reductions of Denmark's emissions of CO_2 and other GHGs. In this report the estimated effects of policies and measures implemented until June 2014 (for non-energy sectors) and until September 2014 (for energy) are included in the projections and the projection of total GHG emissions is therefore a so-called 'with existing measures' projection.

In addition to the implementation of policies and measures with an effect on Denmark's GHG emissions by sources, Parties to the Kyoto Protocol can also make use of certain removals by sinks and emission reductions achieved abroad through Joint Implementation projects (JI) or projects under the Clean Development Mechanism (CDM).

1.2 Greenhouse gases

The GHGs reported under the Climate Convention and projected in this report are:

- Carbon dioxide CO_2
- Methane CH_4
- Nitrous oxide N_2O

- Hydrofluorocarbons HFCs
- Perfluorocarbons PFCs
- Sulphur hexafluoride SF_6

The main GHG responsible for the anthropogenic influence on the heat balance is CO_2. The atmospheric concentration of CO_2 has increased from 280 to 379 ppm (about 35 %) since the pre-industrial era in the nineteenth century (IPCC, Fourth Assessment Report). The main cause is the use of fossil fuels, but changing land use, including forest clearance, has also been a significant factor. Concentrations of the GHGs CH_4 and N_2O, which are very much linked to agricultural production, have increased by approximately 150 % and 18 %, respectively (IPCC, 2007). The lifetime of the gases in the atmosphere needs to be taken into account – the longer they remain in the atmosphere the greater the overall effect. The global warming potential (GWP) for various gases has been defined as the warming effect over a given time of a given weight of a specific substance relative to the same weight of CO_2. The purpose of this measure is to be able to compare and integrate the effects of individual substances on the global climate. Typical atmospheric lifetimes for different substances differ greatly, e.g. for CH_4 and N_2O, approximately 12 and 120 years, respectively. So the time perspective clearly plays a decisive role. The lifetime chosen is typically 100 years. The effect of the various GHGs can then be converted into the equivalent quantity of CO_2, i.e. the quantity of CO_2 producing the same effect with regard to absorbing solar radiation. According to the IPCC and their Fourth Assessment Report, which UNFCCC has decided to use as reference, the global warming potentials (GWP) for a 100-year time horizon are:

- CO_2 1
- CH_4 25
- N_2O 298

Based on weight and a 100 year period, CH_4 is thus 25 times more powerful a GHG than CO_2, and N_2O is 298 times more powerful. Some of the other GHGs (hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) have considerably higher global warming potential values. For example, sulphur hexafluoride has a global warming potential of 22,800 (IPCC, 2007).

1.3 Historical emission data

The GHG emissions are estimated according to the IPCC guidelines and are aggregated into seven main sectors. The GHGs include CO_2, CH_4, N_2O, HFCs, PFCs and SF_6. Figure 1.1 shows the estimated total GHG emissions in CO_2 equivalents from 1990 to 2012. The emissions are not corrected for electricity trade or temperature variations. CO_2 is the most important GHG, followed by CH_4 and N_2O in relative importance. The contribution to national totals in 2012 from HFCs, PFCs and SF_6 is approximately 2 %. Stationary combustion plants, transport and agriculture represent the largest sources, followed by Industrial Processes (including product use and F-gases) and Waste. The net CO_2 removal by forestry and soil in 2012 was approximately 4 % of the total emission in CO_2 equivalents. The national total GHG emission in CO_2 equivalents excluding LULUCF has decreased by 23.4 % from 1990 to 2012 and decreased 19.4 % including LULUCF.

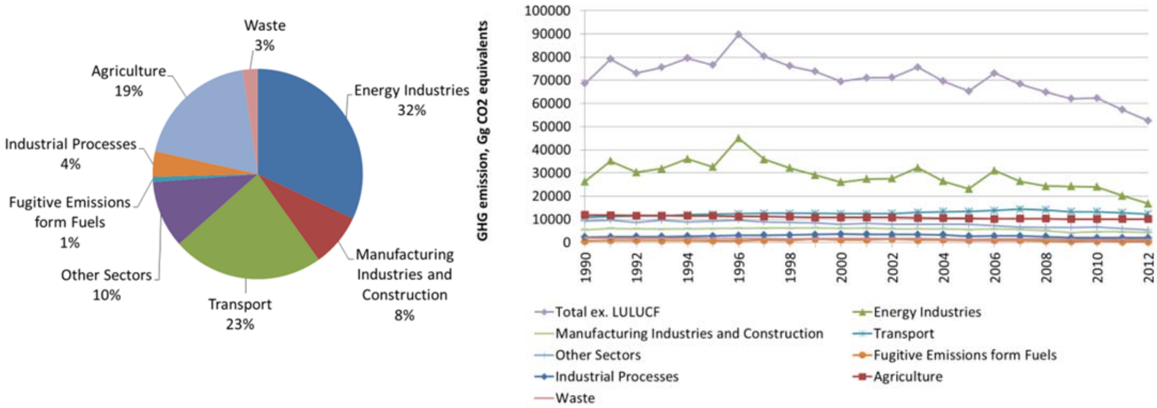


Figure 1.1 Greenhouse gas emissions in CO_2 equivalents distributed on main sectors for 2012 and time series for 1990 to 2012.

1.3.1 Carbon dioxide

The largest source to the emission of CO_2 is the energy sector, which includes combustion of fossil fuels like oil, coal and natural gas (Figure 1.2). Energy Industries contribute with 42 % of the emissions. About 39 % of the CO_2 emission comes from the transport sector. In 2012, the actual CO_2 emission was about 26 % lower than the emission in 1990.

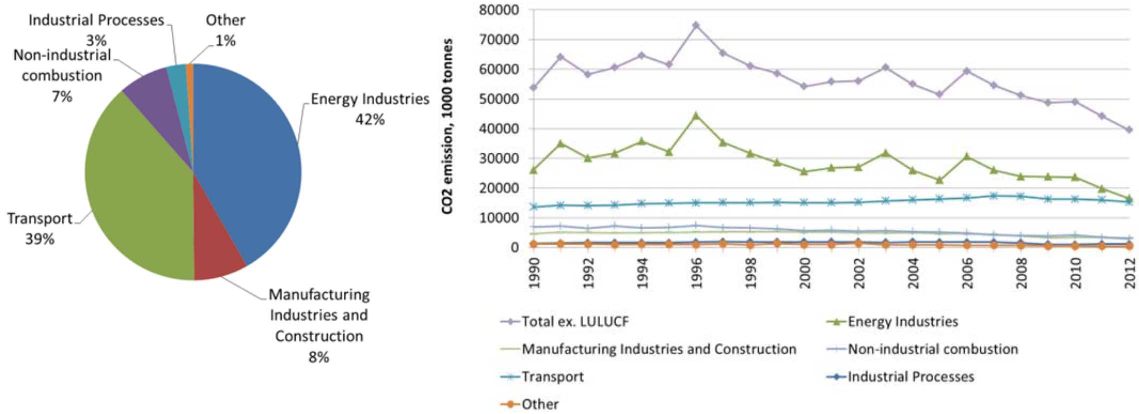


Figure 1.2 CO_2 emissions. Distribution according to the main sectors (2012) and time series for 1990 to 2012.

1.3.2 Nitrous oxide

Agriculture is the most important N_2O emission source in 2012 contributing 87.8 % (Figure 1.3) of which N_2O from soil dominates (75 % of national N_2O emissions in 2012). 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 in the emissions of N_2O in the agricultural sector of 27.6 % from 1990 to 2012 is legislation to improve the utilisation of nitrogen in manure. The legislation has resulted in less nitrogen excreted per unit of livestock produced and a considerable reduction in the use of fertilisers. The basis for the N_2O emission is then reduced. Combustion of fossil fuels in the energy sector, both stationary and mobile sources, contributes 3.8 %. The N_2O emission from transport contributes by 3.5 % in 2012. This emission increased from 1990 to 2007 because of the increase in the use of catalyst cars. Production of nitric acid stopped in 2004 and the emissions from industrial processes is therefore zero from 2005 onwards. The sector Solvent and Other Product Use covers N_2O from e.g. anaesthesia.

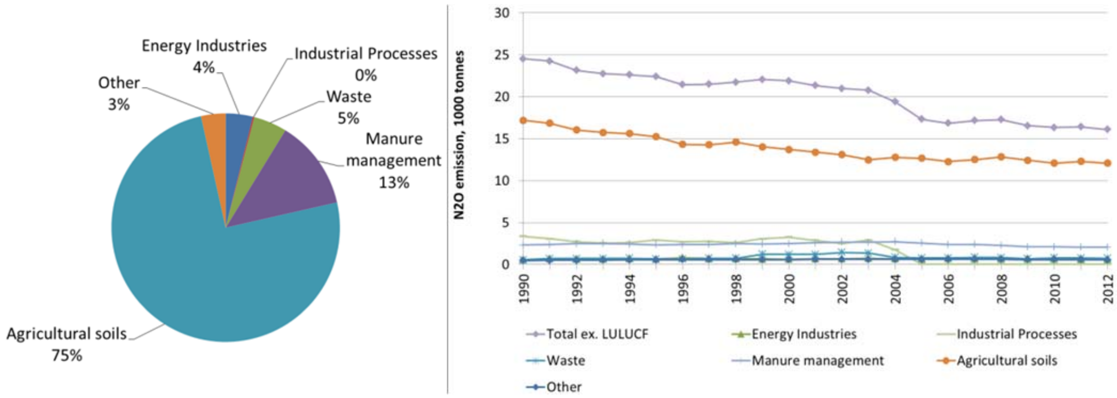


Figure 1.3 N_2O emissions. Distribution according to the main sectors (2012) and time series for 1990 to 2012.

1.3.3 Methane

The largest sources of anthropogenic CH_4 emissions are agricultural activities contributing in 2012 with 68.7 %, waste (12.5 %), and the energy sector (4.5 %) - see Figure 1.4. The emission from agriculture derives from enteric fermentation (51.1 % of national CH_4 emissions) and management of animal manure (27.3 % of national CH_4 emissions), and a minor contribution from field burning of agricultural residues.

The CH_4 emission from public power and district heating plants increases due to the increasing use of gas engines in the decentralized cogeneration plant sector. Up to 3 % of the natural gas in the gas engines is not combusted. In more recent years the natural gas consumption in gas engines has declined causing a lowering of emissions from this source.

Over the time series from 1990 to 2012, the emission of CH_4 from enteric fermentation has decreased 4.8 % mainly due to the decrease in the number of cattle. However, the emission from manure management has in the same period increased 24.9 % due to a change from traditional solid manure housing systems towards slurry-based housing systems. Altogether, the emission of CH_4 from the agriculture sector has increased by 3.8 % from 1990 to 2012.

CH_4 emissions from Waste has decreased by 40.9 % from 1990 to 2012 due to a combination of decreasing emissions from solid waste disposal (48.9 %) and increasing emissions from waste water handling (13.0 %).

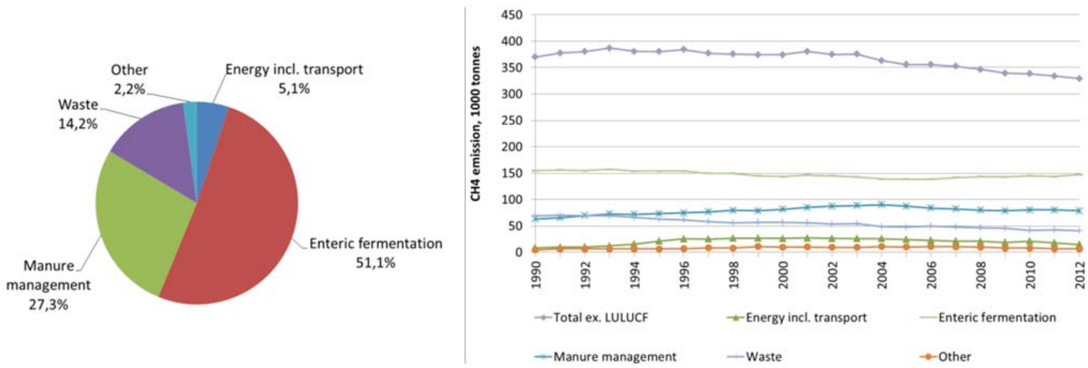


Figure 1.4 CH_4 emissions. Distribution according to the main sectors (2012) and time series for 1990 to 2012.

1.3.4 HFCs, PFCs and SF_6

This part of the Danish inventory only comprises a full data set for all substances from 1995. From 1995 to 2000, there was a continuous and substantial increase in the contribution from the range of F-gases as a whole, calculated as the sum of emissions in CO_2 equivalents, see Figure 1.5. This increase is simultaneous with the increase in the emission of HFCs. For the time series 2000-2008, the increase is lower than for the years 1995 to 2000. From 2008 to 2012 the emission of F-gases expressed in CO_2 equivalents decreased. The increase in emission from 1995 to 2012 is 160 %. SF_6 contributed considerably to the total f-gas emission in earlier years, with 30 % in 1995. Environmental awareness and regulation of these gases has reduced its use in industry, see Figure 1.5. A further result is that the contribution of SF_6 to f-gases in 2012 was only 13.6 %. The use of HFCs has increased several folds. HFCs have, therefore, become the dominant f-gases, comprising 70 % in 1995, but 85 % in 2012. HFCs are mainly used as a refrigerant. Danish legislation regulates the use of f-gases, e.g. since January 1 2007 new HFC-based refrigerant stationary systems are forbidden. Refill of old systems are still allowed and the use of air conditioning in mobile systems increases. The increase in SF_6 emissions in the later years is due to the decommissioning of windows containing SF_6 as insulating gas.

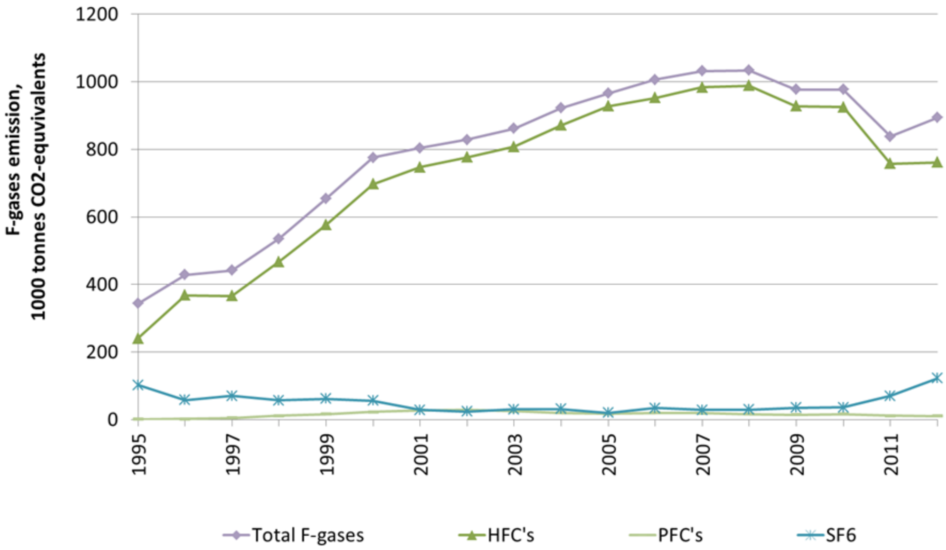


Figure 1.5 F-gas emissions. Time series for 1995 to 2012.

1.4 Projection models

Projection of emissions can be considered as emission inventories for the future in which the historical data is replaced by a number of assumptions and simplifications. In the present project the emission factor method is used and the emission as a function of time for a given pollutant can be expressed as:

$$E = \sum_s A_s(t) \cdot \overline{EF}_s(t) \qquad (1.1)$$

where A_s is the activity for sector s for the year t and $EF_s(t)$ is the aggregated emission factor for sector s.

In order to model the emission development as a consequence of changes in technology and legislation, the activity rates and emission factors of the emission source should be aggregated at an appropriate level, at which relevant parameters such as process type, reduction targets and installation type can be taken into account. If detailed knowledge and information of the technologies and processes are available, the aggregated emission factor for a given pollutant and sector can be estimated from the weighted emission factors for relevant technologies as given in equation 1.2:

(1.2) $$EF_s(t) = \sum_k P_{s,k}(t) \cdot EF_{s,k}(t)$$

where P is the activity share of a given technology within a given sector, $EF_{s,k}$ is the emission factor for a given technology and k is the type of technology.

Official Danish forecasts of activity rates are used in the models for those sectors for which the forecasts are available. For other sectors projected activity rates are estimated in co-operation with relevant research institutes and other organisations. The emission factors are based on recommendations from the IPCC Guidelines (IPCC, 2006), IPCC Good Practice Guidance and Uncertainty Management (2000) and the EMEP/EEA Guidebook (EMEP/EEA, 2013) as well as data from measurements made in Danish plants. The influence of changes in legislation and statutory orders on the development of the emission factors has been estimated and included in the models.

The projection models are based on the same structure and method as the Danish emission inventories in order to ensure consistency. In Denmark the emissions are estimated according to the EMEP/EEA Guidebook (EMEP/EEA, 2013) and the SNAP (Selected Nomenclature for Air Pollution) sector categorisation and nomenclature are used. The detailed level makes it possible to aggregate to both the UNECE/EMEP nomenclature (NFR) and the IPCC nomenclature (CRF).

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2 Stationary combustion

2.1 Methodology

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

The methodology for emission projections are, just as the Danish emission inventory for stationary combustion plants, based on the CORINAIR system described in the EMEP/EEA Guidebook (EMEP/EEA, 2013). The emission projections are based on official activity rates forecast from the Danish Energy Agency and on emission factors for different fuels, plants and sectors. For each of the fuels and categories (sector and e.g. type of plant), a set of general emission factors has been determined. Some emission factors refer to the IPPC Guidelines (IPCC, 2006) and some are country-specific and refer to Danish legislation, EU ETS (Emission Trading System) reports from Danish plants, Danish research reports or calculations based on emission data from a considerable number of plants.

Some of the large plants, such as e.g. power plants and municipal waste incineration plants are registered individually as large point sources and emission data from the actual plants are used. The CO_2 from incineration of the plastic part of municipal waste is included in the projected emissions.

The fuel consumption in the energy projections have been divided into ETS and non-ETS consumption. Together with knowledge of the industrial process emissions that are covered by the EU ETS, it has been possible to provide an emission projection estimate for the ETS sector. The result of this is included in Chapter 14.

2.2 Sources

The combustion of fossil fuels is one of the most important sources of greenhouse gas emissions and this chapter covers all sectors, which use fuels for energy production, with the exception of the transport sector and mobile combustion in e.g. manufacturing industries, households and agriculture. Table 2.1 shows the sector categories used and the relevant classification numbers according to SNAP and IPCC.

Table 2.1 Sectors included in stationary combustion.

Sector	IPCC	SNAP
Public power	1A1a	0101
District heating plants	1A1a	0102
Petroleum refining plants	1A1b	0103
Oil/gas extraction	1A1c	0105
Commercial and institutional plants	1A4a	0201
Residential plants	1A4b	0202
Plants in agriculture, forestry and aquaculture	1A4c	0203
Combustion in industrial plants	1A2	03

In Denmark, all municipal waste incineration is utilised for heat and power production. Thus, incineration of waste is included as stationary combustion in the IPCC Energy sector (source categories *1A1*, *1A2* and *1A4a)*.

Fugitive emissions from fuels connected with extraction, transport, storage and refining of oil and gas are described in Chapter 3. Emissions from flaring in oil refineries and in oil and gas extraction are also included in Chapter 3 on fugitive emissions.

Stationary combustion is the largest sector contributing with roughly 50 % of the total greenhouse gas emission. As seen in Figure 1.1 in Section 1.3, the subsector contributing most to the greenhouse gas emission is energy industries.

2.3 Fuel consumption

Energy consumption in the model is based on the Danish Energy Agency's energy consumption projections to 2035 (Danish Energy Agency, 2014a) and energy projections for individual plants (Danish Energy Agency, 2014b).

In the projection model the sources are separated into area sources and large point sources, where the latter cover all plants larger than 25 MW_e. The projected fuel consumption of area sources is calculated as total fuel consumption minus the fuel consumption of large point sources and mobile sources.

The emission projections are based on the amount of fuel, which is expected to be combusted in Danish plants and is not corrected for international trade in electricity. For plants larger than 25 MW_e, fuel consumption is specified in addition to emission factors. Fuel use by fuel type is shown in Table 2.2, and Figures 2.1 and 2.3.

Table 2.2 Fuel consumption distributed on fuel types, TJ.

Fuel type	2013	2015	2020	2025	2030	2035
Natural gas	135536	130068	119535	111331	105033	104572
Steam coal	117438	102265	36857	32052	22536	24339
Wood and simil.	72987	72769	118005	118488	133067	135307
Municipal waste	43791	43915	43745	43866	43397	42855
Gas oil	17877	17599	15024	12781	11028	10159
Agricultural waste	17858	16847	16991	15644	14440	13882
Refinery gas	15633	15633	15633	15633	15633	15633
Residual oil	9600	8839	7166	6828	5236	5103
Petroleum coke	6625	6897	7257	7377	7260	6987
Biogas	5000	6390	9960	11950	13150	13950
LPG	1380	1453	1644	1721	1691	1631
Coke	691	583	318	251	237	208
Kerosene	24	24	25	26	26	26
Bio oil	7	6	25	35	NO	NO
Total	444445	423286	392184	377982	372732	374651

NO = Not Occurring

Natural gas is the most important fuel throughout the time series. After 2013, wood and similar wood wastes are expected to exceed stem coal as the second most important fuel. The largest variations are seen for coal use, biogas and wood. Coal use peaks in 2013 and decreases significantly until 2020. For biogas the projected consumption increases throughout the period as a whole and from 2026 onwards the consumption of biogas is projected to be higher than the consumption of gasoil.

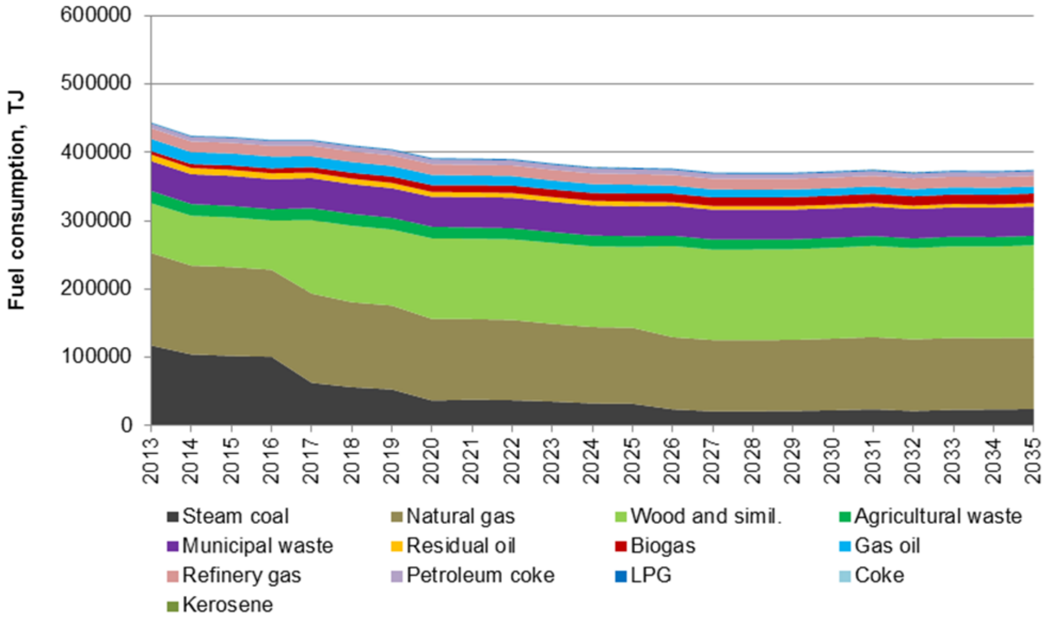

Figure 2.1 Projected energy consumption by fuel type.

Fuel use by sector is shown in Figure 2.2. The sectors consuming the most fuel are public power, residential, manufacturing industries, district heating and off-shore. According to the energy projection the fuel consumption in the public power sector will decrease by 22 % from 2013 to 2035, and the off-shore sector will increase by more than 50 % over the same period.

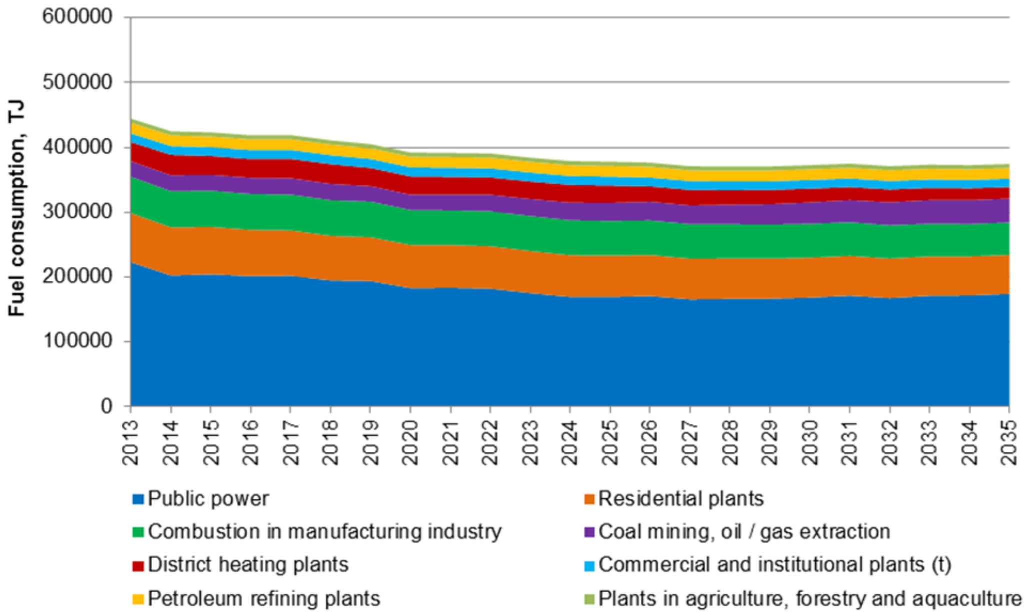

Figure 2.2 Energy use by sector.

Power plants larger than 25 MW_e use between 33 % and 41 % of total fuel, the fuel consumption in these sources decline from 2013 to 2025, thereafter the consumption remain relatively stable but with fluctuations. The amount of wood combusted by large point sources increases whereas the coal and natural gas consumption decreases.

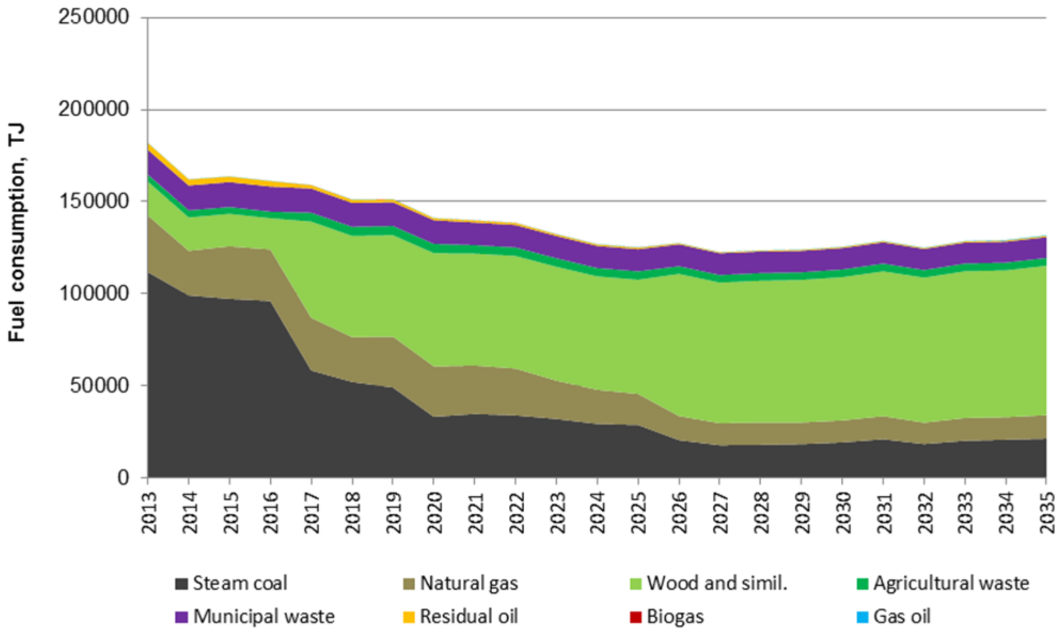

Figure 2.3 Energy consumption for plants > 25 MW_e.

2.4 Emission factors

2.4.1 Area sources

In general, emission factors for areal sources refer to the emission factors for 2012 applied in the 2014 emission inventory (Nielsen et al., 2014). However, emission factors that refer to the IPCC Guidelines have been revised according to the revised IPCC Guideline (IPCC, 2006). The revised IPCC Guideline emission factors have been implemented for both historic inventories and projections.

The CO_2 emission factors for coal, residual oil applied in public power and heat production, refinery gas and off-shore combustion of natural gas (off-shore gas turbines) are all based on EU ETS data and updated annually in the historic emission inventories. In the projection, the average 2006-2012 emission factors have been applied rather than including only the 2012 data.

A time series for the CH_4 emission factor for residential wood combustion have been estimated based on technology specific emission factors and projections of the applied technology. The same methodology is applied in the historic inventories.

The emission factor for CO_2 is only fuel-dependent whereas the N_2O and CH_4 emission factors depend on the sector (SNAP) in which the fuel is used.

Some of the emission factors applied in the projection model are aggregated based on emission factors for different technologies. The technology distribution in 2012 has been applied for the aggregation of implied emission factors. The applied IEFs are shown in Table 2.3. The IEFs are assumed to remain unchanged over the period 2013-2035.

Table 2.2 Implied emission factors (IEF) for CH_4 and N_2O. Calculation of implied emission factors are based on emission factors and fuel consumption in 2012.

SNAP	Fuel	GHG	IEF
0101	Residual oil	CH_4	1.0
0101	Gas oil	CH_4	2.1
0101	Biogas	CH_4	427
0201	Biogas	CH_4	224
0203	Biogas	CH_4	255
03	Gas oil	CH_4	0.8
03	Biogas	CH_4	183
0101	Residual oil	N_2O	0.63
0101	Gas oil	N_2O	0.5
0101	Biogas	N_2O	1.6
0103	Refinery gas	N_2O	0.2
0201	Gas oil	N_2O	0.4
0201	Biogas	N_2O	0.9
0202	Gas oil	N_2O	0.6
0203	Biogas	N_2O	1
03	Gas oil	N_2O	0.45
03	Biogas	N_2O	0.7

The fuel consumption in natural gas fuelled engines has been projected separately. Thus, the emission factors for gas engines that differ considerably from the emission factors for other technologies are not included in the area source emission factors for other technologies. For biogas fuelled engines, the consumption in engines installed in future years has been projected separately and thus the area source emission factor is an implied emission factor for the current technology distribution for biogas fuelled engines.

Gas engines have been implemented in the projection as a point source and the CH_4 emission factor time series is discussed below.

Residential wood combustion is a large emission source for CH_4. The projections are based on data for technology distribution, replacement rate and technology specific emission factors.

The emission projection is based on the wood consumption in residential plants as reported by the DEA. To break the consumption down to the different technologies available, the number of appliances and the consumption per appliance is estimated. The assumptions behind the break down are documented in Nielsen et al. (2014)

The technology specific emission factors applied for the projections are equal to the technology specific emission factors applied for the historic emission inventories. The replacement of old technologies with new technologies results in a decreasing implied emission factors for CH_4, which causes the emissions from residential wood combustion to decrease substantially from 2013 to 2035.

2.4.2 Point sources

Plant-specific emission factors are not used for GHGs. Therefore, emission factors for the fuels/SNAP categories are used. Point sources are, with a few exceptions, large power plants. In addition, natural gas fuelled gas turbines and engines fuelled by natural gas or biogas have been included in the model as “point sources”.

For gas turbines, the emission factors for SNAP 010104 are applied.

The CH_4 emission factor is expected to increase as a result of the increased NO_x tax. The engine settings will be changed leading to an increased CH_4 emission[1]. The increase of the CH_4 emission differs between engine types. Kvist (2012) have estimated a 12 % increase of the CH_4 emission factor. This value is based on an average increase for eight different engines (Kvist, 2012). Kristensen (2013) have estimated that half the engines larger than 5 MW will reduce NO_x emission and thus increase the CH_4 emission from 2013.

2.5 Emissions

Emissions for the individual GHGs are calculated by means of Equation 2.1, where A_s is the activity (fuel consumption) for sector *s* for year *t* and $EF_s(t)$ is the aggregate emission factor for sector *s*.

$$Eq.\ 2.1 \quad E = \sum_s A_s(t) \cdot \bar{EF}_s(t)$$

The total emission in CO_2 equivalents for stationary combustion is shown in Table 2.4.

Table 2.4 Greenhouse gas emissions, Gg CO_2 equivalents.

Sector	1990	2000	2005	2010	2012	2013	2015	2020	2025	2030	2035
Public power	22827	22943	20094	20627	13333	14580	12965	6691	5646	4354	4579
District heating plants	1963	566	437	993	996	867	954	1094	1081	828	709
Petroleum refining plants	908	1001	939	855	985	966	966	966	966	966	966
Oil/gas extraction	548	1470	1629	1497	1445	1387	1416	1360	1611	1900	2141
Commercial and institutional plants	1420	922	975	867	668	737	745	746	727	695	660
Residential plants	5079	4129	3803	3180	2230	2637	2440	2017	1786	1606	1451
Plants in agriculture, forestry and aquaculture	616	791	667	368	277	288	284	286	284	282	279
Combustion in industrial plants	4660	5225	4670	3531	3263	3172	3028	2596	2468	2375	2221
Total	38021	37047	33214	31919	23197	24633	22797	15756	14570	13006	13005

From 1990 to 2035, the total emission falls by approximately 25 000 Gg (CO_2 eqv.) or 66 % due to coal being partially replaced by renewable energy. The emission projections for the three GHGs are shown in Figures 2.4-2.9 and in Tables 2.5-2.7, together with the historic emissions for 1990, 2000, 2005 and 2010 (Nielsen et al., 2012).

[1] The CH_4 tax is low compared to the NO_x tax.

2.5.1 CO_2 emissions

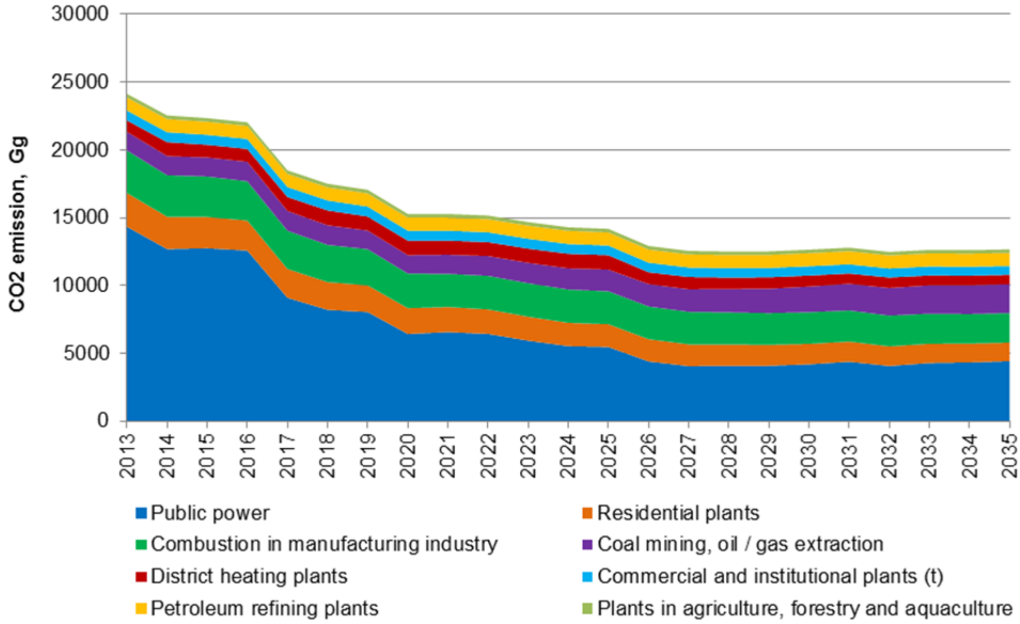

Figure 2.4 CO_2 emissions by sector.

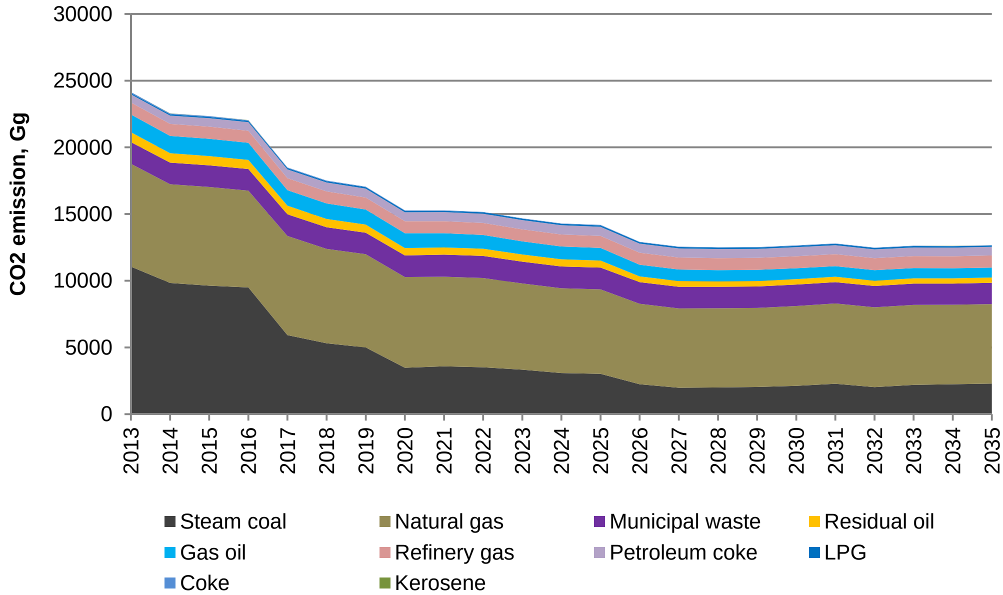

Figure 2.5 CO_2 emissions by fuel.

Table 2.3 CO_2 emissions, Gg.

Sector	1990	2000	2005	2010	2012	2013	2015	2020	2025	2030	2035
Public power	22755	22555	19758	20320	13146	14345	12757	6435	5472	4195	4427
District heating plants	1940	549	417	963	964	838	928	1073	1062	813	697
Petroleum refining plants	906	998	938	854	984	964	964	964	964	964	964
Oil/gas extraction	545	1461	1619	1488	1437	1379	1407	1352	1601	1888	2128
Commercial and institutional plants	1413	898	952	848	653	729	737	736	717	684	649
Residential plants	4965	3987	3622	2981	2062	2482	2298	1898	1679	1509	1364
Plants in agriculture, forestry and aquaculture	587	734	616	335	249	268	264	265	263	260	258
Combustion in industrial plants	4603	5138	4598	3472	3213	3136	2990	2556	2427	2334	2181
Total	37714	36320	32519	31261	22708	24141	22345	15279	14185	12648	12667

CO_2 is the dominant GHG for stationary combustion and comprises, in 2013, approximately 98 % of total emissions in CO_2 equivalents. The most important CO_2 source is the public power sector, which contributes with about 58 % in 2012 to the total emissions from stationary combustion plants. Other important sources are combustion plants in industry, residential plants, district heating plants and oil/gas extraction. The emission of CO_2 decreases by 48 % from 2013 to 2035 due to lower fuel consumption and a fuel shift from coal and natural gas to wood and municipal waste.

2.5.2 CH_4 emissions

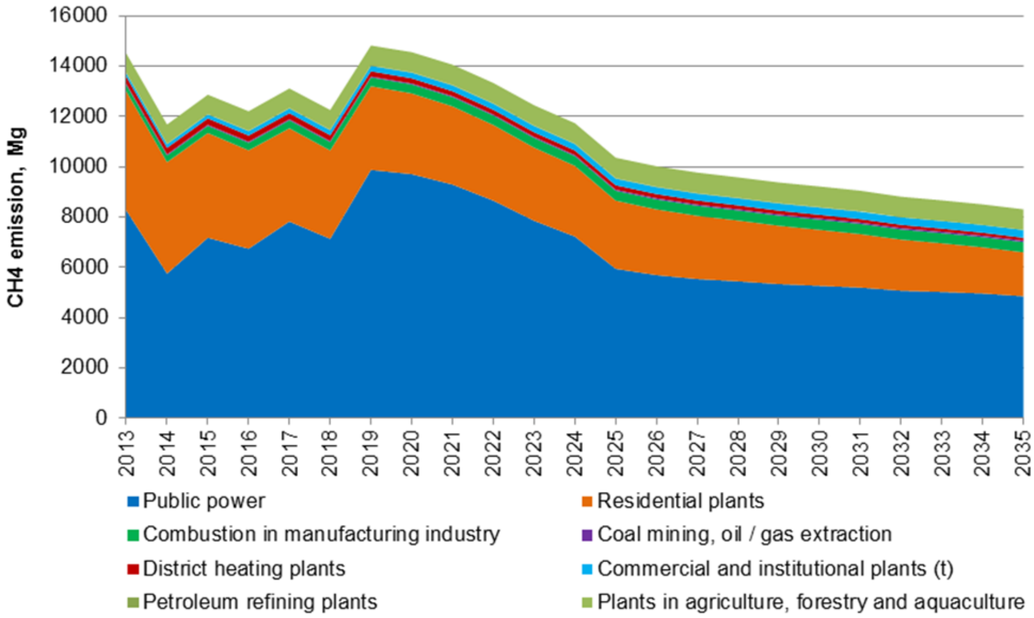

Figure 2.6 CH_4 emissions by sector.

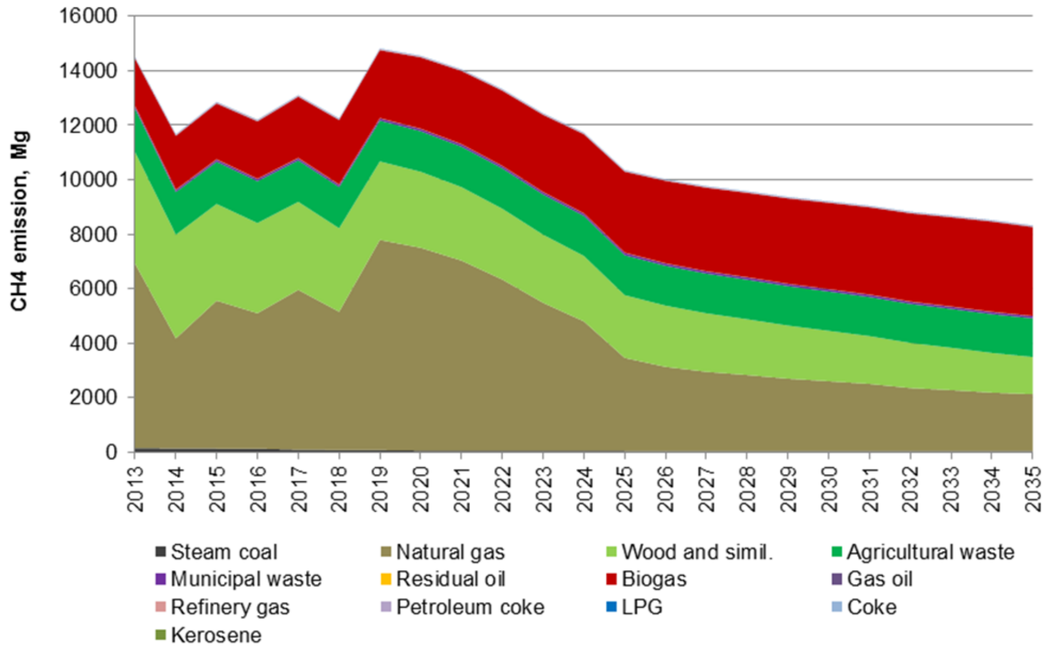

Figure 2.7 CH_4 emissions by fuel.

Table 2.4 CH_4 emissions, Mg.

Sector	1990	2000	2005	2010	2012	2013	2015	2020	2025	2030	2035
Public power	426	14466	12184	10668	6064	8267	7176	9707	5944	5267	4854
District heating plants	170	167	192	279	283	280	250	199	171	136	104
Petroleum refining plants	18	21	19	17	19	20	20	20	20	20	20
Oil/gas extraction	16	43	48	44	43	41	41	40	47	56	63
Commercial and institutional plants	114	901	814	683	480	137	158	225	264	291	314
Residential plants	3862	5029	6216	6514	5453	4736	4166	3208	2712	2224	1742
Plants in agriculture, forestry and aquaculture	1085	2462	2183	1381	1107	764	766	799	812	818	821
Combustion in industrial plants	273	1028	837	543	370	260	288	359	392	405	409
Total	5965	24117	22493	20129	13819	14504	12865	14557	10361	9215	8327

The two largest sources of CH_4 emissions are public power and residential plants, which also fit well with the fact that natural gas, especially combusted in gas engines, biogas and wood when used in residential plants are the fuels contributing the most to the CH_4 emission. There is a significant increase in emissions from 1990 to 2000 due to the increased use of gas engines during the 1990s. Beginning around 2004, the natural gas consumption has begun to show a decreasing trend due to structural changes in the Danish electricity market. The very significant increase in CH_4 emission from biogas is due to the increasing use of biogas, combined with high emission factors when biogas is combusted in gas engines.

2.5.3 N_2O emissions

The contribution from the N_2O emission to the total GHG emission is small and the emissions stem from various combustion plants.

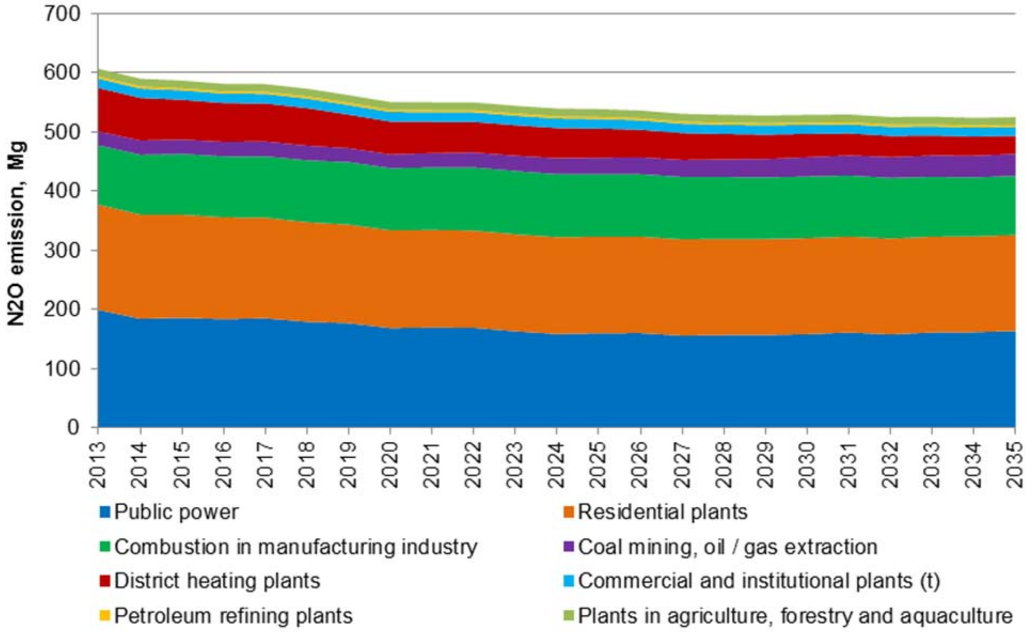

Figure 2.8 N_2O emissions by sector.

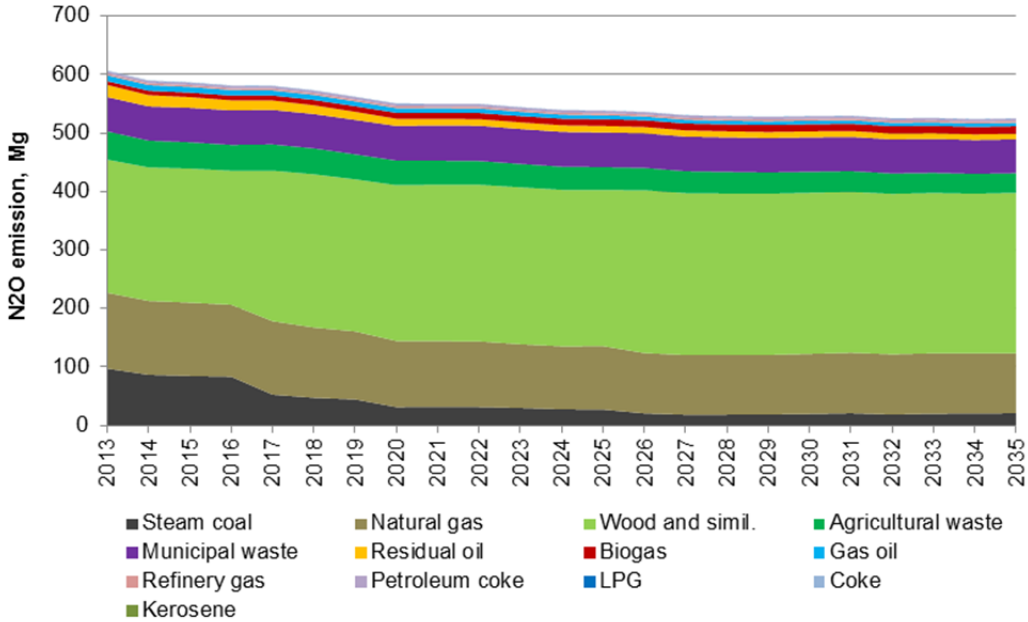

Figure 2.9 N_2O emissions by fuel.

Table 2.7 N_2O emissions, Mg.

Sector	1990	2000	2005	2010	2012	2013	2015	2020	2025	2030	2035
Public power	202	275	261	267	193	199	186	169	160	158	164
District heating plants	64	42	50	78	84	73	67	55	49	39	31
Petroleum refining plants	2	7	5	3	4	4	4	4	4	4	4
Oil/gas extraction	9	26	28	26	25	24	24	23	28	33	37
Commercial and institutional plants	17	15	19	17	14	16	16	16	16	16	15
Residential plants	106	118	162	200	174	178	174	165	163	162	162
Plants in agriculture, forestry and aquaculture	21	17	16	14	13	13	13	13	13	13	13
Combustion in industrial plants	166	210	177	153	136	100	103	105	106	104	100
Total	586	710	718	759	642	607	587	551	539	529	525

2.6 Model description

The software used for the energy model is Microsoft Access 2010, which is a Relational Database Management System (RDBMS) for creating databases. The database is called the 'Fremskrivning 2013-2035' and the overall construction of the database is shown in Figure 2.10.

The model consists of input data collected in tables containing data for fuel consumption and emission factors for combustion plants larger than 25 MW_e and combustion plants smaller than 25 MW_e. 'Area' and 'Point' in the model refer to small and large combustion plants, respectively. However, gas engines as a group is also treated as a point source due to the different emission profile for this type of plant compared to other combustion technologies. The names and the content of the tables are listed in Table 2.8.

Table 2.5. Tables in the 'Fremskrivning 2011-2035'.

Name	Content
tblEmfArea	Emission factors for small combustion plants
tblActArea	Fuel consumption for small combustion plants
tblEmfPoint	Emission factors for large combustion plants
tblActPoint	Fuel consumption for large combustion plants

From the data in these tables a number of calculations and unions are created by means of queries. The names and the functions of the queries used for calculating the total emissions are shown in Table 2.9.

Table 2.6. Queries for calculating the total emissions.

Name	Function
qEmission_Area	Calculation of the emissions from small combustion plants.
	Input: tbArea_act and tblEmfArea
qEmission_Point	Calculation of the emissions from large combustion plants.
	Input: tblPoint_act and tblEmfPoint
qEmission_All	Union of qEmission_Area and qEmission_Point

Based on some of the queries a large number of summation queries are available in the 'Fremskrivning 2011-2035' (Figure 2.11). The outputs from the summation queries are Excel tables.

Name	Output
qxls_Emission_All	Table containing emissions for SNAP groups, Years and Pollutants
qxls_Emission_Area	Table containing emissions for small combustion plants for SNAP groups, Years and Pollutants
qxls_Emission_Point	Table containing emissions for large combustion plants for SNAP groups, Years and Pollutants
qxlsActivityAll	Table containing fuel consumption for SNAP groups, Years and Pollutants
qxlsActivityPoint	Table containing fuel consumption for large combustion plants for SNAP groups, Years and Pollutants

Table 2.7 Summation queries.

All the tables and queries are connected and changes of one or some of the parameters in the tables result in changes in the output tables.

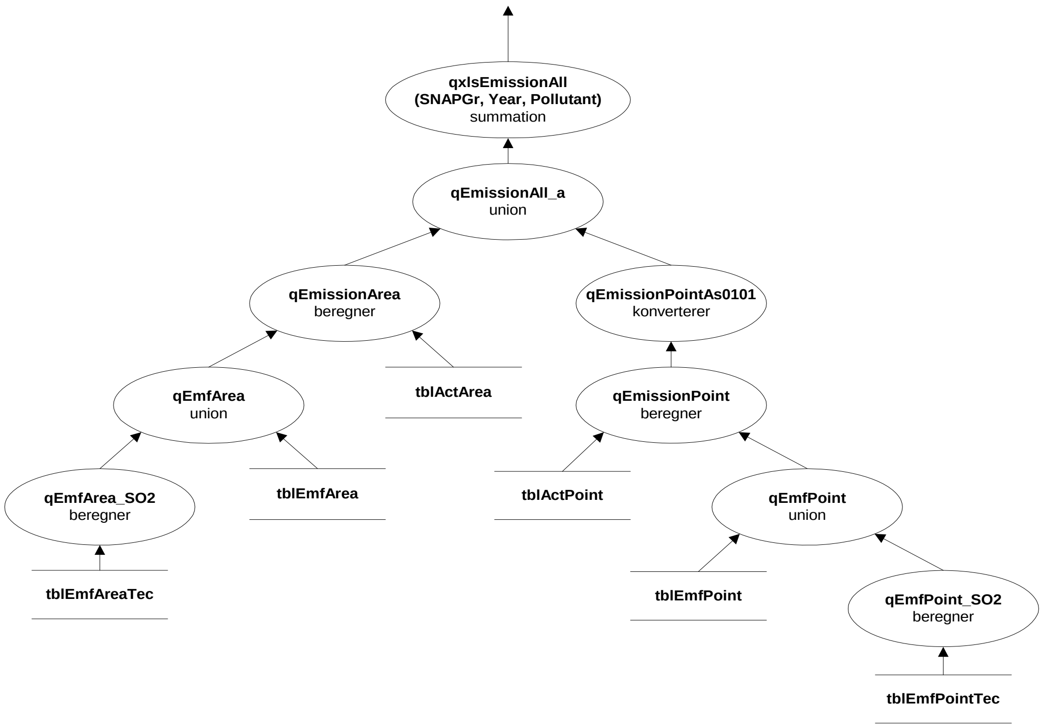

Figure 2.10 The overall construction of the database.

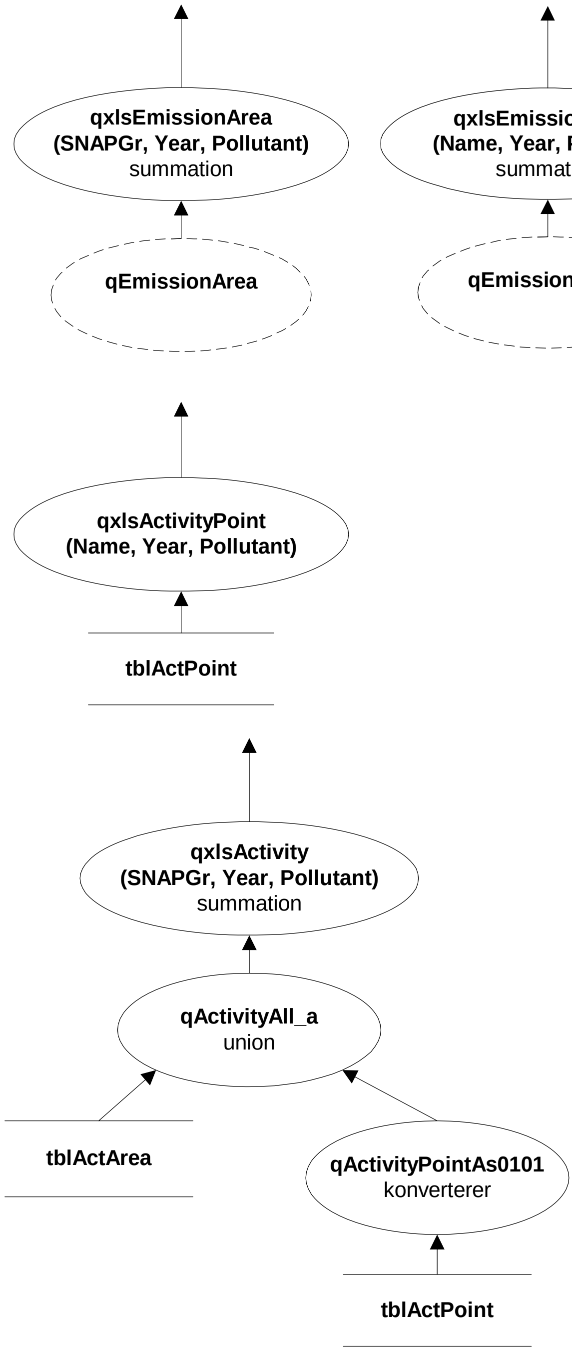

Figure 2.11 Summation queries.

2.7 Recalculations

2.7.1 Recalculations in fuel consumptions

Energy consumption in the model is based on the Danish Energy Agency's energy projections and energy projections for individual plants (Danish Energy Agency, 2014a and 2014b). All recalculations made in these projections are directly observable in the present submission.

The projected fuel consumptions are lower now than in last year's submission.

Especially, the projected consumption of coal is significantly lower compared to the previous projection, while the projected consumption of wood is higher.

2.7.2 Recalculations for emission factors

Emission factors have been revised according to the emission inventory reported in 2014. This update cause only minor recalculations.

Emission factors that refer to the IPCC Guidelines have been updated according to the revised 2006 Guidelines (IPCC, 2006). Both historic and projected emission data have been revised. This revision causes the estimated CO_2 emission in 2012 to decrease less than 0.01 %. The CH_4 emission inventory for 2012 decreases by 3 % and the N_2O emission increases by 12%.

The emission factors time series for CH_4 from residential wood combustion have been revised according to improved data for technology replacement.

The CO_2 emission factor for natural gas has been updated to the value for 2013.

Finally, the EU ETS data for 2011 and 2012 have been implemented for coal, residual oil, refinery gas and natural gas applied in off shore gas turbines.

2.8 References

Astrup, T., Larsen, A.W., Fuglsang, K. & Pedersen, N.H. 2012: PSO-0213, Biogenic Carbon in Danish Combustable Waste. DTU 2012. In press.

Danish Energy Agency, 2014a: Energy projections 2013-2035, September 2014.

Danish Energy Agency, 2014b: Energy projections 2013-2035 of individual plants, RAMSES, September 2014.

EMEP/EEA, 2013: EMEP/EEA air pollutant emission inventory guidebook 2013. Technical report No 12/2013. Available at: http://www.eea.europa.eu/publications/emep-eea-guidebook-2013

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Nielsen, M., Gyldenkærne, S., Mikkelsen, M.H., Albrektsen, R., Thomsen, M., Hjelgaard, K., Hoffmann, L., Fauser, P., Bruun, H.G., Johannsen, V.K., Nord-Larsen, T., Vesterdal, L., Møller, I.S., Caspersen, O.H., Rasmussen, E., Petersen, S.B., Baunbæk, L. & Hansen, M.G. 2014. Denmark's National Inventory Report 2014. Emission Inventories 1990-2012 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Aarhus University, DCE – Danish Centre for Environment and Energy, 1214pp. Scientific Report from DCE – Danish Centre for Environment and Energy. http://www.dce2.au.dk/pub/SR101.pdf

3 Oil and gas extraction (Fugitive emissions from fuels)

This chapter includes fugitive emissions in the CRF sector 1B. The sources included in the Danish emission inventory and in this projection are listed in Table 3. 1. The following chapters describe the methodology, activity data, emission factors and emissions in the projection. For a detailed description of the emission inventory for the historical years, please refer to Plejdrup et al. (2009).

Table 3.1 List of the IPCC sectors and corresponding SNAP codes for the categories included in the Danish emission inventory model for greenhouse gases.

IPCC sectors	SNAP code	SNAP name	Activity
	04	Production processes	
1 B 2 a 4	040101	Petroleum products processing	Oil
1 B 2 a 4	040103	Other	Oil
	05	Extraction and distribution of fossil fuels and geothermal energy	
1 B 2 a 2	050201	Land-based activities	Oil
1 B 2 a 2	050202 *	Off-shore activities	Oil
1 B 2 b/1 B 2 b 3	050601	Pipelines	Natural gas/Transmission
1 B 2 b/1 B 2 b 4	050603	Distribution networks	Natural gas/Distribution
	09	Waste treatment and disposal	
1 B 2 c 2 1	090203	Flaring in oil refinery	Venting and flaring
1 B 2 c 2 2	050699	Venting in gas storage	Venting and flaring
1 B 2 c 2 2	090206	Flaring in oil and gas extraction	Venting and flaring

*In the Danish inventory emissions from extraction of gas are united under “Extraction, 1st treatment and loading of liquid fossil fuels/off-shore activities” (IPCC 1B2a/SNAP 050202).

3.1 Methodology

The methodology for the emission projection corresponds to the methodology in the annual emission inventory, based on the EMEP/EEA Guidebook (EMEP/EEA, 2013).

Activity data are based on official forecasts by the Danish Energy Agency on offshore production and flaring of oil and natural gas (the oil and gas prognosis), and on fuel consumption (the energy consumption prognosis).

Emission factors are based on either the EMEP/EEA guidelines (EMEP-/EEA, 2013), IPCC guidelines (IPCC 2006), or are country-specific based on data for the latest historical years.

3.2 Activity data

The prognosis for the production of oil and gas (DEA, 2014b) is shown in Figure 3.1. The gas production is assumed to decrease over the projection period, while the oil production decreases in the first years, followed by an increase to end up at the same level in 2035 as in 2013. The prognosis includes reserves (production at existing facilities and including justified projects for development), technological resources (estimated additional production due to new technological initiatives, e.g. CO_2 injection) and prospective resources (estimated production from new discoveries). Further, the production prognosis includes offshore flaring. The flaring amounts are expected according to the DEA projection to show a large decrease from 2013 to 2014 followed by a slight decrease over the remaining projection period.

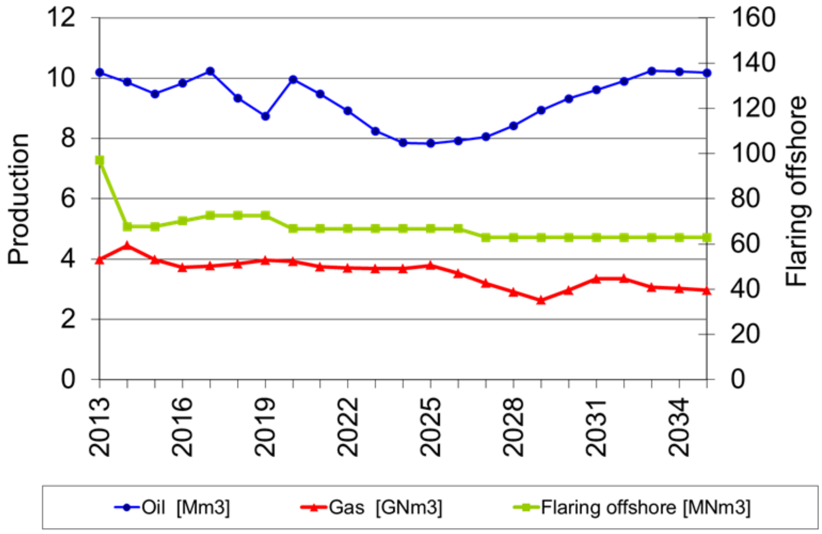

Figure 3.1 Prognosis for the production of oil and gas (DEA, 2014b).

The DEA prognosis of the production of oil and gas are used in projection of a number of sources: extraction of oil and natural gas, transport of oil in pipelines, onshore and offshore loading of ships and offshore flaring.

Data from the energy consumption prognosis by the DEA (2014a) are applied in the projection of fugitive emissions from fuels. Consumption of natural gas is used as proxy to project transmission of natural gas.

3.3 Emission factors

For some sources the emission factors are based on the EMEP/EEA Guidebook (EMEP/EEA, 2013). This is the case for onshore and offshore loading and flaring. For loading of ships the guidebook provides emission factors for different countries. The Norwegian emission factors are applied in the Danish projection. The CH_4 emission factor for onshore loading given in the guidebook has been reduced by 21 % in the projection period due to introduction of new vapour recovery unit (VRU) at the Danish oil terminal in 2010 (Spectrasyne Ltd, 2010). Further, a new degassing system has been built and taken into use medio 2009, which reduced the CH_4 emissions from oil tanks by 53 % (Spectrasyne Ltd, 2010). CH_4 emissions from oil tanks in the projection period are estimated as the emission in the latest historical year scaled to the annual oil production.

Table 3.2 Emission factors for 2011-2035.

Source	CH_4	Unit	Ref.
Ships offshore	0.00005	Fraction of loaded	EMEP/EEA, 2013
Ships onshore	0.0000079	Fraction of loaded	EMEP/EEA, 2013; Spectrasyne Ltd, 2010

Emissions of CO_2 for flaring offshore and in refineries are based on EU-ETS. For flaring offshore the average emission factor based on EU-ETS data for 2008-2012 are applied for the projection years.

The CH_4 emission factor for flaring in refineries is based on detailed fuel data from one of the two refineries (Statoil, 2009).

N_2O emission factors are taken from the EMEP/EEA Guidelines (2013) for flaring offshore and in refineries.

The fuel consumption and flaring amounts for refineries in the DEA prognosis (DEA, 2012a) are constant for the projection period, and correspondingly the emissions from fugitive emissions and flaring in refineries for 2012 are applied for the projection years 2013-2035.

For remaining sources where the emissions in historical years are given by the companies in annual reports or environmental reports, implied emission factors for the average of the latest five historical years are applied for the projection years. This approach is applied for transmission and distribution of natural gas and town gas, and for venting and flaring in gas storage and treatment plants.

3.4 Emissions

The majority of the emissions are calculated due to the standard formula (Equation 1) while the emissions in the last historical year, given in e.g. annual reports, are adopted for the remaining sources.

$$E_{s,t} = AD_{s,t} * EF_{s,t} \qquad \text{(Equation 1)}$$

where E is the emission, AD is the activity data and EF is the emission factor for the source s in the year t.

Table 3.3 include CH_4 emission on sub-sector level in selected historical years and projection years. The total fugitive CH_4 emission is expected to decrease in the projection period. The decrease is mainly caused by a decrease in production of gas and oil, which contribute to lower the CH_4 emissions from offshore extraction and offshore loading of ships. Emissions of CH_4 are also shown in Figure 3.2 for selected years in the time series 1990-2035.

Table 3.3 CH_4 emissions, Mg, in historical years (1990, 1995, 2000, 2005, 2010, 2012) and projection years (2013, 2015, 2020, 2025, 2030, 2035).

	1990	1995	2000	2005	2010	2012
Refining	37	125	188	716	2.219	2.227
Oil, onshore activities	817	1.271	1.809	2.225	1.047	837
Oil, offshore activities	1.956	2.408	4.514	4.558	3.153	2.208
Gas, transmission and distribution	448	907	311	383	170	160
Venting and flaring	1.208	1.745	2.732	2.021	1.332	816
Total	4.467	6.456	9.555	9.903	7.920	6.248

Continued	2013	2015	2020	2025	2030	2035
Refining	2.188	2.188	2.188	2.188	2.188	2.188
Oil, onshore activities	727	677	711	559	727	665
Oil, offshore activities	1.841	1.831	1.799	1.780	1.569	1.522
Gas, transmission and distribution	171	145	100	70	39	50
Venting and flaring	1.119	808	798	798	757	757
Total	6.045	5.649	5.596	5.396	5.280	5.182

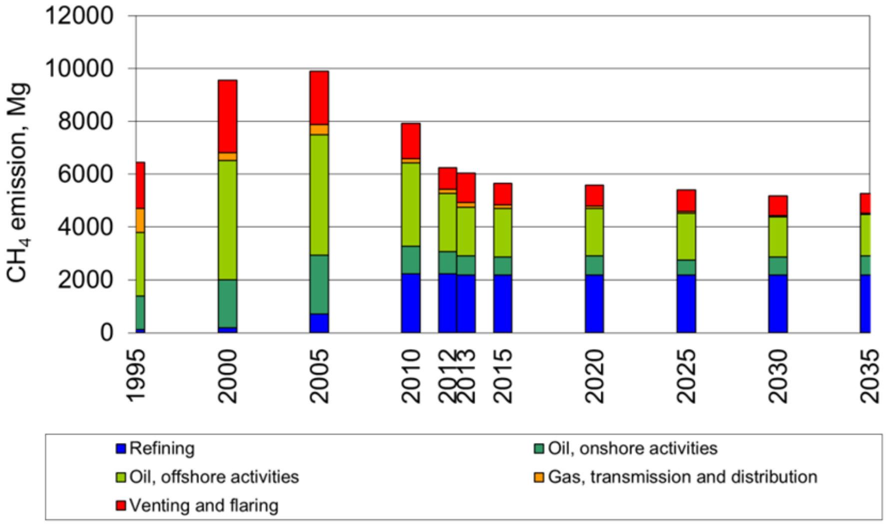

Figure 3.2 CH_4 emissions for selected years in the time-series 1990-2035 by sector.

By far the major source to fugitive emissions of CO_2 is offshore flaring (Figure 3.3). CO_2 emissions from offshore flaring peaked in 1999 and have shown a decreasing trend over the following historical years. In the projection years the annual emission from offshore flaring is rather constant. The increase from the latest historical year 2012 and the first projection year 2013 owe to the applied methodology in the projection. The CO_2 emission from offshore flaring is estimated from the projected flaring amounts (DEA, 2014b) and an average emission factor for the years 2008-2012. The CO_2 emission factor in 2012 was 2,707 kg/Nm^3, while the average emission factor applied in the projection is 2,978 kg Nm^3.

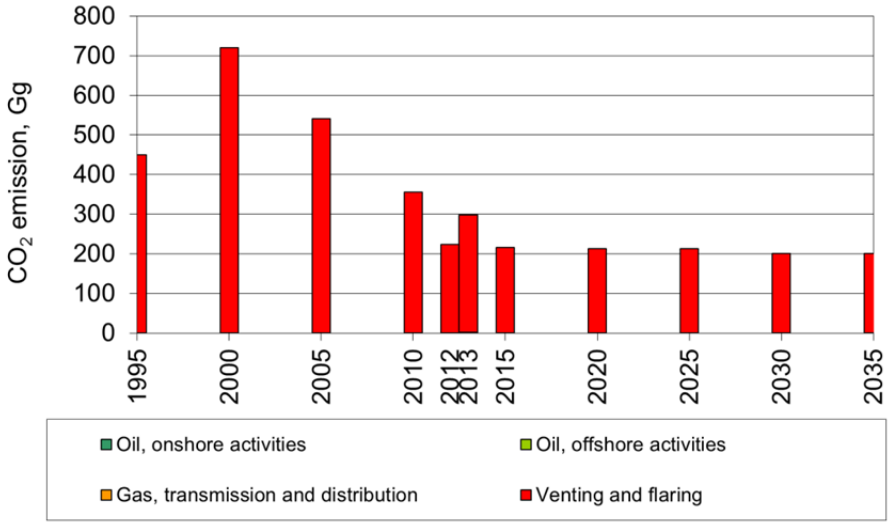

Figure 3.3 CO_2 emissions for selected years in the time-series 1990-2035 by sector.

The summarised greenhouse gas emissions for selected historical years and projection years are shown in Figure 3.4 on sub-sector level. The main source to fugitive GHG emissions is CO_2 from offshore flaring, but also production of oil and gas, oil storage at the raw oil terminal, and fugitive emissions from refineries contribute. Emissions from onshore activities (storage of oil and loading of ships) have shown a large decrease from 2005 to 2010 due to new technology. The only source of N_2O emissions in the fugitive emission sector is flaring offshore, in refineries and in gas storage and treatment plants. The fugitive N_2O emission is very limited.

The GHG emissions from flaring and venting dominate the summarised GHG emissions. The GHG emissions reached a maximum in year 2000 and show a decreasing trend in the later historical years and in the projection years. The decrease owe to decreasing production amounts of oil and natural gas and to better technologies leading to less flaring on the offshore installations. The increase from 2012 to 2013 owe to the methodology applied in the projection, where an implied emission factor is used for CCO2 emission calculation. The implied emission factor is calculated as the average emission factor for the years 2008-2012.

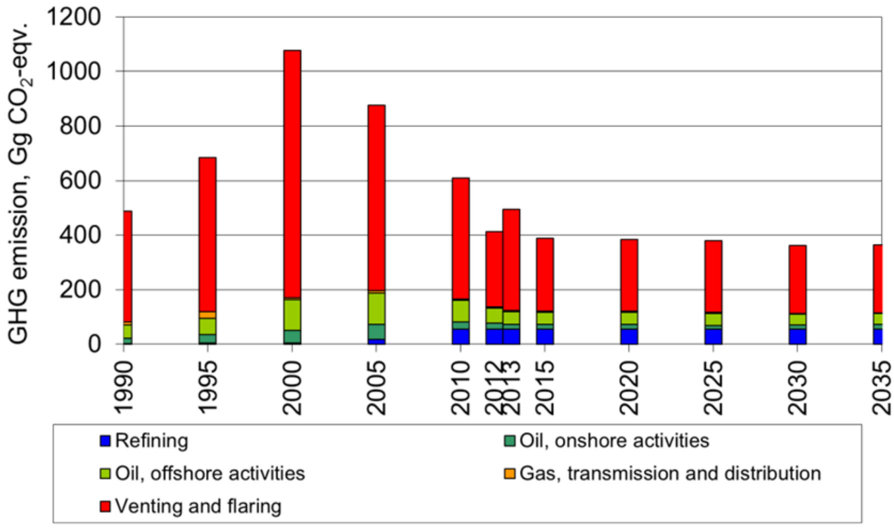

Figure 3.4 GHG emissions for selected years in the time-series 1990-2035.

3.5 Model description

The model for projection of fugitive emissions from fuels, the "Fugitive emissions projection model", is created in Microsoft Excel. The projection model is built in accordance with the model used in the national emission inventory system; the "Fugitive emission model". For sources where the historical emissions are used to estimate emissions in the projection years, the "Fugitive emissions projection model" links to the "Fugitive emission model". Historical emission from Refineries and transmission/distribution of gas are treated in separate workbook models ("Refineries" and "Gas losses"). The names and content of the sub models are listed in Table 3.4.

Table 3.4 Tables in the 'Fugitive emissions projection model'.

Name	Content
Projection Fugitive emissions projection model	Activity data and emission factors for extraction of oil and gas, loading of ships and storage in oil tanks at the oil terminal for the historical years 1990 to 2012 plus prognosis and projected activity rates and emission factors for the projection years 2013 to 2035. Further, the resulting emission the projection years for all sources in the fugitive sector are stored in the worksheet "Projected emissions".
Refineries	Activity data and emission factors for refining and flaring in refineries for the historical years 1990-2012.
Gas losses	Activity data and emission factors for transmission and distribution of natural gas and town gas for the historical years 1990-2012.

Activity data, emission factors, calculations and results are kept in separate sheets in the sub models. Changing the data in the input data tables or emission factor tables will automatically update the projected emissions.

3.6 References

Danish Energy Agency, 2014a: Energy consumption prognosis 2013-2035, September 2014.

Danish Energy Agency, 2014b: Oil and gas production prognosis 2013-2035, May 2014.

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Plejdrup, M.S., Nielsen, O.-K. & Nielsen, M. 2009: Emission Inventory for Fugitive Emissions in Denmark. National Environmental Research Institute, Aarhus University, Denmark. 47 pp. – NERI Technical Report no. 739. Available at: http://www.dmu.dk/pub/FR739.pdf

Spectrasyne Ltd (2009): Fugitive Hydrocarbon Emission Survey of 8 Crude Oil Storage Tanks at DONG, Fredericia. Spectrasyne, Environmental Surveying, Sep/Oct 2009.

Statoil A/S, 2009: Personal communication. September 2009.

4 Industrial processes and product use

4.1 Sources

Industrial processes and product use includes the CRF categories 2*A Mineral Industries, 2B Chemical Industries, 2C Metal Industries, 2D Non-Energy Products from Fuels and Solvent Use, 2F Product Use as Substitutes for Ozone Depleting Substances, 2G Other Product Manufacturing and Use* and *2H Other*. A range of sources is covered within each of these categories; the included sources are shown in Table 4.1.

Table 4.1 Sources/processes included in the projection of process emissions.

IPCC code			Sources/processes	SNAP code
2A	Mineral industry	2A1	Cement production	04 06 12
		2A2	Lime production	04 06 14
		2A3	Glass production	04 06 13
		2A4	Other process uses of carbonates	
		-	2A4a Ceramics	04 06 91/92
		-	2A4d Flue gas cleaning	04 06 18
		2A5	Other	
		-	Mineral wool production	04 06 18
2B	Chemical industry	2B10	Other	
		-	Catalysts/fertilisers	04 04 16
2C	Metal industry	2C1	Iron and steel production	04 02 08
2D	Non-energy products from fuels and solvent use	2D1	Lubricant use	06 06 04
		2D2	Paraffin wax use	06 06 04
		2D3	Other	
		-	Solvent use	06 04
		-	Asphalt roofing	04 06 10
		-	Road paving with asphalt	04 06 11
		-	Fireworks	06 06 01
		-	Barbeques	06 06 04
		-	Tobacco	06 06 02
2F	Product Use as Substitutes for Ozone Depleting Substances	2F1	Refrigeration and air conditioning	06 05 02
		2F2	Foam blowing agents	06 05 04
		2F4	Aerosols	06 05 06
2G	Other product manufacture and use	2G1	Electrical equipment	
		-	2G1b Use of electrical equipment	06 05 07
		2G2	SF6 and PFCs from product use	
		-	2G2c Double-glazed windows	06 05 08
		2G3	N_2O from product use	
		-	2G3a Medical applications	06 05 01
2H	Other	2H2	Food and beverages industry	
		-	Refining of sugar	04 06 25

The projection of emissions from industrial processes is based on the national emissions inventory (Nielsen et al., 2014).

4.2 Methodology

The projection of greenhouse gas (GHG) emissions includes CO_2, N_2O, NMVOC, HFC, PFC and SF_6.

The emission projections are for some of the industrial sources based on projected production values for the energy and production industries. These production value projections are available for steel-, glass- and cement industry, building/construction and incineration of coal and waste for energy production; see Table 4.3 and (Danish Energy Agency, 2014a; 2014b).

For *Substitutes for Ozone Depleting Substances*, also known as F-gasses, emission projections are based on an F-gas projection done by Poulsen & Werge (2012).

For the remaining sources emissions, projections are based on historical emissions.

For more detailed information on the methodologies and sources used within the different categories, find the relevant category descriptions in the sections 4.2.1 to 4.2.7 below.

4.2.1 2A – Mineral Industry

There are nine sources of GHG emissions within the CRF category *2A Mineral Industry*; production of cement, lime, glass, glass wool, yellow bricks, expanded clay and mineral wool along with flue gas cleaning at combined heat and power plants (CHPs) and at waste incineration plants (WIPs), see Table 4.2.

Table 4.1 Sources/processes included in *2A Mineral Industry*.

		Sources/processes
2A1	Cement production	Cement production
2A2	Lime production	Lime production
2A3	Glass production	Glass production Glass wool production
2A4	Other process uses of carbonates	Ceramics - Yellow bricks - Expanded clay Flue gas cleaning - at CHPs - at WIPs
2A5	Other	Mineral wool production

Cement production is the major CO_2 source within industrial processes. Information on the emission of CO_2 in 2013 is based on the company report to EU-ETS (Aalborg Portland, 2014). The emission for 2014-2035 is estimated by extrapolating the average value for the historical years 2009-2013 with a factor based on projected production values for "cement industry" (Danish Energy Agency, 2014b).

Table 4.2 Extrapolation factors for estimation of CO_2 emissions from industrial processes based on production and energy value projections by Danish Energy Agency (2014a; 2014b).

	Steel industry	Glass industry	Cement industry	Building and construction	Central plants CHP, Coal/coke	Decentral plants WIP, Waste
2012	1	1		1	1	1
2013	1.03	1.03	1	1.08	1.10	1.19
2014	1.09	1.09	1.04	1.13	0.98	1.19
2015	1.15	1.15	1.04	1.12	0.96	1.19
2016	1.20	1.19	1.07	1.15	0.95	1.20
2017	1.25	1.24	1.10	1.18	0.58	0.20
2018	1.32	1.30	1.13	1.22	0.52	1.19
2019	1.38	1.37	1.17	1.26	0.49	1.18
2020	1.44	1.42	1.20	1.30	0.33	1.19
2021	1.49	1.47	1.23	1.33	0.34	1.22
2022	1.54	1.52	1.25	1.35	0.34	1.21
2023	1.56	1.55	1.28	1.38	0.32	1.20
2024	1.58	1.57	1.29	1.39	0.29	1.19
2025	1.60	1.58	1.30	1.40	0.28	1.19
2026	1.61	1.59	1.31	1.41	0.20	1.19
2027	1.63	1.62	1.33	1.43	0.18	1.19
2028	1.64	1.62	1.34	1.45	0.18	1.18
2029	1.65	1.63	1.36	1.46	0.18	1.18
2030	1.69	1.67	1.38	1.48	0.19	1.18
2031	1.68	1.67	1.39	1.50	0.21	1.18
2032	1.69	1.68	1.40	1.51	0.18	1.17
2033	1.68	1.67	1.41	1.53	0.20	1.17
2034	1.68	1.66	1.42	1.53	0.21	1.17
2035	1.72	1.70	1.45	1.56	0.21	1.17

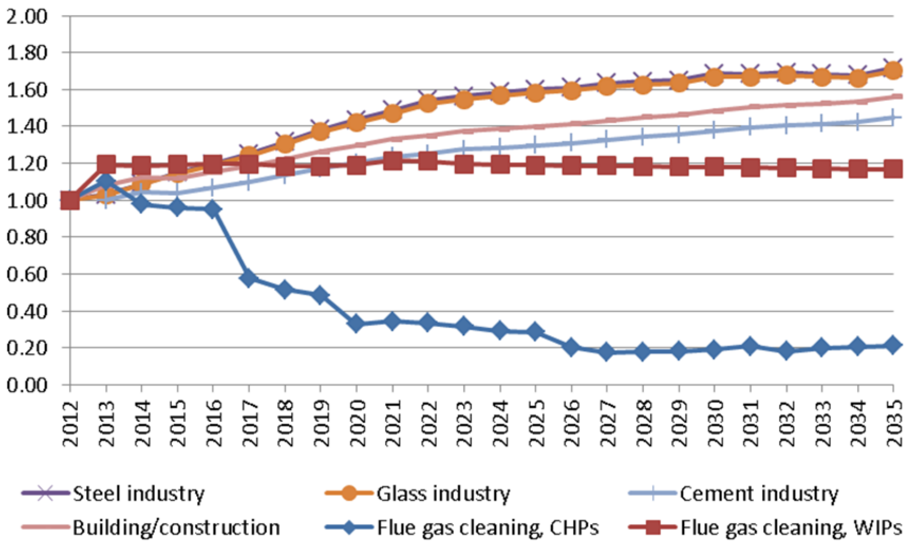

Figure 4.1 Extrapolation factors for estimation of CO_2 emissions from industrial processes based on production and energy value projections by Danish Energy Agency (2014a; 2014b).

Lime is used for a number of different applications. There are no projected production values available for lime production and the emission for 2013-2035 is therefore estimated to be the constant average value for 2008-2012.

Glass is mainly produced for packaging. The emission for 2013-2035 is estimated by extrapolating the average value for the historical years 2008-2012 with a factor based on projected production values for “glass industry” (Danish Energy Agency, 2014b); see Table 4.3.

Production of building materials i.e. glass wool, yellow bricks, expanded clay products and stone wool contributes significantly to industrial process emissions. The emissions for 2013-2035 are estimated individually for the four sources by extrapolating the average value for the historical years 2008-2012 with a factor based on projected production values for “building and construction” (Danish Energy Agency, 2014b); see Table 4.3.

Consumption of lime for flue gas cleaning depends primarily on the consumption of coal at combined heat and power plants (CHPs) and waste at waste incineration plants (WIPs). The emissions for 2013-2035 are estimated individually for the two sources by extrapolating the average value for the historical years 2008-2012 with a factor based on projected consumption values of “coal and coke” and “waste” respectively; see Table 4.3 and Figure 4.1.

The calculated emission projections are shown in Table 4.7 and Table 4.8.

4.2.2 2B – Chemical Industry

There is only one source of GHG emissions within the emission projection of CRF category *2B Chemical Industry*; production of catalysts/fertilisers categorised under *2B10 Other*.

Historically the emission in CO_2 equivalents declines sharply in 2004 as the production of nitric acid ceased in mid-2004 (Kemira, 2004). There are no projected production values available for the production of catalysts/fertilisers; the emission for 2013-2035 is therefore estimated to be the constant average value for 2008-2012

4.2.3 2C – Metal Industry

There has been no production at Danish steelworks since 2006. There is also no planned reopening of these productions and there are therefore no projected emissions from this category in the time series 2013-2035.

4.2.4 2D – Non-Energy Products from Fuels and Solvent Use

This category includes CO_2, N_2O and NMVOC emissions from the source categories 2D1 Lubricant use, 2D2 Paraffin wax use, 2D3 Other; Solvent use (Paint application, Degreasing and dry cleaning , Chemical products, manufacture and processing and Other solvent and product use), Road paving with asphalt, Asphalt roofing, Fireworks, Tobacco and Barbeques.

The projections are based on the historical emissions calculated for the period 1990 – 2012. The emission inventory methodology is based on the detailed approach described in EMEP/CORINAIR (2004) and emissions are calculated for industrial sectors, households in the CRF categories mentioned above, as well as for individual chemicals and/or chemical groups. Further details on the inventory methodology can be seen in Nielsen et al. (2014).

4.2.5 2F – Product Uses as Substitutes for Ozone Depleting Substances

There are three sources of GHG emissions within the projection of the CRF category *2F Product Uses as Substitutes for Ozone Depleting Substances* (ODS); "refrigeration and air conditioning", "foam blowing agents" and "aerosols".

Emission projections from this source category include eight HFCs and one PFC.

The fluorinated gases (F-gases) comprise HFCs, PFCs and SF_6. They all contain fluorine, hence the name F-gases. None of the F-gases are produced in Denmark. The emission of these gases is therefore associated only with their use.

An account of the annual consumption and emission of F-gases is prepared by a consultant on behalf of the Danish Environmental Protection Agency (DEPA) (Poulsen & Werge, 2012). In this connection, projections to 2020 are also prepared. Annual reports that contain both consumption and emission data are available. The present report extends that projection with projections for 2021 to 2035.

F-gases are powerful GHGs with global warming potentials (GWPs) between 124 and 22 800. F-gases, therefore, receive a great deal of attention in connection with GHG emission inventories. For many F-gas applications, the gases can be controlled and/or replaced, which has been, and continues to be, the case in Denmark. Data for the projections mentioned here take this into consideration, but the projections do not take the potential influence of new EU legislation in this field into consideration. The EU legislation will, however, only have a lowering effect on emissions from mobile air conditioning equipment. As for the remaining application areas the legislation are already covered by different existing Danish legislation. Exemptions from the Danish bans on e.g. refrigeration equipment have been taken into account in the projections. In the 2012 emission inventories the total contribution from F-gases, converted into CO_2 equivalents, constituted 1.5 % of the Danish total without CO_2 from LULUCF. Of this contribution the HFCs dominate with 99 %.

Emissions are calculated with a model for the individual substance's lifecycle over the years, taking the emissions associated with the actual processes into consideration. The processes for refrigeration and high voltage equipment are filling up/topping up, operation and destruction. For foam, the processes are production of the products in which the substances are used as well as use and destruction of the product. The model has been developed and used in connection with the annual historic emission inventories for the Climate Convention, see NIR, 2014 (Nielsen et al., 2014). As a result, the model corresponds with the guidelines produced for this purpose. For details of the model and the calculation methodologies, refer also to the DEPA's annual reports produced as a basis for the F-gas inventories.

The report and the data collected in Poulsen & Werge (2012) provides emission projections based on 'steady state' consumption with 2006 as the reference year. Cut-off dates in relation to the phasing out of individual substances, in connection with Danish regulation concerning the phasing out of powerful GHGs, are taken into account. HFCs used in foaming agents in flexible foam plastic were phased out from of January 1st 2006. Furthermore, a tax effect has been introduced for relevant applications and, as far as possible, expected increases in the use of these substances will be taken into consideration in a number of application areas – as will reductions expected. Projection of the use of HFC-404a is based on a balancing exercise, as the development of the used of HCFC-22 refrigeration systems can, on the one hand, be expected to lead to higher than predicted increases in consumption of HFC-404a in commercial refrigeration plant, as HFC-404a together with CO_2 systems are the most obvious potential substitutes. On the other hand, from January 1st 2000, building new HCFC-22-based systems has not been permitted and from January 1st 2002 substitution with HCFC-22 in existing systems has been banned.

It should be noted that the basic data for the years before 1995 is not entirely adequate with regard to coverage, in relation to actual emissions. Under the Kyoto Protocol, it is possible to choose 1995 as base year for F-gases. Due to the lack of coverage prior to 1995 this option is used in Denmark. For 2020 and onwards the emission of F gases are divided up in application areas and the tendencies seen in a graphical presentation has been continued until 2035.

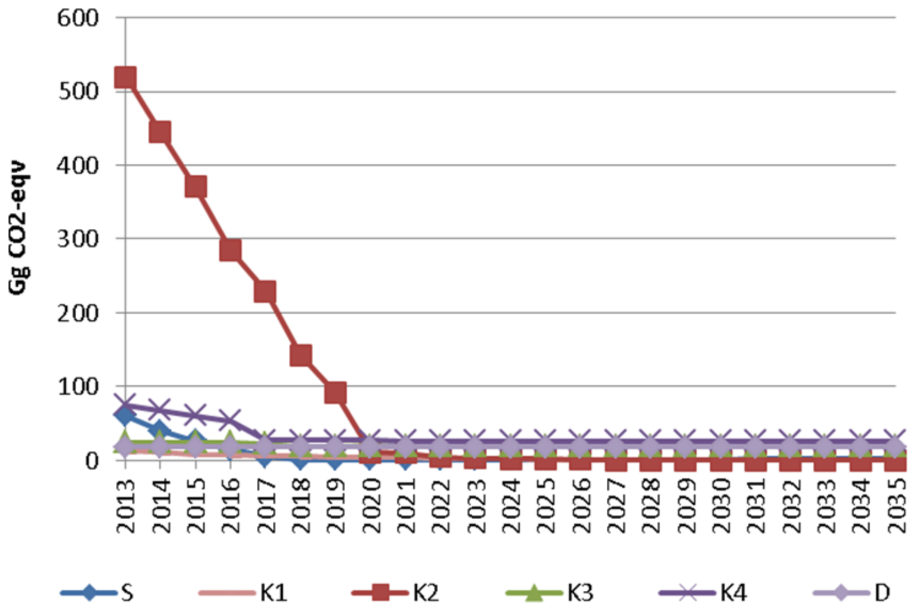

Figure 4.1 Projected F-gas emissions for the years 2013 to 2035 (Gg CO_2 eqv.). S: Foam blowing, K1 Residential refrigerant, K2 Commercial refrigerant, K3 Transport refrigerant, K4 Mobile A/C. D Aerosols.

HFCs

HFCs comprise a range of substances, of which the following, relevant for Denmark, are approved for inventory under the Climate Convention and the Kyoto Protocol (KP) with stated and approved GWP values.

Table 4.3 Global Warming Potentials (GWPs) for the HFCs.

Substance:	Typical use	GWP CO_2 eqv.
HFC-32	Fibre optics	675
HFC-125	Refrigerants	3500
HFC-134a	Refrigerants	1430
HFC-143a	Refrigerants, foam blowing	4470
HFC-152a	Foam blowing	124
Other HFCs	Refrigerants	1725

However, HFCs in Denmark are estimated in accordance with the trade names for HFC mixtures, which are put together from the "pure" HFCs listed in Table 4.5.

Table 4.4 Relationship (mass %) between HFCs, as calculated for the Climate Convention ("'pure" HFCs) and the HFC mixtures used under trade names in Denmark.

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-407c	23	25	52		
HFC-507a		50		50	

HFCs are mostly used as refrigerants in stationary and mobile air-conditioning and refrigeration systems. A minor application is in insulation foams and foams of other types.

Emissions from the use of HFC-23 are covered by category *2G1 Electrical equipment*.

PFCs

PFCs comprise a range of substances, of which only PFC-218 is relevant for source category 2F and approved for inventory under the Climate Convention and KP with stated and approved GWP values. The GWP value for PFC-218 is 8830, PCF-218 is used as a refrigerant. The use of PFCs in Denmark is limited.

Emissions of PFC-14 and PFC-318 are covered by category *2G2 SF_6 and PFCs from other product uses*.

Calculated emission projections from "product uses as substitutes for ODS" are shown in Table 4.7 and Table 4.10.

4.2.6 2G – Other Product Manufacture and Use

There are three sources of GHG emissions within the CRF category *2G Other Product Manufacture and Use*; "use of electrical equipment", "use of other products containing SF_6/PFCs" and "N_2O from medical applications".

The different substances reported within category 2G are shown in Table 4.6 along with their typical use and their respective GWPs.

Table 4.5 Global Warming Potentials (GWPs) for substances in category 2G.

Substance:	Typical use	GWP CO_2 eqv.
HFC-23	Fibre optics	14 800
PFC-14	Fibre optics	7390
PFC-318	Fibre optics	10 300
SF_6	Double glazing. high voltage equipment, laboratories	22 800
N_2O	Anaesthetics	298

In 2013 91 % of the CO_2 equivalent emission from category 2G originates from SF_6 emissions. Of this SF_6 emission 76 % is emitted from double glazed windows.

The annual F-gas report from Poulsen & Werge, (2012) contains both consumption and emission data for both historic years and projected years until 2020. For more details on this report and the model it is based on, see section 4.2.5.

The emission projections for the sources "use of electrical equipment" and "use of other products containing SF_6/PFCs" are available from Poulsen & Werge, (2012). Emissions from the "use of electrical equipment" cover HFC-23, PCF-14 and PFC-318 from fibre optics and SF_6 from high voltage equipment. The emissions from "use of other products containing SF_6 and PFCs" cover SF_6 from double glazed windows and use of SF_6 in laboratories. The use of SF_6 in connection with double-glazing was banned in 2002, but throughout the projection period there will be emission of SF_6 in connection with the disposal of double-glazing panes where SF_6 has been used.

The third source, "N_2O from medical applications", covers N_2O from medical use i.e. anaesthetics. The emission projection for this source is calculated as the constant average of the five latest historical years, 2008-2012.

The calculated emission projections are shown in Table 4.7 and Table 4.11.

4.2.7 2H – Other

The category "other" covers emissions from the food and beverage industry. There are no projected production values available for these production types and the emission for 2013-2035 is therefore estimated to be the constant average value for the historic years 2008-2012.

The calculated emission projections are shown in Table 4.7.

4.3 Emissions

The results of the GHG emission projections for the entire industrial sector are presented in Table 4.7.

In 2013 49 % of GHG emissions from *Industrial processes and product use* originate from *Mineral industry*, in 2035 the number will have increased to 80 % due to an increase in emissions from this source category but also due to a decrease in F-gas emissions (*Product uses as ODS substitutes*).

The second largest source category in respect to GHG emissions is for 2013-2018 *Product uses as ODS substitutes* with 14-35 % of emissions. Due to the strong decrease in emissions from this source category *Non-energy products from fuels and solvent use* becomes the second largest source of emissions from 2019-2035 with 13-14 %.

Table 4.6 Projection of CO_2 process emissions, Gg CO_2 equivalents.

Source Categories		1990	1995	2000	2005	2010	2011	2012	2013	2014	2015
2A	Mineral Industry	1067	1403	1614	1542	794	965	965	994	967	963
2B	Chemical Industry	1	1	1	1	2	1	1	2	2	2
2C	Metal Industry	58	73	61	0	0	0	0	0	0	0
2D	Non-energy products from fuels and solvent use	168	188	194	218	183	205	190	191	192	193
2F	Product uses as ODS substitutes	0	241	716	942	931	859	774	710	605	508
2G	Other product manufacture and use	10	66	36	31	59	93	133	145	157	143
2H	Other	4	4	4	4	2	2	2	2	2	2
	Total	1309	1975	2626	2737	1971	2125	2066	2044	1925	1811
		2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
2A	Mineral Industry	988	1003	1032	1064	1086	1114	1129	1148	1156	1167
2B	Chemical Industry	2	2	2	2	2	2	2	2	2	2
2C	Metal Industry	0	0	0	0	0	0	0	0	0	0
2D	Non-energy products from fuels and solvent use	194	195	196	197	198	199	200	201	202	203
2F	Product uses as ODS substitutes	401	307	212	161	80	78	72	69	69	68
2G	Other product manufacture and use	116	102	102	102	82	72	62	52	42	38
2H	Other	2	2	2	2	2	2	2	2	2	2
	Total	1703	1612	1547	1528	1450	1466	1467	1474	1472	1479
		2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
2A	Mineral Industry	1176	1189	1203	1213	1231	1247	1255	1264	1271	1291
2B	Chemical Industry	2	2	2	2	2	2	2	2	2	2
2C	Metal Industry	0	0	0	0	0	0	0	0	0	0
2D	Non-energy products from fuels and solvent use	205	206	207	208	209	210	211	213	214	215
2F	Product uses as ODS substitutes	67	66	65	65	65	65	65	65	65	65
2G	Other product manufacture and use	36	34	33	32	32	32	32	32	32	32
2H	Other	2	2	2	2	2	2	2	2	2	2
	Total	1486	1498	1511	1522	1540	1558	1566	1576	1585	1606

The emission projections for the individual categories are presented in the following sections.

Figure 4.3 illustrates CO_2 equivalent emission projections for the entire industrial sector divided between pollutants. Different legislation on F-gasses were introduced during the 2000s, this involved regulations such as taxes and bans. As a result F-gas emissions started to decrease in the end of the 2000s, this decreasing trend is expected to continue throughout the 2010s. The figure shows that emissions from the industrial sector are dominated by CO_2 and that of the F-gasses HFCs contributes the most to GHG emissions.

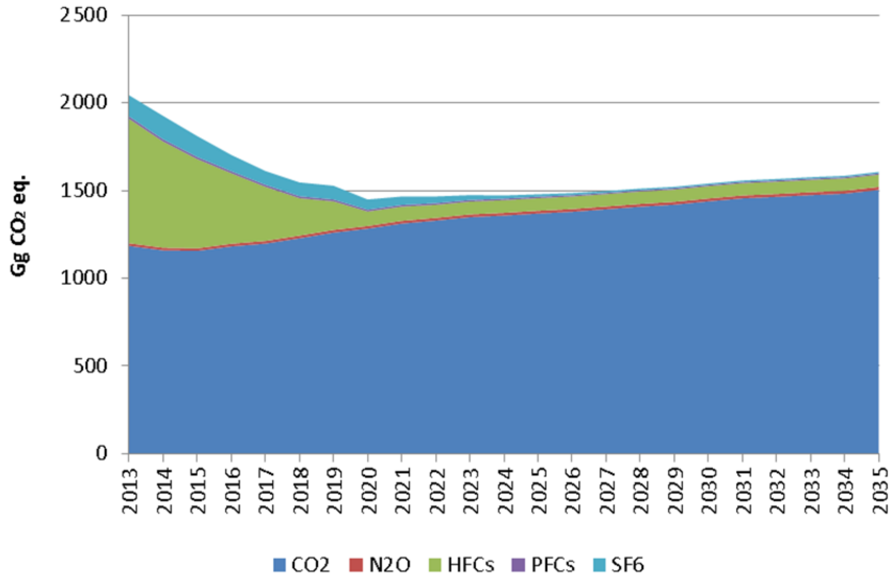

Figure 4.2 Time series for emissions, divided into individual pollutants.

4.3.1 2A – Mineral Industry

Emission projections for mineral industries are shown in Table 4.8.

Table 4.7 Emission projections for mineral industries, Gg CO_2 eqv.

		1990	1995	2000	2005	2010	2011	2012	2013	2014	2015
2A1	Cement production	882	1204	1385	1363	672	862	871	867	842	838
2A2	Lime production	116	88	77	63	46	30	40	45	45	45
2A3	Glass production	16	12	15	11	8	8	9	9	10	11
2A3	Glass wool production	2	2	1	2	1	1	1	2	2	2
2A4a	Yellow bricks production	23	29	33	32	16	20	17	21	22	22
2A4a	Expanded clay production	15	15	14	14	6	7	6	9	9	9
2A4d	Flue gas cleaning, CHP	10	49	82	51	37	29	13	33	29	28
2A4d	Flue gas cleaning, WIP	0.02	0.5	1	1	1	1	1	1	1	1
2A5	Stone wool production	4	4	6	4	7	7	7	7	7	7
	Total	1067	1403	1614	1542	794	965	965	994	967	963
		2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
2A1	Cement production	862	886	915	946	970	997	1011	1029	1038	1048
2A2	Lime production	45	45	45	45	45	45	45	45	45	45
2A3	Glass production	11	11	12	13	13	14	14	14	14	15
2A3	Glass wool production	2	2	2	2	2	2	2	2	2	2
2A4a	Yellow bricks production	23	23	24	25	26	26	27	27	27	28
2A4a	Expanded clay production	9	10	10	10	11	11	11	11	11	12
2A4d	Flue gas cleaning, CHP	28	17	15	14	10	10	10	9	9	8
2A4d	Flue gas cleaning, WIP	1	1	1	1	1	1	1	1	1	1
2A5	Stone wool production	7	7	7	8	8	8	8	8	8	9
	Total	988	1003	1032	1064	1086	1114	1129	1148	1156	1167
		2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
2A1	Cement production	1058	1072	1085	1095	1111	1126	1134	1142	1149	1168
2A2	Lime production	45	45	45	45	45	45	45	45	45	45
2A3	Glass production	15	15	15	15	15	15	15	15	15	16
2A3	Glass wool production	2	2	2	2	2	2	3	3	3	3
2A4a	Yellow bricks production	28	28	29	29	29	30	30	30	30	31
2A4a	Expanded clay production	12	12	12	12	12	12	12	13	13	13
2A4d	Flue gas cleaning, CHP	6	5	5	5	6	6	5	6	6	6
2A4d	Flue gas cleaning, WIP	1	1	1	1	1	1	1	1	1	1
2A5	Stone wool production	9	9	9	9	9	9	9	9	9	9
	Total	1176	1189	1203	1213	1231	1247	1255	1264	1271	1291

4.3.2 2B – Chemical Industry

There is only one source of GHG emissions within this category; production of catalysts/fertilisers categorised under *2B10 Other*. There is therefore no additional aggregation available to the data presented in Table 4.7.

4.3.3 2D – Non-Energy Products from Fuels and Solvent Use

Regarding use of solvents, defined as NMVOC, in industries and products; Production, use, marketing and labelling of VOC containing products in Denmark is regulated by two statutory orders; BEK no. 1452 of 20/12/2012 "Bekendtgørelse om anlæg og aktiviteter, hvor der bruges organiske opløsningsmidler" and its amendment BEK no. 295 of 20/03/2013. Further regulation on certain paints and lacquers follows BEK no. 1049 of 27/10/2005 "Bekendtgørelse om markedsføring og mærkning af flygtige organiske forbindelser i visse malinger og lakker samt produkter til autoreparationslakering" and its amendments BEK no. 1073 of 27/10/2009, BEK no. 84 of 02/02/2011 and BEK no. 1456 of 20/12/2012.

NMVOC emission threshold values that these categories must comply with refer to single installations. As the solvent consumption for any category is only known as a total, it is not known how big a fraction of the solvent use exceeds the emission threshold values. A worst-case assumption could be that the entire solvent consumption in a category must comply with the emission limit. However, this is not a realistic scenario as the emission values, for the solvent fraction that exceeds the thresholds in BEK 1452, are considerably lower than the emission factors that are used in the inventory. Furthermore BEK 1452 only covers industrial installations, and adhesive coating, which constitutes the largest fraction of the emissions covered by BEK 1452, also includes diffuse use.

The predominant emissions thus represent diffuse uses from highly diverse activities and product uses, each comprising a number of chemicals, which cannot be attributed to an industrial sector or trade organisation, and therefore it is not feasible to perform projections according to the above statutory orders. The emission projection of all categories will be based on extrapolation of historic 1990-2012 emissions.

Tables 4.9a-c shows the historic and the projected CO_2, N_2O and indirect NMVOC emissions from 1990 to 2035 for the CRF 2D categories. The following projection models are used, with the fraction in % relative to the total 2012 CO_2-eq emission for 2D noted after each category:

2D.1 Lubricants (CO_2): Constant projection of 2012 emission (18%).

2D.2 Paraffin Wax (Candles) (CO_2, N_2O): Linear projection (increasing) of 2002 to 2012 activity data (45%).

2D.3 Solvents (NMVOC): All categories show decreasing trends and a stagnation in the period 2007 to 2012. The most realistic projection is a sum of 25% of an exponential fit for the period 1990 to 2012, and 75% of the historic 2007 – 2012 average (35%).

2D.3 Road Paving with Asphalt (NMVOC): Constant projection of 2012 emissions (1.0%).

2D.3 Asphalt Roofing (NMVOC): Projected according to Energistyrelsens Produktionsværdier (Byggeri) (0.01%).

2D.3 Tobacco (N_2O): Linear projection (decreasing) of 1980 to 2012 activity data (1.3% for Tobacco, Charcoal og Fireworks).

2D.3 Charcoal (N_2O): Constant projection of average (2008 to 2012) activity data.

2D.3 Fireworks (CO_2, N_2O): Linear projection (increasing) of 2007 to 2012 activity data.

Table 4.8a Projected CO_2, N_2O and NMVOC emissions from CRF 2D.

	Unit	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015
2D1. Lubricant Use	Gg CO_2	49.7	48.8	39.7	37.6	33.2	33.2	31.7	31.7	31.7	31.7
2D2. Paraffin Wax Use	Mg N_2O	0.18	0.22	0.4	0.8	0.85	0.73	0.67	0.76	0.77	0.78
As above	Gg CO_2-eq (N_2O)	0.05	0.07	0.12	0.25	0.25	0.22	0.20	0.23	0.23	0.22
As above	Gg CO_2	21.7	26.5	49.3	100	103	87.9	81.2	91.7	93.1	94.4
2D3. Other-Solvent Use (Paint Application)	Gg CO_2-eq (NMVOC)	13.2	15.0	16.3	10.7	6.91	7.26	7.23	7.15	7.06	6.97
2D3. Other-Solvent Use (Degreasing, Dry cleaning and Electronics)	Gg CO_2-eq (NMVOC)	3.7E-05	4.1E-05	1.6E-05	9.7E-06	6.6E-06	6.0E-06	1.5E-06	5.2E-06	5.1E-06	5.0E-06
2D3. Other-Solvent Use (Chemical Products Manufacturing and Processing)	Gg CO_2-eq (NMVOC)	19.4	22.0	17.0	15.6	12.5	12.0	12.2	12.4	12.3	12.2
2D3. Other-Solvent Use (Other Use of Solvents and Products)	Gg CO_2-eq (NMVOC)	60.6	71.3	66.8	49.2	44.0	44.0	44.0	42.8	42.4	42.1
2D3. Other-Road Paving with Asphalt	Gg CO_2-eq (NMVOC)	1.76	1.77	1.72	1.84	1.73	1.88	1.77	1.77	1.77	1.77
2D3. Other-Asphalt Roofing	Gg CO_2-eq (NMVOC)	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02
2D3. Other-Fireworks, Tobacco, Charcoal for BBQs	Mg N_2O	3.5	6.8	11	8.2	11	9.9	7.7	12	12	12
As above	Gg CO_2-eq (N_2O)	1.05	2.02	3.14	2.46	3.37	2.95	2.29	3.43	3.52	3.61
As above	Gg CO_2	0.06	0.13	0.21	0.16	0.23	0.2	0.15	0.24	0.24	0.25
2D Total	Mg N_2O	3.7	7.0	11	9.1	12	11	8.4	12	13	13
As above	Gg CO_2-eq	168	188	194	218	205	190	180	191	192	193

Table 4.9b Projected CO_2, N_2O and NMVOC emissions from CRF 2D (continued).

	Unit	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
2D1. Lubricant Use	Gg CO_2	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7
2D2. Paraffin Wax Use	Mg N_2O	0.79	0.8	0.81	0.83	0.84	0.85	0.86	0.87	0.88	0.89
As above	Gg CO_2-eq (N_2O)	0.24	0.24	0.24	0.25	0.25	0.25	0.26	0.26	0.26	0.27
As above	Gg CO_2	95.7	97.1	98.4	99.7	101	102	103	105	106	107
2D3. Other-Solvent Use (Paint Application)	Gg CO_2-eq (NMVOC)	6.89	6.81	6.74	6.67	6.61	6.55	6.49	6.43	6.38	6.34
2D3. Other-Solvent Use (Degreasing, Dry cleaning and Electronics)	Gg CO_2-eq (NMVOC)	4.9E-06	4.8E-06	4.8E-06	4.7E-06	4.7E-06	4.6E-06	4.6E-06	4.6E-06	4.5E-06	4.5E-06
2D3. Other-Solvent Use (Chemical Products Manufacturing and Processing)	Gg CO_2-eq (NMVOC)	12.1	12.0	11.9	11.8	11.8	11.7	11.6	11.5	11.5	11.4
2D3. Other-Solvent Use (Other Use of Solvents and Products)	Gg CO_2-eq (NMVOC)	41.8	41.5	41.2	40.9	40.7	40.4	40.1	39.9	39.7	39.4
2D3. Other-Road Paving with Asphalt	Gg CO_2-eq (NMVOC)	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77
2D3. Other-Asphalt Roofing	Gg CO_2-eq (NMVOC)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03
2D3. Other-Fireworks, Tobacco, Charcoal for BBQs	Mg N_2O	12	13	13	13	14	14	14	14	15	15
As above	Gg CO_2-eq (N_2O)	3.69	3.78	3.87	3.96	4.04	4.13	4.22	4.30	4.39	4.48
As above	Gg CO_2	0.26	0.27	0.27	0.28	0.29	0.29	0.3	0.31	0.31	0.32
2D Total	Mg N_2O	13	13	14	14	14	15	15	15	16	16
As above	Gg CO_2-eq	194	195	196	197	198	199	200	201	202	203

Table 4.9c Projected CO_2, N_2O and NMVOC emissions from CRF 2D (continued).

	Unit	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
2D1. Lubricant Use	Gg CO_2	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7
2D2. Paraffin Wax Use	Mg N_2O	0.9	0.91	0.92	0.94	0.95	0.96	0.97	0.98	0.99	1.0
As above	Gg CO_2-eq (N_2O)	0.27	0.27	0.28	0.28	0.28	0.29	0.29	0.29	0.30	0.30
As above	Gg CO_2	109	110	112	113	114	116	117	118	120	121
2D3. Other-Solvent Use (Paint Application)	Gg CO_2-eq (NMVOC)	6.29	6.25	6.21	6.17	6.13	6.10	6.07	6.04	6.01	5.98
2D3. Other-Solvent Use (Degreasing, Dry cleaning and Electronics)	Gg CO_2-eq (NMVOC)	4.5E-06	4.5E-06	4.4E-06	4.4E-06	4.4E-06	4.4E-06	4.4E-06	4.4E-06	4.4E-06	4.4E-06
2D3. Other-Solvent Use (Chemical Products Manufacturing and Processing)	Gg CO_2-eq (NMVOC)	11.3	11.3	11.2	11.2	11.1	11.0	11.0	10.9	10.9	10.9
2D3. Other-Solvent Use (Other Use of Solvents and Products)	Gg CO_2-eq (NMVOC)	39.2	39.0	38.8	38.6	38.4	38.2	38.0	37.9	37.7	37.5
2D3. Other-Road Paving with Asphalt	Gg CO_2-eq (NMVOC)	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77
2D3. Other-Asphalt Roofing	Gg CO_2-eq (NMVOC)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
2D3. Other-Fireworks, Tobacco, Charcoal for BBQs	Mg N_2O	15	16	16	16	16	17	17	17	18	18
As above	Gg CO_2-eq (N_2O)	4.57	4.65	4.74	4.83	4.92	5.00	5.09	5.18	5.26	5.35
As above	Gg CO_2	0.33	0.33	0.34	0.35	0.35	0.36	0.37	0.37	0.38	0.39
2D Total	Mg N_2O	16	17	17	17	17	18	18	18	19	19
As above	Gg CO_2-eq	205	206	207	208	209	210	211	213	214	215

Previous emission projections (Nielsen et al., 2012) of four industrial sectors were elaborated in more detail: Auto paint and repair, plastic industry, graphic industry and lacquer and paint industry. Their emissions are not directly derivable from the above table, but an estimate is that they represent 1 %, 4 %, <1 % and <1 % of the 2012 emissions and show decreasing emission trends. No new actions are applied to these sectors since the last projection report.

In conclusion the projections in Table 4.9 show a 19 % increase in total CO_2 eqv. emissions from 2012 to 2035.

4.3.4 2F – Product Uses as Substitutes for Ozone Depleting Substances

Table 4.10 presents the CO_2 equivalent emissions from the category *2F Product Uses as Substitutes for Ozone Depleting Substances* for all projected years and a few chosen historic years.

Table 4.9 Emission projections for product uses as substitutes for ODS, Gg CO_2 eqv.

			1995	2000	2005	2010	2011	2012	2013	2014	2015
2F1	Refrigeration and air conditioning		41	509	788	817	756	683	631	547	464
2F2	Foam blowing agents		200	184	130	96	85	73	61	40	26
2F4	Aerosols		0	21	23	18	18	18	18	18	18
	Total		241	716	942	931	859	774	710	605	508
		2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
2F1	Refrigeration and air conditioning	369	285	193	142	61	59	53	51	50	49
2F2	Foam blowing agents	14	5	1	1	1	1	1	1	1	1
2F4	Aerosols	18	18	18	18	18	18	18	18	18	18
	Total	401	307	212	161	80	78	72	69	69	68
		2026	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
2F1	Refrigeration and air conditioning	48	46	46	46	46	46	46	46	46	46
2F2	Foam blowing agents	1	1	1	1	1	1	1	2	2	2
2F4	Aerosols	18	18	18	18	18	18	18	18	18	18
	Total	67	66	65	65	65	65	65	65	65	65

The CO_2 equivalent emissions from *refrigeration and air conditioning* stem mainly from HFCs; 95 – 100 % (lowest in 2020). All emissions from *foam blowing agents* and *aerosols* are caused by HFCs. The only PFC emissions identified from this source category for the projected years are a small fraction from *refrigeration and air conditioning* (a maximum of 6 Gg CO_2 eqv. in 2013).

4.3.5 2G – Other Product Manufacture and Use

Emission projections for *Other Product Manufacture and Use* are shown in Table 4.11.

Table 4.11 Emission projections for other product manufacture and use, Gg CO_2 eqv.

		1990	1995	2000	2005	2010	2011	2012	2013	2014	2015
2G1	Electrical equipment	1.4	3.7	10.7	11.9	26.2	26.3	26.5	26.8	27.1	27.3
2G2	SF_6 and PFCs from other product uses	9.1	62.2	25.1	8.4	22.6	54.0	97.7	107.0	118.6	104.4
3G3	Medical application			0.6	10.2	10.2	12.5	9.0	11.0	11.0	11.0
	Total	10.5	65.9	36.4	30.5	59.0	92.8	133.2	144.8	156.7	142.7
		2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
2G1	Electrical equipment	27.6	27.9	28.1	28.4	28.7	22.2	20.2	18.2	16.2	15.4
2G2	SF_6 and PFCs from other product uses	77.6	63.1	63.3	62.2	42.4	38.4	30.4	22.4	14.4	11.2
3G3	Medical application	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
	Total	116.3	102.1	102.5	101.6	82.1	71.6	61.6	51.6	41.6	37.6
		2026	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
2G1	Electrical equipment	15.0	14.6	14.4	14.2	14.2	14.2	14.2	14.2	14.2	14.2
2G2	SF_6 and PFCs from other product uses	9.6	8.0	7.2	6.4	6.4	6.4	6.4	6.4	6.4	6.4
3G3	Medical application	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
	Total	35.6	33.6	32.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6

4.3.6 2H – Other

There is no distinguishing between the individual food and beverage sources being made. Emission projections are calculated based on the total emissions from sources included in the *2H Other* category. There is therefore no additional aggregation available to the data presented in Table 4.7.

4.4 Recalculations

Table 4.12 shows emissions from this projection report and the last along with the difference between the two. Descriptions of the recalculations are given for each category in the following sections.

Table 4.10 Recalculations in the industrial processes and product use sector.

		Unit	2013	2014	2015	2020	2025	2030	2035
2A	**Mineral Industry**								
	2014 Projection	Gg CO_2	994	967	963	1086	1167	1231	1291
	2012 Projection	Gg CO_2	1027	1032	1049	1162	1203	1266	1340
	Difference	Gg CO_2	-33.0	-64.4	-85.5	-76.2	-36.4	-34.7	-48.2
	Difference	%	-3%	-6%	-8%	-7%	-3%	-3%	-4%
2B	**Chemical Industry**								
	2014 Projection	Gg CO_2	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	2012 Projection	Gg CO_2	2.3	2.3	2.4	2.7	2.8	3.0	3.1
	Difference	Gg CO_2	-0.8	-0.8	-0.9	-1.2	-1.3	-1.5	-1.6
	Difference	%	-35%	-36%	-37%	-44%	-46%	-49%	-52%
2D	**Non-Energy Products from Fuels and Solvent Use**								
	2014 Projection	Gg CO_2	191	192	193	198	203	209	215
	2012 Projection	Gg CO_2	107	106	105	100	97	94	91
	Difference	Gg CO_2	84.3	86.3	88.2	97.7	106.7	115.3	123.6
	Difference	%	79%	81%	84%	97%	110%	123%	135%
2F	**Product uses as ODS substitutes**								
	2014 Projection	Gg CO_2	710	605	508	80	68	65	65
	2012 Projection	Gg CO_2	751	672	573	142	83	75	76
	Difference	Gg CO_2	-41.2	-66.9	-65.5	-62.2	-15.4	-10.6	-10.6
	Difference	%	-5%	-10%	-11%	-44%	-19%	-14%	-14%
2G	**Other product manufacture and use (new category)**								
	2014 Projection	Gg CO_2	145	157	143	82	38	32	32
	2012 Projection	Gg CO_2							
	Difference	Gg CO_2							
	Difference	%							
2H	**Other**								
	2014 Projection	Gg CO_2	2	2	2	2	2	2	2
	2012 Projection	Gg CO_2	2	2	2	2	2	3	3
	Difference	Gg CO_2	0.5	0.4	0.4	-0.1	-0.2	-0.4	-0.6
	Difference	%	32%	25%	22%	-4%	-10%	-17%	-23%
Total									
	2014 Projection	Gg CO_2	2044	1925	1811	1450	1479	1540	1606
	2012 Projection	Gg CO_2	1889	1814	1731	1409	1388	1441	1512
	Difference	Gg CO_2	154.5	111.3	79.4	40.1	90.9	99.8	94.2
	Difference	%	8%	6%	5%	3%	7%	7%	6%

4.4.1 2A – Mineral Industry

About 90 % of emissions in this category come from cement production, it is therefore also, almost entirely, recalculations from this source that show up in Table 4.12. The performed recalculation of emissions from cement production results in a decrease between 95 Gg in 2015 and 14 Gg in 2029 equal to -10 to -1 %. This decrease is a result of the base year (2011 and the 2009-2013 average respectively) being lower in this year's projection. The decrease is counteracted a little by an increased expectation to this industry along with a change in the industry classification in the national accounts made by Statistics Denmark (2014), see Figure 4.4.

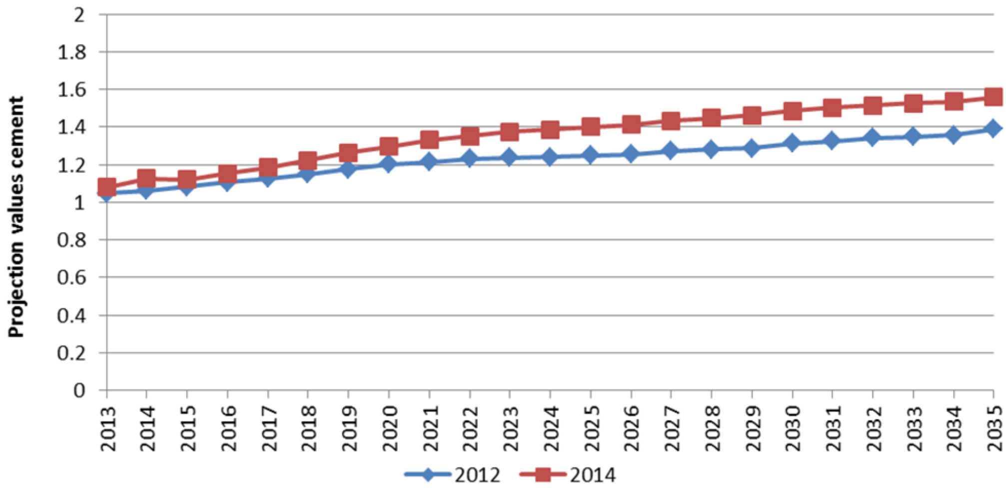

Figure 4.3 Expected development in the cement industry, production value projections performed in 2012 and 2014 respectively.

In addition to the cement production there are smaller changes for the production of burnt lime and production of bricks and tiles. Generally, there is a decrease in the projected emissions in this projection report compared to the last because projected production values are only available for a few industrial groups this year. The emission trends for these sources are therefore projected as constant throughout the time series.

The sources "asphalt roofing" and "road paving with asphalt" are no longer aggregated under *2A Mineral Industry* but has due to the implementation of the new IPCC Guidelines been moved to category *2D Non-Energy Products from Fuels and Solvent Use*. The two sources made up for less than 0.2 % of the emissions from category 2A in 2012 submission.

4.4.2 2B – Chemical Industry

In the previous projection report emissions from chemical industry were calculated based on production values projections done by the Danish Energy Agency and the 2010 emission. Since no production values are available this year, emissions are estimated to hold the constant average value of the 2008-2012 emissions. This in itself will lower the projected emissions but the main reason for the decrease is the lower base year values. Though the change in emissions is miniscule (1-2 Gg) the percentage change is quite high; 35-52 %.

4.4.3 2D – Non-Energy Products from Fuels and Solvent Use

Due to the change to new categories and additions to the inventory there are deviations between the 2012 and 2014 projections:

- In the 2012 projection use of candles was not included. In the 2014 projection CO_2 and N_2O emissions from candles account for 121.4 Gg CO_2 eqv. in 2035, which corresponds to 98 % of the difference between the two projections.
- N_2O in products is not included in 2D in the 2014 projection, but is included in 2G.
- GWP for N_2O is changed from 310 to 298.
- The projection of fireworks was in 2012 set constant to the 2010 activity data. In 2014 the projection is linearly increasing, calculated from the 2007 to 2012 activity data.

4.4.4 2F – Product Uses as Substitutes for Ozone Depleting Substances

The transition to the new IPCC Guidelines has led to a number of changes for the source category previously called *2F - Consumption of Halocarbons and SF_6*. The previous source category has been split into two new categories (the new *2F Product Uses as Substitutes for Ozone Depleting Substances* and *2G Other Product Manufacture and Use*) and N_2O from product use is now reported under category 2G3.

Besides the reallocations and updates of GWP values the 2006 IPCC Guidelines have not given cause to any recalculation in the projected emissions.

According to the new Guidelines *Electrical equipment* and *SF_6 and PFCs from Other Product Uses* are no longer reported under 2F. This result in a decrease of between 10 Gg (2029) and 71 Gg (2019) (calculated with the new GWPs). These two sources that are being reallocated are about twice the size of the mentioned decrease in emissions but the new GWPs result in an increase in the remaining sources that counteracts the decrease.

4.4.5 2G – Other Product Manufacture and Use

This category is new and covers sources that were previously included elsewhere. As mentioned under *2F Product Uses as Substitutes for Ozone Depleting Substances* the sources *Electrical equipment* and *SF_6 and PFCs from Other Product Uses* have been moved here along with *N_2O from Product Use* that was previously reported under *Solvents.*

In addition to being moved and receiving new GWP values no recalculations were made to the sources included in this source category.

4.4.6 2H – Other

This category has been given a new name but is otherwise unchanged; previously *2D Food and Drink*. The emission projection from this category was previously calculated from a production value projection for the food industry done by the Danish Energy Agency. This production value projection estimated an increase of 70 % in the food industry until 2035; since a production value projection is not available this year emissions for 2013-2035 are assumed to take the constant level of the average 2008-2012 emission. This change results in a recalculation of less than 1 Gg throughout the time series (equal to between -23 % in 2035 and +32 % in 2013).

4.5 References

BEK nr. 350 af 29/05/2002 Bekendtgørelse om begrænsning af emissionen af flygtige organiske forbindelser fra anvendelse af organiske opløsningsmidler i visse aktiviteter og anlæg, aka the VOC directive.

BEK no. 1049 af 27/10/2005 Bekendtgørelse om markedsføring og mærkning af flygtige organiske forbindelser i visse malinger og lakker samt produkter til autoreparationslakering.

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Danish Energy Agency, 2014b: Production values for industry – 2013-2035. Personal communication, Anne Lund Bender, Danish Energy Agency, 15th of May 2014.

Directive no 350 on Limitation of Emissions of Volatile Organic Compounds from use of Organic Solvents in Certain Activities, aka VOC directive.

Directive no 1049 on Marketing and Labelling of Volatile Organic Compounds in Certain Paints and Lacquers and Products for Auto Repair Lacquering, aka Directive 1049.

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5 Transport and other mobile sources

In the forecast model all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution) according to the CORINAIR system. The aggregation to the sector codes used for both the UNFCCC and UNECE Conventions is based on a correspondence list between SNAP and IPCC classification codes (CRF) shown in Table 5.1 (mobile sources only).

Table 5.1 SNAP – CRF correspondence table for transport.

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

Military transport activities (land and air) refer to the CRF sector Other (1A5), while the Transport-Navigation sector (1A3d) comprises national sea transport (ship movements between two Danish ports) and recreational craft. The working machinery and materiel in industry is grouped in Industry-Other (1A2f), while agricultural and forestry machinery is accounted for in the Agriculture/forestry/fisheries (1A4c) sector together with fishing activities. For aviation, LTO (Landing and Take Off)[2] refers to the part of flying, which is below 1000 m. According to UNFCCC the emissions from domestic LTO (0805010) and domestic cruise (080503) and flights between Denmark and Greenland or the Faroe Islands are regarded as domestic flights. 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.

5.1 Methodology and references for road transport

For road transport, the detailed methodology is used to make annual estimates of the Danish emissions, as described in the EMEP/EEA Emission Inventory Guidebook (EMEP/EEA, 2013). The actual calculations are made with a model developed by DCE, using the European COPERT IV model methodology. The latter model approach is explained in (EMEP/EEA, 2013). In COPERT, fuel consumption and emission simulations can be made for

[2] A LTO cycle consists of the flying modes approach/descent, taxiing, take off and climb out. In principle the actual times-in-modes rely on the actual traffic circumstances, the airport configuration, and the aircraft type in question.

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.

5.1.1 Vehicle fleet and mileage data

Corresponding to the COPERT fleet classification, all present and future vehicles in the Danish traffic fleet are grouped into vehicle classes, sub-classes and layers. The layer classification is a further division of vehicle sub-classes into groups of vehicles with the same average fuel consumption and emission behaviour according to EU emission legislation levels. Table 5.2 gives an overview of the different model classes and sub-classes and the layer level with implementation years are shown in Annex 5.I.

Table 5.2 Model vehicle classes and sub-classes.

Vehicle classes	Fuel type	Engine size/weight
PC	Gasoline	< 1.4 l.
PC	Gasoline	1.4 – 2 l.
PC	Gasoline	> 2 l.
PC	Diesel	< 2 l.
PC	Diesel	> 2 l.
PC	LPG	
PC	2-stroke	
LDV	Gasoline	
LDV	Diesel	
LDV	LPG	
Trucks	Gasoline	
Trucks	Diesel	Diesel RT 3,5 - 7,5t
Trucks	Diesel	Diesel RT 7,5 - 12t
Trucks	Diesel	Diesel RT 12 - 14 t
Trucks	Diesel	Diesel RT 14 - 20t
Trucks	Diesel	Diesel RT 20 - 26t
Trucks	Diesel	Diesel RT 26 - 28t
Trucks	Diesel	Diesel RT 28 - 32t
Trucks	Diesel	Diesel RT >32t
Trucks	Diesel	Diesel TT/AT 14 - 20t
Trucks	Diesel	Diesel TT/AT 20 - 28t
Trucks	Diesel	Diesel TT/AT 28 - 34t
Trucks	Diesel	Diesel TT/AT 34 - 40t
Trucks	Diesel	Diesel TT/AT 40 - 50t
Trucks	Diesel	Diesel TT/AT 50 - 60t
Trucks	Diesel	Diesel TT/AT >60t
Buses	Gasoline	Gasoline Urban Buses
Buses	Diesel	Diesel Urban Buses <15t
Buses	Diesel	Diesel Urban Buses 15 - 18t
Buses	Diesel	Diesel Urban Buses >18t
Buses	Gasoline	Gasoline Coaches
Buses	Diesel	Diesel Coaches <15t
Buses	Diesel	Diesel Coaches 15 - 18t
Buses	Diesel	Diesel Coaches >18t
Mopeds	Gasoline	
Motorcycles	Gasoline	2 stroke
Motorcycles	Gasoline	< 250 cc.
Motorcycles	Gasoline	250 – 750 cc.
Motorcycles	Gasoline	> 750 cc.

To support the emission projections fleet and annual mileage data are provided by DTU Transport for the vehicle categories present in COPERT IV (Jensen, 2013). For information on the historical vehicle stock and annual mileage, please refer to Nielsen et al. (2014).

In addition data from a survey made by the Danish Road Directorate (Hansen, 2010) has information on the total mileage driven by foreign trucks on Danish roads in 2009. This mileage contribution has been added to the total mileage for Danish trucks on Danish roads, for trucks > 16 tonnes of gross vehicle weight. The data has been further processed by DTU Transport; by using appropriate assumptions, the mileages have been backcasted to 1985 and forecasted to 2035.

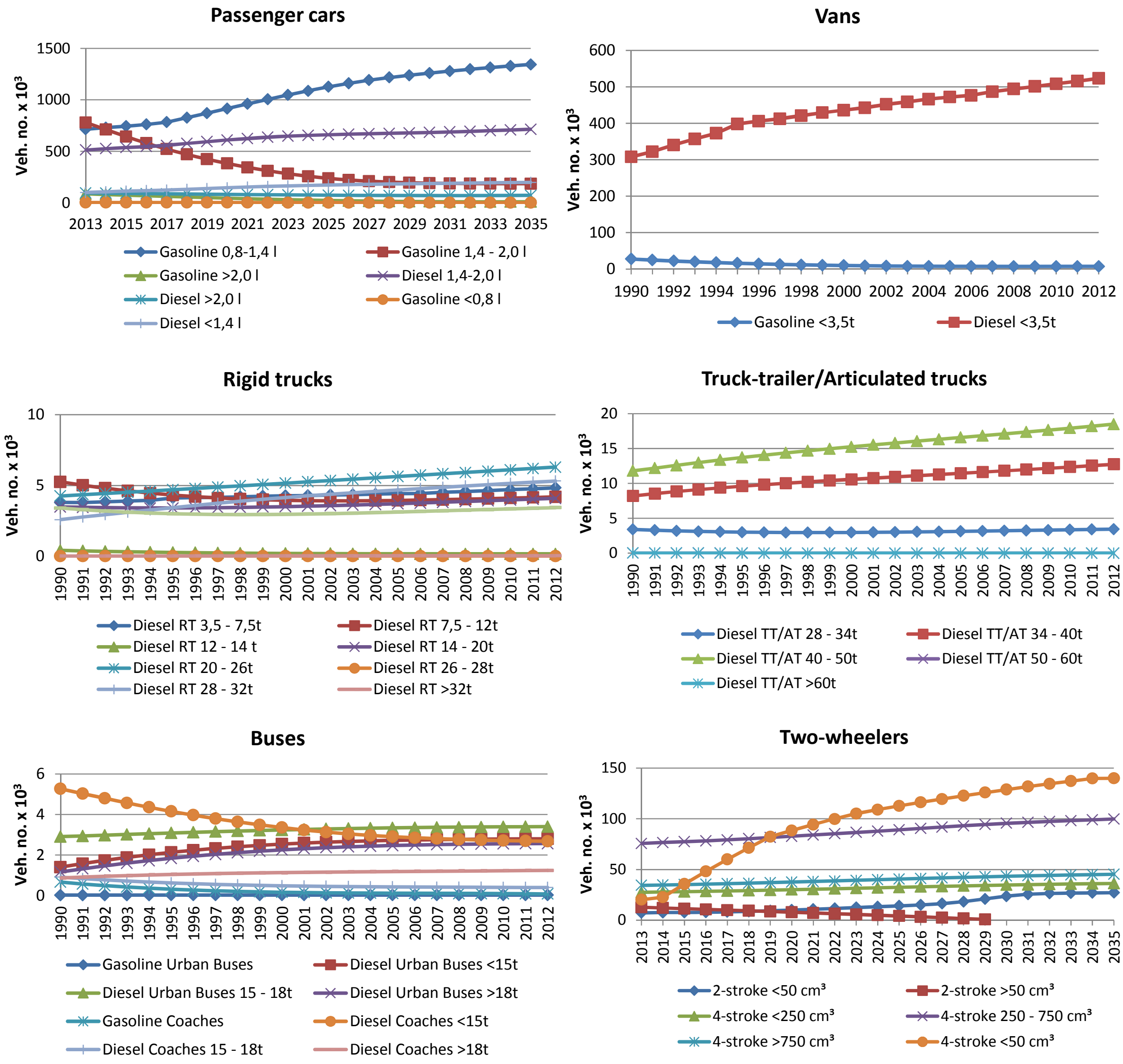

Figure 5.1 Number of vehicles in sub-classes from 2013-2035.

The vehicle numbers per sub-class are shown in Figure 5.1. The engine size differentiation is associated with some uncertainty.

The vehicle numbers are summed up in layers for each year (Figure 5.2) by using the correspondence between layers and first registration year:

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

where N = number of vehicles, j = layer, y = year, i = first registration year.

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.

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

Vehicle numbers and weighted annual mileages per layer are shown in Annex 5.1 for 2013-2035. The trends in vehicle numbers per EU layer are also shown in Figure 5.2 for the 2013-2035 periods. The latter figure clearly shows how vehicles complying with the gradually stricter EU emission levels (EURO IV, V and VI) are introduced into the Danish motor fleet in the forecast period.

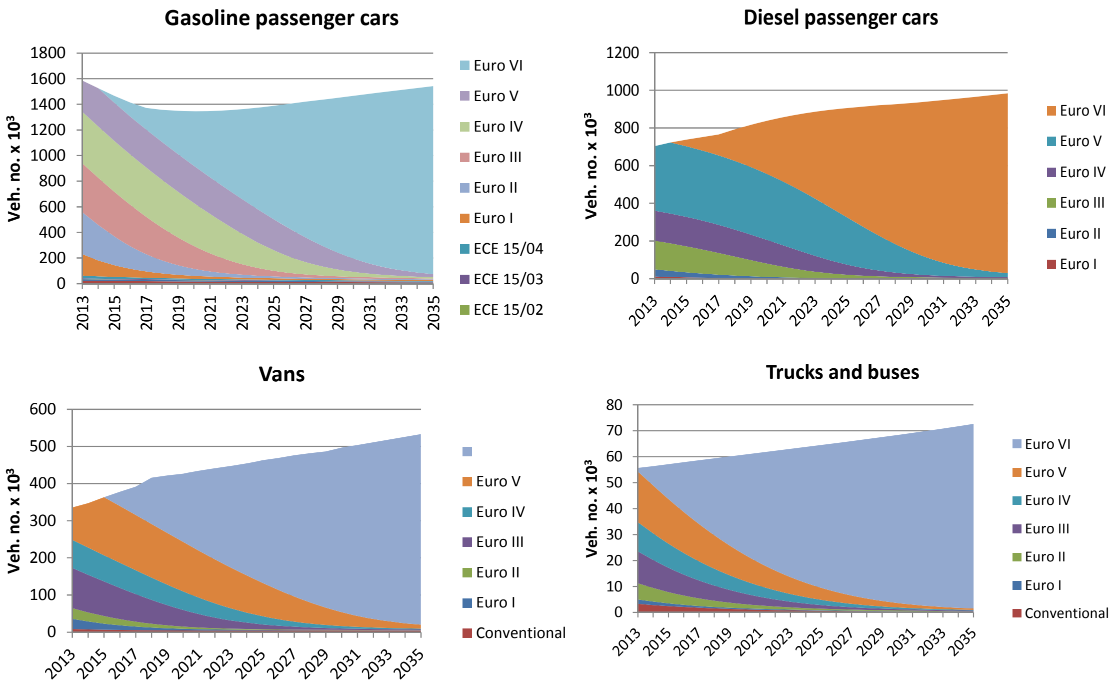

Figure 5.2 Layer distribution of vehicle numbers per vehicle type in 2013-2035.

5.1.2 Emission legislation

The EU 443/2009 regulation sets new emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles. Some key elements of the adopted text are as follows:

- **Limit value curve:** the fleet average to be achieved by all cars registered in the EU is 130 gram CO_2 per kilometre (g per km). A so-called limit value curve implies that heavier cars are allowed higher emissions than lighter cars while preserving the overall fleet average.

- **Further reduction:** a further reduction of 10 g CO_2 per km, or equivalent if technically necessary, will be delivered by other technological improvements and by an increased use of sustainable biofuels.
- **Phasing-in of requirements:** in 2012, 65 % of each manufacturer's newly registered cars must comply on average with the limit value curve set by the legislation. This will rise to 75 % in 2013, 80 % in 2014, and 100 % from 2015 onwards.
- **Lower penalty payments for small excess emissions until 2018:** if the average CO_2 emissions of a manufacturer's fleet exceed its limit value in any year from 2012, the manufacturer has to pay an excess emissions premium for each car registered. This premium amounts to €5 for the first g per km of exceedance, €15 for the second g per km, €25 for the third g per km, and €95 for each subsequent g per km. From 2019, already the first g per km of exceedance will cost €95.
- **Long-term target:** a target of 95g CO_2 per km is specified for the year 2020.
- **Eco-innovations:** because the test procedure used for vehicle type approval is outdated, certain innovative technologies cannot demonstrate their CO_2 reducing effects under the type approval test. As an interim procedure until the test procedure is reviewed by 2014, manufacturers can be granted a maximum of 7g per km of emission credits on average for their fleet if they equip vehicles with innovative technologies, based on independently verified data.

The EU 510/2011 regulation sets new emission performance standards for new light commercial vehicles (vans). Some key elements of the regulation are as follows:

- **Target dates:** the EU fleet average of 175 g CO_2 per km will be phased in between 2014 and 2017. In 2014 an average of 70 %of each manufacturer's newly registered vans must comply with the limit value curve set by the legislation. This proportion will rise to 75 % in 2015, 80 % in 2016, and 100% from 2017 onwards.
- **Limit value curve:** emissions limits are set according to the mass of vehicle, using a limit value curve. The curve is set in such a way that a fleet average of 175 grams of CO_2 per kilometre is achieved. A so-called limit value curve of 100 % implies that heavier vans are allowed higher emissions than lighter vans while preserving the overall fleet average. Only the fleet average is regulated, so manufacturers will still be able to make vehicles with emissions above the limit value curve provided these are balanced by other vehicles which are below the curve.
- **Vehicles affected:** the vehicles affected by the legislation are vans, which account for around 12 % of the market for light-duty vehicles. This includes vehicles used to carry goods weighing up to 3.5t (vans and car-derived vans, known as N1) and which weigh less than 2610 kg when empty.
- **Long-term target:** a target of 147g CO_2 per km is specified for the year 2020.
- **Excess emissions premium for small excess emissions until 2018:** if the average CO_2 emissions of a manufacturer's fleet exceed its limit value in any year from 2014, the manufacturer has to pay an excess emissions premium for each van registered. This premium amounts to €5 for the first g per km of exceedance, €15 for the second g per km, €25 for the

third g per km, and €95 for each subsequent g per km. From 2019, the first g per km of exceedance will cost €95. This value is equivalent to the premium for passenger cars.

- **Super-credits:** vehicles with extremely low emissions (below 50g per km) will be given additional incentives whereby each low-emitting van will be counted as 3.5 vehicles in 2014 and 2015, 2.5 in 2016 and 1.5 vehicles in 2017.
- **Eco-innovations:** because the test procedure used for vehicle type approval is outdated, certain innovative technologies cannot demonstrate their CO_2 reducing effects under the type approval test. As an interim procedure until the test procedure is reviewed by 2014, manufacturers can be granted a maximum of 7g per km of emission credits on average for their fleet if they equip vehicles with innovative technologies, based on independently verified data.
- **Other flexibilities:** manufacturers may group together to form a pool and act jointly in meeting the specific emissions targets. Independent manufacturers who sell fewer than 22,000 vehicles per year can also apply to the Commission for an individual target instead.

The test cycle used in the EU for measuring fuel is the New European Driving Cycle (NEDC) used also for emission testing. The NEDC cycle consists of two parts, the first part being a 4-times repetition (driving length: four km) of the ECE test cycle - the so-called urban driving cycle (average speed: 19 km per h). The second part of the test is the Extra Urban Driving Cycle (EUDC) test driving segment, simulating the fuel consumption under rural and highway driving conditions. The driving length in the EUDC is seven km at an average speed of 63 km per h. More information regarding the fuel measurement procedure can be found in the EU Directive, 80/1268/EØF.

For NO_x, VOC (NMVOC + CH_4), CO and PM, the emissions from road transport vehicles have to comply with the different EU directives listed in Table 5 .3. In the latter table, EU directive starting dates for vehicles new registrations are also listed. The specific emission limits can be seen in Winther (2012).

Table 5.3 Overview of the existing EU emission directives for road transport vehicles.

Vehicle category	Emission layer	EU directive	First reg. date
Passenger cars (gasoline)	PRE ECE	-	-
	ECE 15/00-01	70/220 - 74/290	1972[a]
	ECE 15/02	77/102	1981[b]
	ECE 15/03	78/665	1982[c]
	ECE 15/04	83/351	1987[d]
	Euro I	91/441	1.10.1990[e]
	Euro II	94/12	1.1.1997
	Euro III	98/69	1.1.2001
	Euro IV	98/69	1.1.2006
	Euro V	715/2007	1.1.2011
	Euro VI	715/2007	1.9.2015
Passenger cars (diesel and LPG)	Conventional	-	-
	ECE 15/04	83/351	1987[d]
	Euro I	91/441	1.10.1990[e]
	Euro II	94/12	1.1.1997
	Euro III	98/69	1.1.2001
	Euro IV	98/69	1.1.2006
	Euro V	715/2007	1.1.2011
	Euro VI	715/2007	1.9.2015
Light duty trucks (gasoline and diesel)	Conventional	-	-
	ECE 15/00-01	70/220 - 74/290	1972[a]
	ECE 15/02	77/102	1981[b]
	ECE 15/03	78/665	1982[c]
	ECE 15/04	83/351	1987[d]
	Euro I	93/59	1.10.1994
	Euro II	96/69	1.10.1998
	Euro III	98/69	1.1.2002
	Euro IV	98/69	1.1.2007
	Euro V	715/2007	1.1.2012
	Euro VI	715/2007	1.9.2016
Heavy duty vehicles	Euro 0	88/77	1.10.1990
	Euro I	91/542	1.10.1993
	Euro II	91/542	1.10.1996
	Euro III	1999/96	1.10.2001
	Euro IV	1999/96	1.10.2006
	Euro V	1999/96	1.10.2009
	Euro VI	595/2009	1.10.2013
Mopeds	Conventional	-	-
	Euro I	97/24	2000
	Euro II	2002/51	2004
	Euro III	2002/51	2014[f]
	Euro IV	168/2013	2017
	Euro V	168/2013	2021
Motor cycles	Conventional	Conventional	0
	Euro I	97/24	2000
	Euro II	2002/51	2004
	Euro III	2002/51	2007
	Euro IV	168/2013	2017
	Euro V	168/2013	2021

a,b,c,d: Expert judgement suggest that Danish vehicles enter into the traffic before EU directive first registration dates. The effective inventory starting years are a: 1970; b: 1979; c: 1981; d: 1986. e: The directive came into force in Denmark in 1991 (EU starting year: 1993).

For passenger cars and light duty vehicles the emission approval tests are made on a chassis dynamometer, and for Euro I-IV vehicles the EU NEDC test cycle is used (see Nørgaard & Hansen, 2004). The emission directives distinguish between three vehicle classes: passenger cars and light duty vehicles (<1 305 kg), light duty vehicles (1 305-1 760 kg) and light duty vehicles (>1 760 kg).

In practice the emissions from vehicles in traffic are different from the legislation limit values and, therefore, the latter figures are considered to be too inaccurate for total emission calculations. A major constraint is that the emission approval test conditions only in a minor way reflect the large variety of emission influencing factors in real traffic situations, such as cumulated mileage driven, engine and exhaust after treatment maintenance levels, and driving behaviour. Therefore, in order to represent the Danish fleet and to support average national emission estimates, emission factors, which derive from numerous emissions measurements must be chosen using a broad range of real world driving patterns and sufficient numbers of test vehicles. It is similarly important to have separate fuel consumption and emission data for cold start emission calculations and gasoline evaporation (hydrocarbons).

For heavy duty vehicles (trucks and buses) the emission limits are given in g per kWh. The measurements are carried out for engines in a test bench, using the EU European Stationary Cycle (ESC) and European Transient Cycle (ETC) test cycles, depending on the Euro norm and the exhaust gas after instalment of treatment system. A description of the test cycles are given by Nørgaard & Hansen (2004). Measurement results in g per kWh from emission approval tests cannot be directly used for inventory work. Instead, emission factors used for national estimates must be transformed into g per km and derived from a sufficient number of measurements, which represent the different vehicle size classes, Euro engine levels and real world variations in driving behaviour.

5.1.3 Fuel consumption and emission factors

Trip speed dependent basis factors for fuel consumption and emissions are taken from the COPERT IV model, for trip speeds related to urban, rural and highway driving. The scientific basis for COPERT IV is fuel consumption and emission information from various European measurement programmes, transformed into trip speed dependent fuel consumption and emission factors for all vehicle categories and layers.

Real measurement data lies behind the emission factors for passenger cars (Euro 4 and prior), vans (Euro 1 and prior), trucks and buses (Euro V and prior), and for mopeds and motorcycles (Euro 1-3).

The emission factors for later engine technologies are produced by using reduction factors (see Winther, 2012). The latter factors are determined by assessing the EU emission limits and the relevant emission approval test conditions for each vehicle type and Euro class.

In order to account for the trend towards more fuel efficient vehicles being sold in Denmark in the later years, fuel consumption factors for Euro 5 and Euro 6 passenger cars are estimated in the following way.

In the Danish fleet and mileage database, the type approval fuel efficiency value based on the NEDC driving cycle (TA_{NEDC}) is registered for each single car. Further, a modified fuel efficiency value (TA_{inuse}) is calculated using TA_{NEDC}, vehicle weight and engine size as input parameters. The TA_{inuse} value better reflects the fuel consumption associated with the NEDC driving cycle under real ("inuse") traffic conditions (Emisia, 2012).

From 2006 up to last historical year represented by fleet data, the average CO_2 emission factor (by fleet number) is calculated for each year's new sold cars, based on the registered TA_{NEDC} values. Using the average CO_2 emission factor for the last historical year as starting point, the average emission factor for each year's new sold cars are linearly reduced, until the emission factor reaches 95 g CO_2 per km in 2020.

From 2006 up to last historical year, the average CO_2 emission factor (by fleet number) is also calculated for each year's new sold cars, and for each fuel type/engine size combination, based on TA_{NEDC} and TA_{inuse}.

The linear reduction of the average emission factor for each year's new sold cars is then used to reduce the CO_2 emission factors for new sold cars based on TA_{inuse}, between last historical year and 2020, for each of the fuel type/engine size fleet segments.

Subsequently for each layer and inventory year, CO_2 emission factors are calculated based on TA_{inuse} and weighted by total mileage. On the same time corresponding layer specific CO_2 factors from COPERT IV are set up valid for Euro 4+ vehicles in the COPERT model. The COPERT IV CO_2 factors are derived from fuel consumption factors assessed by the developers of COPERT IV (Emisia, 2012) to represent the COPERT test vehicles under the NEDC driving cycle in real world traffic ($TA_{COPERT\ IV,inuse}$).

In a final step the ratio between the layer specific CO_2 emission factors for the Danish fleet and the COPERT Euro IV vehicles under TA_{inuse} are used to scale the trip speed dependent fuel consumption factors provided by COPERT IV for Euro 4 layers onwards.

5.1.4 Fuel consumption and emission calculations

The fuel consumption and emissions are calculated for operationally hot engines and for engines during cold start. A final fuel balance adjustment is made in order to account for the statistical fuel sold according to Danish energy statistics. It must be noted that a certain amount of gasoline fuel – the difference between bottom-up estimates and fuel sales statistics for non-road machinery - is subtracted from the road transport fuel input data prior to inventory calculations in order to maintain the overall national statistical fuel balance. This is explained in more details in section 5.2 below.

The calculation procedure for hot engines is to combine basis fuel consumption and emission factors, number of vehicles and annual mileage numbers (Annex 5.1) and mileage road type shares. For additional description of the hot and cold start calculations and fuel balance approach, please refer to Winther (2012).

Fuel consumption and emission results per layer and vehicle type, respectively, are shown in Annex 5.1 from 2013-2035. The layer specific emission factors (km based) for CO_2, CH_4 and N_2O derived from the basis input data are also shown in Annex 5.1.

5.2 Other mobile sources

Other mobile sources are divided into several sub-sectors: sea transport, fishery, air traffic, railways, military, and working machinery and equipment in the sectors agriculture, forestry, industry and residential. The emission calculations are made using the detailed method as described in the EMEP/EEA Emission Inventory Guidebook (EMEP/EEA, 2013) for air traffic, off-road working machinery and equipment, and ferries, while for the remaining sectors the simple method is used.

5.2.1 Activity data

Air traffic

For historical years, the activity data for air traffic consists of air traffic statistics provided by Danish Transport Authority and Copenhagen Airport. For 2001-2012, records are given per flight by CAA-DK as data for aircraft type and origin and destination airports. For inventory years prior to 2001 detailed LTO/aircraft type statistics are obtained from Copenhagen Airport (for this airport only) while information of total take-off numbers for other Danish airports is provided by the Danish Transport Authority. Fuel statistics for jet fuel consumption and aviation gasoline are obtained from the Danish energy projections (DEA, 2014).

Prior to emission calculations for historical years, the aircraft types are grouped into a smaller number of representative aircraft for which fuel consumption and emission data exist in the EMEP/EEA databank. In this procedure the actual aircraft types are classified according to their overall aircraft type (jets, turbo props, helicopters and piston engine). Secondly, information on the aircraft Maximum Take-Off Mass (MTOM) and number of engines are used to append a representative aircraft to the aircraft type in question. A more thorough explanation is given in Nielsen et al. (2014).

No forecast of air traffic movements is available as input to the emission projection calculations. Instead, the official Danish national fuel consumption projections from the DEA (2014) are used as activity data in the projection period.

Non road working machinery

Non road working machinery and equipment are used in agriculture, forestry and industry, for household/gardening purposes and inland waterways (recreational craft). The specific machinery types comprised in the Danish inventory are shown in Table 5.4.

Table 5.4 Machinery types comprised in the Danish non road inventory.

Sector	Diesel	Gasoline/LPG
Agriculture	Tractors, harvesters, machine pool, other	ATV's (All Terrain Vehicles), other
Forestry	Silvicultural tractors, harvesters, forwarders, chippers	-
Industry	Construction machinery, fork lifts, building and construction, Airport GSE, other	Fork lifts (LPG), building and construction, other
Residential and Commercial/ institutional	-	Riders, lawn movers, chain saws, cultivators, shrub clearers, hedge cutters, trimmers, other

A Danish research project has provided information of the number of different types of machines, their load factors, engine sizes and annual working hours for non-road machinery for historical years as well as methodology descriptions of how to forecast stock data for emission projection purposes (Winther et al., 2006). The most recent update of the historical data can be seen in Winther (2012).

The energy projections from DEA for the sector "Agriculture (gasoline/diesel)" are used as an input for the fuel balance for the DCE sectors "Agriculture (gasoline/diesel)" and "Forestry (gasoline/diesel)", whereas DEA "Agriculture" LPG fuel is transferred to agriculture stationary sources. The DEA fuel data for "Manufacturing industries (gasoline/diesel/LPG)" and "Building and Construction (gasoline/diesel/LPG)" are used as an input for the fuel balance for the DCE sector "Industry (gasoline/diesel/LPG)". In cases for industrial non road where DCE bottom-up estimates are smaller than DEA reported values, the fuel difference is transferred to industrial stationary sources.

The total DCE fuel estimate for gasoline working machinery used in the agriculture, forestry, industry, residential and commercial/institutional sectors is considerably larger than the statistical fuel sales reported by DEA in the DEA sectors "Agriculture", "Industry", "Building and Construction" and "Residential". The fuel difference is subtracted from the road transport fuel input data prior to inventory calculations for this sector in order to maintain the overall national statistical fuel balance.

National sea transport

An internal DCE model is used to estimate the fuel consumption figures for national sea transport based on fleet activity estimates for regional ferries, local ferries, sailing activities between Denmark and Greenland/Faroe Islands, and other national sea transport (Winther, 2012; Nielsen et al., 2014).

Further, the statistical fuel sales and energy projections from DEA for the sectors "National sea transport" and "Greenland/Faroe Islands maritime" are used as an input for the fuel balance made in the subsequent emission calculations.

Table 5.5 lists the most important domestic ferry routes in Denmark in the period 1990-2012. For these ferry routes and the years 1990-2005, the following detailed traffic and technical data have been gathered by Winther (2008): Ferry name, year of service, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size and sailing time (single trip).

For 2006-2012, the above mentioned traffic and technical data for specific ferries have been provided by Kristensen (2013) in the case of Mols-Linien (Sjællands Odde-Ebeltoft, Sjællands Odde-Århus, Kalundborg-Århus), by Jørgensen (2013) for Færgen A/S (Køge-Rønne, Tårs-Spodsbjerg). For Esbjerg/Hanst-holm/Hirtshals-Torshavn traffic and technical data have been provided by Dávastovu (2011).

Table 5.5 Ferry routes comprised in the Danish inventory.

Ferry service	Service period
Esbjerg-Torshavn	1990-1995, 2009+
Halsskov-Knudshoved	1990-1999
Hanstholm-Torshavn	1991-1992, 1999+
Hirtshals-Torshavn	2010
Hundested-Grenaa	1990-1996
Kalundborg-Juelsminde	1990-1996
Kalundborg-Samsø	1990+
Kalundborg-Århus	1990+
Korsør-Nyborg, DSB	1990-1997
Korsør-Nyborg, Vognmandsruten	1990-1999
København-Rønne	1990-2004
Køge-Rønne	2004+
Sjællands Odde-Ebeltoft	1990+
Sjællands Odde-Århus	1999+
Tårs-Spodsbjerg	1990+

Other sectors

The activity data for military, railways, international sea transport and fishery consists of fuel consumption information from DEA (2014). For international sea transport, the basis is expected fuel sold in Danish ports for vessels with a foreign destination, as prescribed by the IPCC guidelines.

For all other mobile sectors, fuel consumption figures are given in Annex 5.2 for the years 2013-2035 in both CollectER and CRF formats.

5.2.2 Emission legislation

For the engines used by other mobile sources, no legislation limits exist for specific fuel consumption or the directly fuel dependent emissions of CO_2. The engine emissions, however, have to comply with the general emission legislation limits agreed by the EU and, except for ships (no VOC exhaust emission regulation), the VOC emission limits influence the emissions of CH_4, the latter emissions being a part of total VOC.

For non-road working machinery and equipment, recreational craft and railway locomotives/motor cars, the emission directives list specific emission limit values (g per kWh) for CO, VOC, NO_X (or VOC + NO_X) and TSP, depending on engine size (kW for diesel, ccm for gasoline) and date of implementation (referring to engine market date).

For diesel, the directives 97/68 and 2004/26 (Table 5.6) relate to non-road machinery other than agricultural and forestry tractors and the directives have different implementation dates for machinery operating under transient and constant loads. The latter directive also comprises emission limits for railway machinery (Table 5.8c). For tractors the relevant directives are 2000/25 and 2005/13. For gasoline, Directive 2002/88 distinguishes between handheld (SH) and non-handheld (NS) types of machinery.

For engine type approval, the emissions (and fuel consumption) are measured using various test cycles (ISO 8178). Each test cycle consists of a number of measurement points for specific engine loads during constant operation. The specific test cycle used depends on the machinery type in question and the test cycles are described in more detail in the directives.

Table 5.6 Overview of EU emission directives relevant for diesel fuelled non road machinery.

Stage/Engine size [kW]	CO	VOC	NO_X	$VOC+NO_X$	PM	Diesel machinery			Tractors	
	[g per kWh]					EU directive	Implement. date Transient	Implement. date Constant	EU directive	Imple-ment. date
Stage I										
37<=P<75	6.5	1.3	9.2	-	0.85	97/68	1/4 1999	-	2000/25	1/7 2001
Stage II										
130<=P<560	3.5	1	6	-	0.2	97/68	1/1 2002	1/1 2007	2000/25	1/7 2002
75<=P<130	5	1	6	-	0.3		1/1 2003	1/1 2007		1/7 2003
37<=P<75	5	1.3	7	-	0.4		1/1 2004	1/1 2007		1/1 2004
18<=P<37	5.5	1.5	8	-	0.8		1/1 2001	1/1 2007		1/1 2002
Stage IIIA										
130<=P<560	3.5	-	-	4	0.2	2004/26	1/1 2006	1/1 2011	2005/13	1/1 2006
75<=P<130	5	-	-	4	0.3		1/1 2007	1/1 2011		1/1 2007
37<=P<75	5	-	-	4.7	0.4		1/1 2008	1/1 2012		1/1 2008
19<=P<37	5.5	-	-	7.5	0.6		1/1 2007	1/1 2011		1/1 2007
Stage IIIB										
130<=P<560	3.5	0.19	2	-	0.025	2004/26	1/1 2011	-	2005/13	1/1 2011
75<=P<130	5	0.19	3.3	-	0.025		1/1 2012	-		1/1 2012
56<=P<75	5	0.19	3.3	-	0.025		1/1 2012	-		1/1 2012
37<=P<56	5	-	-	4.7	0.025		1/1 2013	-		1/1 2013
Stage IV										
130<=P<560	3.5	0.19	0.4	-	0.025	2004/26	1/1 2014		2005/13	1/1 2014
56<=P<130	5	0.19	0.4	-	0.025		1/10 2014			1/10 2014

Table 5.7 Overview of the EU emission directive 2002/88 for gasoline fuelled non road machinery.

	Category	Engine size [ccm]	CO [g per kWh]	HC [g per kWh]	NO_X [g per kWh]	$HC+NO_X$ [g per kWh]	Implementa-tion date
	Stage I						
Hand held	SH1	S<20	805	295	5.36	-	1/2 2005
	SH2	20=<S<50	805	241	5.36	-	1/2 2005
	SH3	50=<S	603	161	5.36	-	1/2 2005
Not hand held	SN3	100=<S<225	519	-	-	16.1	1/2 2005
	SN4	225=<S	519	-	-	13.4	1/2 2005
	Stage II						
Hand held	SH1	S<20	805	-	-	50	1/2 2008
	SH2	20=<S<50	805	-	-	50	1/2 2008
	SH3	50=<S	603	-	-	72	1/2 2009
Not hand held	SN1	S<66	610	-	-	50	1/2 2005
	SN2	66=<S<100	610	-	-	40	1/2 2005
	SN3	100=<S<225	610	-	-	16.1	1/2 2008
	SN4	225=<S	610	-	-	12.1	1/2 2007

For recreational craft, Directive 2003/44 comprises the Stage 1 emission legislation limits for diesel engines, and for 2-stroke and 4-stroke gasoline engines, respectively. The CO and VOC emission limits depend on engine size (kW) and the inserted parameters presented in the calculation formulas in Table 5.8a. For NO_X, a constant limit value is given for each of the three engine types. For TSP, the constant emission limit regards diesel engines only.

In Table 5.8b the Stage II emission limits are shown for recreational craft. CO and HC+NOx limits are provided for gasoline engines depending on the rated engine power and the engine type (stern-drive vs. outboard) while CO, HC+NOx, and particulate emission limits are defined for Compression Ignition (CI) engines depending on the rated engine power and the swept volume.

Table 5.8a Overview of the EU Emission Directive 2003/44 for recreational craft.

Engine type	Impl. date	CO=A+B/P^n			HC=A+B/P^n			NO_X	TSP
		A	B	n	A	B	n		
2-stroke gasoline	1/1 2007	150.0	600.0	1.0	30.0	100.0	0.75	10.0	-
4-stroke gasoline	1/1 2006	150.0	600.0	1.0	6.0	50.0	0.75	15.0	-
Diesel	1/1 2006	5.0	0.0	0	1.5	2.0	0.5	9.8	1.0

Table 5.8b Overview of the EU Emission Directive 2013/53 for recreational craft.

Diesel engines					
Swept Volume, SV	Rated Engine Power, P_N	Impl. Date	CO	HC + NO_x	PM
l/cyl.	kW		g/kWh	g/kWh	g/kWh
SV < 0.9	P_N < 37				
	37 <= P_N < 75 (*)	18/1 2017	5	4.7	0.30
	75 <= P_N < 3 700	18/1 2017	5	5.8	0.15
0.9 <= SV < 1.2	P_N < 3 700	18/1 2017	5	5.8	0.14
1.2 <= SV < 2.5		18/1 2017	5	5.8	0.12
2.5 <= SV < 3.5		18/1 2017	5	5.8	0.12
3.5 <= SV < 7.0		18/1 2017	5	5.8	0.11
Gasoline engines					
Engine type	Rated Engine Power, P_N		CO	HC + NO_x	PM
	kW		g/kWh	g/kWh	g/kWh
Stern-drive and inboard engines	P_N <= 373	18/1 2017	75	5	-
	373 <= P_N <= 485	18/1 2017	350	16	-
	P_N > 485	18/1 2017	350	22	-
Outboard engines and PWC engines (**)	P_N <= 4.3	18/1 2017	500 – (5.0 x P_N)	15.7 + (50/PN$^{0.9}$)	-
	4.3 <= P_N <= 40	18/1 2017	500 – (5.0 x P_N)	15.7 + (50/PN$^{0.9}$)	-
	P_N > 40	18/1 2017	300		-

(*) Alternatively, this engine segment shall not exceed a PM limit of 0.2 g/kWh and a combined HC + NO_x limit of 5.8 g/kWh

(**) Small and medium size manufacturers making outboard engines <= 15 kW have until 18/1 2020 to comply

Table 5.8c Overview of the EU emission directive 2004/26 for railway locomotives and motor cars.

	Engine size [kW]		CO [g per kWh]	HC [g per kWh]	NO_X [g per kWh]	HC+NO_X [g per kWh]	PM [g per kWh]	Implementation date
Locomotives	Stage IIIA							
	130<=P<560	RL A	3.5	-	-	4	0.2	1/1 2007
	560<P	RH A	3.5	0.5	6	-	0.2	1/1 2009
	2000<=P and piston displacement >= 5 l/cyl.	RH A	3.5	0.4	7.4	-	0.2	1/1 2009
	Stage IIIB	RB	3.5	-	-	4	0.025	1/1 2012
Motor cars	Stage IIIA							
	130<P	RC A	3.5	-	-	4	0.2	1/1 2006
	Stage IIIB							
	130<P	RC B	3.5	0.19	2	-	0.025	1/1 2012

Aircraft engine emissions of NO_x, CO, VOC and smoke are regulated by the International Civil Aviation Organization (ICAO). The engine emission certification standards are contained in Annex 16 — Environmental Protection, Volume II — Aircraft Engine Emissions to the Convention on International Civil Aviation (ICAO Annex 16, 1993). The emission standards relate to the total emissions (in grams) from the so-called LTO (Landing and Take Off) cycle divided by the rated engine thrust (kN). The ICAO LTO cycle contains the idealised aircraft movements below 3000 ft (915 m) during approach, landing, airport taxiing, take off and climb out.

For smoke all aircraft engines manufactured from 1 January 1983 must meet the emission limits agreed by ICAO. For NO_x, CO, VOC, the emission legislation is relevant for aircraft engines with a rated engine thrust larger than 26.7 kN. In the case of CO and VOC, the ICAO regulations apply for engines manufactured from 1 January 1983.

The equivalent limits for HC and CO are D_p/F_{oo} = 19.6 for HC and D_p/F_{oo} = 118 for CO (ICAO Annex 16 Vol. II paragraph 2.2.2). Smoke is limited to a regulatory smoke number = 83 $(F_{oo})^{-0.274}$ or a value of 50, whichever is the lower.

A further description of the technical definitions in relation to engine certification as well as actual engine exhaust emission measurement data can be found in the ICAO Engine Exhaust Emission Database. The latter database is accessible from http://www.caa.co.uk, hosted by the UK Civil Aviation Authority.

5.2.3 Emission factors

The CO_2 emission factors are country specific and come from the DEA. The N_2O emission factors are taken from the EMEP/EEA guidebook (EMEP/EEA, 2013). For military machinery aggregated CH_4 emission factors for gasoline and diesel are derived from the road traffic emission simulations. The CH_4 emission factors for railways are derived from specific Danish VOC measurements from the Danish State Railways (Delvig, 2013) and a NMVOC/CH_4 split based on own judgment.

For agriculture, forestry, industry, household gardening and inland waterways, the VOC emission factors are derived from various European measurement programmes; see IFEU (2004) and Winther et al. (2006). The NMVOC/CH_4 split is taken from USEPA (2004).

For national sea transport and fisheries, the VOC emission factors come from Trafikministeriet (2000). Specifically for the ferries used by Mols Linjen new VOC emission factors are provided by Kristensen (2008), originating from measurement results by Hansen et al. (2004), Wismann (1999) and PHP (1996). Kristensen (2013) has provided complementary emission factor data for new ferries. For the remaining domestic ferries, other national and international sea transport and fisheries, the VOC emission factors come from the Danish TEMA2000 model. The NMVOC/CH_4 split comes from the EMEP/EEA guidebook (EMEP/EEA, 2009). The latter source also provides CH_4 emission factors for the remaining sectors.

Emission factors are given in CollectER and CRF formats in Annex 5.2 for the years 2013-2035.

5.2.4 Calculation method

Air traffic

For aviation the estimates are made separately for landing and take-off (LTOs < 3000 ft), and cruise (> 3000 ft). The calculations furthermore distinguish between national and international flights. For more details regarding the calculation procedure please refer to Winther (2001a, 2001b and 2012).

Non-road working machinery and recreational craft

The fuel consumption and emissions are calculated as the product of the number of engines, annual working hours, average rated engine size, load factor and fuel consumption/emission factors. For diesel and gasoline engines, the deterioration effects (due to engine ageing) are included in the emission calculation equation by using deterioration factors according to engine type, size, age, lifetime and emission level. For diesel engines before Stage IIIB and IV, transient operational effects are also considered by using average transient factors. For more details regarding the calculation procedure, please refer to Winther et al. (2006).

National sea transport

The fuel consumption and emissions for Danish regional ferries are calculated as the product of the number of round trips, sailing time per round trip, engine size, load factor, and fuel consumption/emission factors. For local ferries and other ships, simple fuel based calculations are made using fuel-related emission factors and fuel consumption estimates from Winther (2008a). Please refer to the latter report for more details regarding this calculation procedure.

Other sectors

The emissions for fishing vessels, military and railways are estimated with the simple method using fuel-related emission factors and fuel consumption from DEA (2014).

5.3 Fuel consumption and emission results

An overview of the fuel consumption and emission results is given in Table 5.13 for all mobile sources in Denmark.

Table 5.9 Summary table of fuel consumption and emissions for mobile sources in Denmark.

		1990	1995	2000	2005	2010	2012	2013	2015	2020	2025	2030	2035
Energy, PJ	Industry-Other (1A2f)	11,5	11,6	12,0	13,0	14,4	13,9	9,7	9,4	9,1	9,0	9,0	8,9
	Civil Aviation (1A3a)	3,4	2,8	2,1	1,9	2,2	1,8	2,0	2,0	2,0	2,1	2,1	2,1
	Road (1A3b)	126,4	144,2	152,5	166,1	165,2	160,9	160,2	158,1	154,3	146,6	145,4	145,0
	Railways (1A3c)	4,0	4,1	3,1	3,1	3,3	3,4	3,4	3,0	2,9	2,3	0,8	0,8
	Navigation (1A3d)	10,5	11,3	7,9	7,8	7,9	6,6	8,3	8,3	8,3	8,3	8,3	8,3
	Commercial/Institutional (1A4a)	1,0	1,1	1,2	2,2	2,4	2,3	2,3	2,3	2,3	2,3	2,3	2,3
	Residential (1A4b)	0,5	0,5	0,6	0,8	0,9	0,9	1,2	1,2	1,2	1,2	1,2	1,2
	Ag./for./fish. (1A4c)	25,7	23,4	23,8	23,8	24,5	24,9	19,4	19,2	19,5	19,5	19,3	19,1
	Military (1A5)	1,6	3,4	1,5	3,7	1,5	1,6	1,9	1,9	1,9	1,9	1,9	1,9
	Navigation int. (1A3d)	39,1	65,1	52,6	30,7	27,0	19,8	21,8	21,8	21,8	21,8	21,8	21,8
	Civil Aviation int. (1A3a)	24,1	25,9	32,6	35,7	33,6	34,9	35,6	37,0	39,3	40,8	41,9	42,4
		1990	1995	2000	2005	2010	2012	2013	2015	2020	2025	2030	2035
CO_2, Gg	Industry-Other (1A2f)	839	846	877	952	1051	1021	705	686	664	657	657	648
	Civil Aviation (1A3a)	243	199	154	135	156	133	143	145	147	149	150	151
	Road (1A3b)	9284	10589	11203	12214	12080	11224	11111	10966	10229	9720	9642	9616
	Railways (1A3c)	297	303	228	232	242	249	248	222	216	170	58	58
	Navigation (1A3d)	796	850	588	585	591	498	623	623	623	623	623	623
	Commercial/Institutional (1A4a)	74	78	87	162	173	171	164	164	154	154	154	154
	Residential (1A4b)	39	40	43	59	63	62	82	82	77	77	77	77
	Ag./for./fish. (1A4c)	1899	1728	1762	1758	1809	1839	1435	1421	1441	1437	1423	1407
	Military (1A5)	119	252	111	271	107	116	139	139	139	139	139	139
	Navigation int. (1A3d)	3005	4976	4021	2352	2063	1505	1659	1659	1659	1659	1659	1659
	Civil Aviation int. (1A3a)	1736	1867	2350	2574	2421	2510	2561	2667	2826	2939	3017	3054
		1990	1995	2000	2005	2010	2012	2013	2015	2020	2025	2030	2035
CH_4, Mg	Industry-Other (1A2f)	60	53	50	45	38	36	32	30	28	27	27	27
	Civil Aviation (1A3a)	4	5	4	4	2	2	2	2	2	2	2	2
	Road (1A3b)	2233	2230	1788	1274	695	538	492	412	308	274	266	256
	Railways (1A3c)	12	13	10	9	7	7	6	4	0	0	0	0
	Navigation (1A3d)	32	36	33	35	35	34	15	15	15	15	15	15
	Commercial/Institutional (1A4a)	99	89	92	157	160	151	150	147	147	147	147	147
	Residential (1A4b)	51	47	45	62	65	65	85	82	81	81	81	81
	Ag./for./fish. (1A4c)	139	106	91	90	116	111	101	99	98	98	98	99
	Military (1A5)	5	17	5	12	3	3	4	3	3	3	3	3
	Navigation int. (1A3d)	64	108	91	55	50	37	41	42	43	44	44	44
	Civil Aviation int. (1A3a)	9	11	12	12	10	12	14	15	16	16	17	17
N_2O, Mg		1990	1995	2000	2005	2010	2012	2013	2015	2020	2025	2030	2035
	Industry-Other (1A2f)	34	35	37	40	45	43	30	29	29	28	29	28
	Civil Aviation (1A3a)	10	10	8	8	8	7	5	5	5	5	5	5
	Road (1A3b)	292	368	415	422	388	376	369	355	341	338	344	347
	Railways (1A3c)	8	8	6	6	7	7	7	6	6	5	2	2
	Navigation (1A3d)	48	51	34	34	34	29	37	37	37	37	37	37
	Commercial/Institutional (1A4a)	1	1	1	2	3	3	3	3	3	3	3	3
	Residential (1A4b)	1	1	1	1	1	1	2	2	2	2	2	2
	Ag./for./fish. (1A4c)	87	81	87	87	87	88	68	68	70	71	71	71
	Military (1A5)	4	7	3	9	4	4	5	5	5	5	5	5
	Navigation int. (1A3d)	189	313	253	148	130	95	105	105	105	105	105	105
	Civil Aviation int. (1A3a)	59	64	82	89	83	86	107	111	118	123	126	128
GHG eqv., Gg		1990	1995	2000	2005	2010	2012	2013	2015	2020	2025	2030	2035
	Industry-Other (1A2f)	851	858	890	966	1066	1036	715	696	674	666	666	657
	Civil Aviation (1A3a)	246	202	157	138	158	135	145	147	149	151	152	153

(Continued) GHG eqv., Gg	1990	1995	2000	2005	2010	2012	2013	2015	2020	2025	2030	2035
Road (1A3b)	9421	10750	11369	12371	12214	11352	11236	11085	10341	9830	9754	9729
Railways (1A3c)	300	306	230	234	244	252	250	224	218	172	58	58
Navigation (1A3d)	811	867	600	597	602	507	635	634	634	634	634	634
Commercial/Institutional (1A4a)	76	80	89	166	177	175	167	167	158	158	158	158
Residential (1A4b)	40	41	44	60	64	64	85	84	79	79	79	79
Ag./for./fish. (1A4c)	1929	1755	1791	1787	1839	1869	1458	1444	1465	1461	1447	1431
Military (1A5)	120	254	112	274	108	117	140	140	140	140	140	140
Navigation int. (1A3d)	3065	5076	4101	2400	2105	1536	1693	1693	1693	1693	1693	1693
Civil Aviation int. (1A3a)	1755	1887	2376	2602	2447	2536	2595	2702	2863	2978	3056	3094

5.3.1 Road transport

The total fuel consumption for road traffic is expected to decrease by 10 % from 2013 to 2035. Passenger cars have the largest fuel consumption share followed by heavy duty vehicles, light duty vehicles, buses and 2-wheelers in decreasing order, see Figure 5.3.

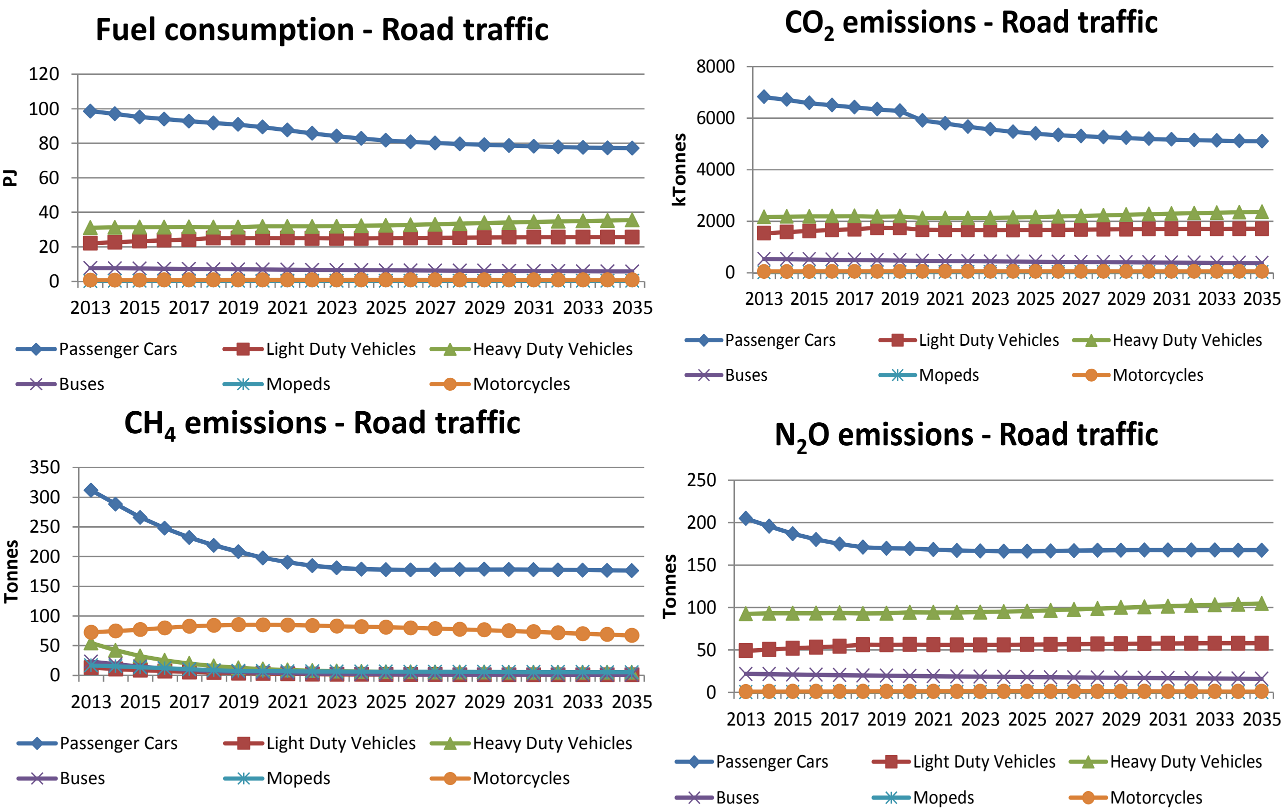

Figure 5.3 Fuel consumption, CO_2, CH_4 and N_2O emissions from 2013-2035 for road traffic.

The CO_2 emissions directly depend of the fuel consumption and the percentage amount of biofuels used in the Danish road transportation sector. From 2013-2019, the DEA (2014) assumes this percentage to be 5.75, after which the biofuel percentage reaches 10 % in 2020 (clearly visible from Figure 5.3 and following the EU directive 2003/30). The total CO_2 emissions decrease is expected to be 13 % from 2013-2035.

The majority of the CH_4 and N_2O emissions from road transport come from gasoline passenger cars (Figure 5.3). The CH_4 and N_2O emission decreases of 48 % and 6 %, respectively, from 2013 to 2035 is explained by the introduction of gradually more efficient catalytic converters for gasoline cars.

5.3.2 Other mobile sources

The development in CO_2 emissions for other mobile sources, see Figure 5.5, corresponds with the development in fuel consumption forecasted by the DEA (2014). Agriculture/forestry/fisheries (1A4c) is by far the largest source of CO_2 emissions followed by Industry (1A2f) and Navigation (1A3d). Minor CO2 emission contributing sectors are Commercial/institutional (1A4a), Military (1A5), Domestic aviation (1A3a), Railways (1A3c) and Residential (1A4b).

Agriculture/forestry/fisheries (1A4c) is the most important source of N_2O emissions, followed by Navigation (1A3d) and Industry (1A2f). The emission contributions from Railways (1A3c), Domestic aviation (1A3a) and Military (1A5) are small compared to the overall N_2O total for other mobile sources.

The majority of the CH_4 emission comes, by far, from gasoline gardening machinery in Commercial/institutional (1A4a) and Residential (1A4b), whereas for the railway, domestic air traffic and military categories only small emission contributions are noted. The CH_4 emission reduction for the residential category is due to the introduction of the cleaner gasoline stage II emission technology. Also for Agriculture/forestry/fisheries (1A4c) and Industry (1A2f), the gradually stricter emission standards for diesel engines cause the CH_4 emissions to decrease over the forecast period.

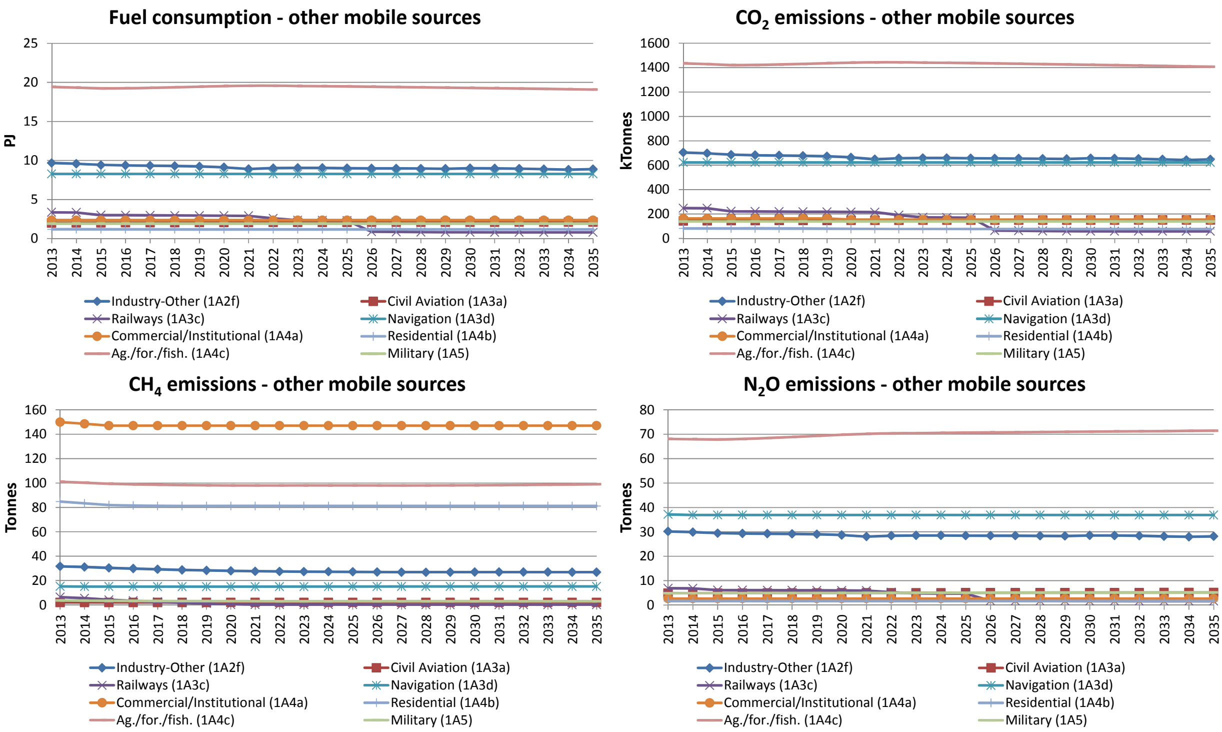

Figure 5.4 Fuel consumption, CO_2, CH_4 and N_2O emissions from 2013-2035 for other mobile sources.

5.4 Model structure for DCE transport models

More detailed emission models for transport comprising road transport, air traffic, non-road machinery and sea transport have been developed by DCE. The emission models are organised in databases. The basis is input data tables for fleet and operational data as well as fuel sale figures. Output fuel consumption and emission results are obtained through linked database queries. A thorough documentation of the database input data side and data manipulation queries will be given in a later DCE report, along with flow-chart diagrams.

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6 Agriculture

The emission of greenhouse gases from the agricultural sector includes the emission of methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). The emission is mainly related to the livestock production and includes CH_4 emission from enteric fermentation and manure management and N_2O emission from manure management and agricultural soils. Furthermore, a minor CH_4 and N_2O emission is estimated from burning of straw on field. CO_2 emission from the agricultural sector covers emissions from liming and use of inorganic N fertilizer.

The latest official reporting of emissions includes time series until 2012. Thus, the projection comprises an assessment of the greenhouse gas emissions from the agricultural sector from 2013 to 2035.

It must be noted that CO_2 removals/emissions from agricultural soils are not included in the agricultural sector. According to the IPCC guidelines this removal/emission should be included in the LULUCF sector (Land-Use, Land-Use Change and Forestry). The same comment applies to the emission related to agricultural machinery (tractors, harvesters and other non-road machinery), these emissions are included in the energy sector.

6.1 Projected agricultural emission 2013 - 2035

Projection of greenhouse gas emissions is regularly updated in line with new scientific knowledge as a consequence of new emission sources, changes of emission factors or changes of the agricultural production conditions e.g. changes regarding the export market or the legislation and regulation. Some of the changes can lead to revision in the historical emission inventory as well and therefore, some deviations are apparent in comparison with the projection scenarios published in previous reports. Compared to previous projections, new IPCC Guidelines has been implemented (IPCC, 2006) and the most important change is adjustment of the global warming potential, which increase the CH_4 emission and decrease the N_2O emission. The present projection of greenhouse gases replaces the latest projection published in Scientific Report from DCE – Danish Centre for Environment and Energy No. 48, 2013 (Nielsen et al., 2013).

Regarding the environmental regulation for the agricultural production it has until now primarily focused on the ammonia emission and nitrogen losses to the aquatic environment. However, improvements of the nitrogen utilization and subsequent decrease in nitrogen losses will indirectly reduce the greenhouse gas emission. Biogas treated slurry has a direct influence on reducing the methane emission and following the Agreement on Green Growth (2009 and 2010), a strategy for expansion of the biogas production is agreed. However, the new IPCC 2006 guidelines challenge the calculation methodology Denmark has used to estimate the greenhouse gas reduction until now.

Increasing demands to reduce unwanted environmental effects of the livestock production has led to additional legislation regarding approvals and establishment of new animal houses with focus on ammonia reducing technologies. The current projection includes an increase in the uptake of ammonia reducing technologies, which has an indirect impact on nitrous oxide emissions. The new expectations to expansion of the biogas production are based on assumptions provided by the Danish Energy Agency.

The main part of the emissions is related to the livestock production and thus the assumption regarding the development in the number of animals is very important. The primary productions are dairy cattle, swine and fur bearing animals, and the development in these productions are highly driven by the export conditions. The assumptions on the future animal production are based on the historical development combined with assessment from the agricultural production sector.

The current projection includes the latest changes in definitions of animal units for fattening pigs in BEK No. 853 of 18/06/2014, where one animal unit change from 36 to 39 produced pigs. This change implies that farmers can increase the production with max. 8 % without needing to apply for new environmental approval. It should also be mentioned that the projection includes expectations to increases in the production of bull calves with further 65 000 in 2020 due to the Cattle Agreement from June 2014 (Ministry of Food, Agriculture and Fisheries, 2014).

The development of agricultural greenhouse gases from 1990 to 2012 shows a decrease from 11.90 million tonnes CO_2 equivalents to 10.06 million tonnes CO_2 equivalents, which correspond to a 15 % reduction. The current projection, based on the assumptions provided, estimated an increase in emissions by 8 % in 2035 compared to 2012, which corresponds to 10.83 million tonnes CO_2 equivalents (Table 6.1). The increase is mainly a result of a higher CH_4 emission, while the emission of N_2O is almost unaltered. The higher CH_4 emission is due to an expansion of the production of dairy cattle and expectations to higher milk yields.

Table 6.1 Projected emission from the agricultural sector, given in CO_2 equivalents.

Gg CO_2 equivalents	2012	2013	2015	2020	2025	2030	2035
Enteric fermentation	3 681	3 688	3 758	3 940	4 121	4 322	4 428
Manure management	2 579	2 606	2 622	2 654	2 639	2 662	2 626
Direct soil emission[a]	2 989	3 046	3 031	3 037	3 045	3 052	3 041
Indirect emissions[b]	613	594	591	584	568	556	550
Field burning of agricultural residue	4	4	4	4	4	4	4
Liming	188	182	180	179	178	176	175
Urea application (CO_2 emission)	1	1	1	1	1	1	1
Other carbon-containing fert.	2	3	3	3	3	3	3
Total	10 058	10 123	10 190	10 401	10 558	10 775	10 828

[a] Direct soil emission includes emissions from: Inorganic N fertilizers, animal manure applied to soils, sewage sludge, other organic fertilizers, grazing animals, crop residues, mineralization, cultivation of histosols and other direct emissions.

[b] Indirect emissions includes emissions from: Atmospheric deposition and nitrogen leaching and run-off.

Despite, that the N_2O emission expects to be nearly unaltered, some changes in emission from subcategories takes place. The implementation of ammonia reducing technology in animal housing leads to higher nitrogen content in manure, which also leads to higher emission from manure applied on agricultural soils. On the other hand, the higher N content in animal manure combined with the decrease in agricultural area, implies that the use of inorganic fertilizer and thus the emission from this source is expected to decrease. However, these upward and downwards trends equalizes and result in a nearly unaltered emission from 2012 to 2035.

6.2 Comparison with previous projection

Compared to the previous projection some changes have been implemented. First of all this projection is based on IPCC Guidelines 2006 whereas the previous projection was based on IPCC 1996 and IPCC 2000. Compared with the previous projection, these changes have resulted in an increase of the total agricultural emissions by 9 to 22 % through the time-series (2013 to 2035). The increase is mainly related to the CH_4 emission (Figure 6.1).

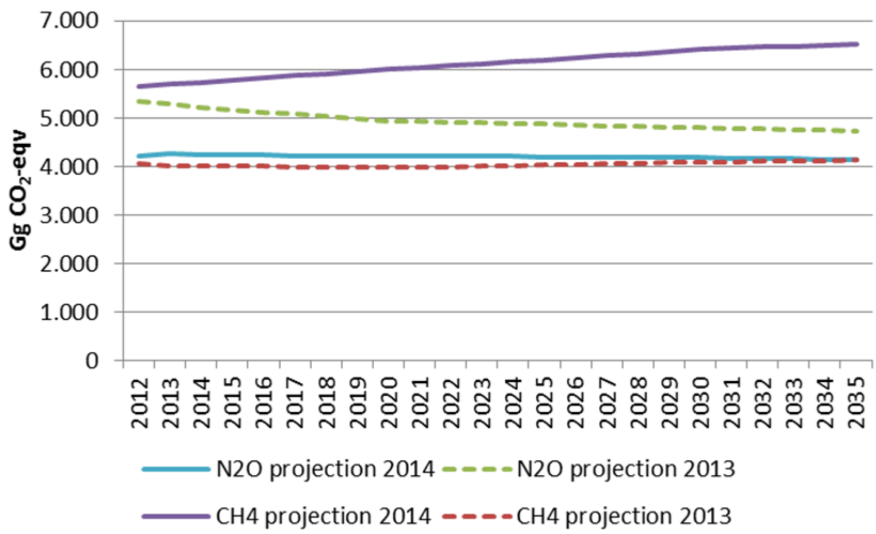

Figure 6.1 Projection 2014 compared to projection 2013.

The most important changes from the previous projection are described below. The former projection will be termed the 2013-projection.

The global warming potential (GWP) for CH_4 has been changed from 21 to 25, and for N_2O from 310 to 298. This means that only because of the change in GWP, the CH_4 emission increases by 20 %.

The CH_4 emission depends chiefly on the production of cattle and the current projection assumes a higher increase in the production and higher milk yield compared to the previous projection. Besides, the emission factors for CH_4 from manure management have been changed due to new IPCC definitions of manure management systems, which also lead to a higher emission.

Figure 6.2 shows the difference in emissions between the current and the previous projection for each of the N_2O emissions sources. Values below zero indicate a lower emission in the current projection, while values above zero indicate that the emission is highest in the previous projection.

The IPCC default N_2O emission factors has been lowered for nearly all emission categories and has in general reduced the N_2O emission and especially the emission from N-leaching and run-off. The emission from N-fixing crops is no longer considered as an emission category in IPCC 2006. Instead emission from agricultural crop residues includes N in roots and explain the higher emission from this source.

The N_2O emission from manure management is higher in the current projection, which is due to expectations of a higher livestock production than assumed in the previous projection. The area with organic soils has increased compared to the 2013-projection because organic soils with grass have been included. Furthermore the emission factor for organic soils has increased.

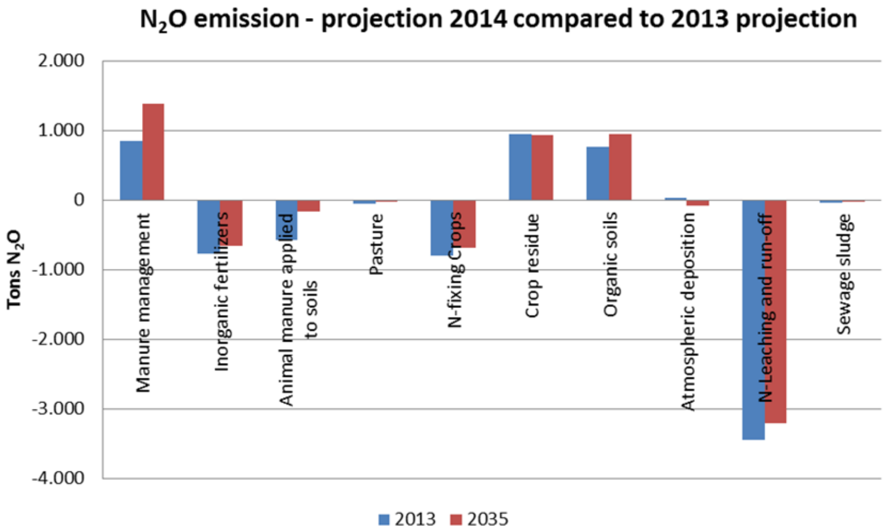

Figure 6.2 The difference in N_2O emission in the 2014 projection compared with the 2013 projection, in tonnes N_2O. Values below zero indicate a lower emission in the 2014 projection compared with the 2013 projection.

The Danish Energy Agency expectations to expansion of the biogas production are lower compared to previous projection. The current projection estimate the amount of biogas treated slurry, but does not include the reduced emission as a consequence of biogas treated slurry. As mentioned before, the new IPCC 2006 Guidelines methodology provides challenges in maintaining the methodology Denmark until now has used to estimate the greenhouse gas reduction. An ongoing project expects to provide data, which is consistent with the methodology given in the IPCC 2006.

6.3 Methodology

The methodology used to estimate the projected emission is based on the same methodology as used in the annual emission inventories, which is described in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). Thus, the same database setup is used, same estimation approach and the same emission factors.

The main emission contributors in Danish agriculture are cattle, swine and fur animals, which represent the most important variables in determination of projected emissions. Little information exits on how agriculture is expected to develop in the future, and the ongoing economic crisis that began in 2008 makes it even more difficult to foresee. Therefore the Knowledge Centre for Agriculture was contacted to discuss possibilities for the future production conditions and development expectations. This information has been used to provide assumptions regarding the development of the number of animals, type of housing, N-excretion, feed intake, implementation of ammonia reducing technology and the development of the biogas production. In this process the historical development is also taken into account.

There is always some uncertainty associated with predicting future developments and this is particularly the case for the swine production, which is highly dependent on the development of export conditions and therefore closely related to supply and demand on the world market.

6.4 Livestock production

The main part of the greenhouse gas emission is related to the livestock production and particularly the production of swine and dairy cattle. Expectations to the development of this production until 2035 are described in the section below.

The number of fur animals and broilers are based on expert judgement based on the Danish Poultry Meat Association and Kopenhagen Fur. It is assumed that the production will increase until 2020 and thereafter kept constant.

All other livestock categories have a minor effect of the total emission and the population is therefore kept at a level equivalent to average production conditions in 2008-2012 until 2035.

6.4.1 Dairy cattle

The Knowledge Centre for Agriculture expect that the number of dairy cattle may increase to 600 000 in 2020 and further to 625 000 in 2030 (Clausen, 2013). From 2030 to 2035 the number of dairy cattle is kept constant, while the efficiency is expected to increase further. This relatively high expansion of the milk production is due to the release of EU milk quota in 2015 and the expectation that Denmark is doing well on the world market.

The milk yield and the N-excretion are closely related and the assumption is provided by the Knowledge Centre for Agriculture (Aaes, 2012).

From 2012 to 2020 an increase in milk yields of 1.25 % per year is assumed, while the rate of increase from 2020 to 2035 is not expected to be as high, and thus assumed to be 1.0 % yield per year. The increase in the efficiency gives an average yield of approximately 9 900 kg milk per cow per year in 2020 and 11 800 kg milk per cow per year in 2035. This corresponds to a N-excretion 2020 for large breed cattle at 144 kg N and increased to 154 kg N in 2035.

Table 6.2 Number of dairy cattle and milk yield - figures used in the projection to 2035.

	2012	2013	2015	2020	2025	2030	2035
Dairy cattle, 1000 unit	587	581	586	600	613	625	625
Milk yield, kg milk per cow per year	8 962	9 049	9 284	9 871	10 504	11 094	11 805
Large breed, kg N-excretion	140.9	140.8	141.7	144.0	149.2	149.9	154.0
Jersey, kg N-excretion	119.9	119.9	121.3	124.9	129.7	130.6	134.5

6.4.2 Non-dairy cattle

The production of non-dairy cattle is based on the number of dairy cattle. The number of bull calves is increased until 2020 due to a political agreement regarding the cattle production, which means that production of bulls is subsidized (Ministry of Food, Agriculture and Fisheries, 2014). Based on this agreement a surplus production of 65 000 more bull calves is expected in 2020. No significant change in the allocation of the subcategories of non-dairy cattle; heifers, bulls and suckling cattle, is expected until 2035. The allocation of sub-categories is based on an average of 2008-2012 distribution.

The historic normative data for N-excretion for all cattle sub-categories shows few changes. In the projection no significant changes in N-excretion is expected and therefore kept at the same level as in 2012.

6.4.3 Housing system - cattle

In 2012, around 80 % of the dairy cattle and 35 % of the heifers are placed in housing systems with cubicles. In 2020, it is assumed that 98 % dairy cattle will be housed in systems with cubicles and thus most of the tethering and housing systems with deep litter are phased out. The result is that almost all manure from dairy cattle in 2020 is handled as slurry. For heifers, the tethering housing is assumed to be phased out in 2020. Around 20 % expects to be housed in deep litter systems and the remaining part is assumed to be placed in housing systems with cubicles.

6.4.4 Swine

It is expected that the agricultural structural development towards larger farm units will contribute to additional growth in swine production. However, at the same time the development is strongly influenced by the present economic crises and stricter environmental regulations due to the Law on environmental approval of animal holdings.

The assumptions regarding the swine production have been discussed with the Pig Research Centre (Tybirk, 2013). The number of sows is essential for the production of weaners and fattening pigs. The historical development shows an increase in production of sows from 1990 to 2007, followed by a decrease in recent years due to a combination of increased productivity given as number of weaners per sow per year and the unfavourable economic situation. In the current projection a production level of 1 million sows is assumed for all years 2013–2035 corresponding to the same level as the last couple of years. However, the production of weaners and fattening pigs will increase as a consequence of increased productivity in the form of an increase in produced weaners per sow.

Another important variable is the production of weaners per sow. During the period 1990-2012 a constant increase in the number of weaners per sow per year is observed and this development is expected to continue. In the current projection the efficiency development rate is based on a relatively conservative judgement and is expected to increase by 0.5 piglets per sow per year until 2025 and 0.4 piglets per year for 2025-2030. This results in an average production of nearly 38 produced weaners per sow in 2030. No increase in the number of weaners per sow is estimated in 2030-2035.

The weaners will either be exported or fattened in Denmark. Thus the number of produced fattening pigs depends to a high degree on the export conditions. Export data from Statistics Denmark shows a significant increase in export from 2004 and this trend is expected to continue. The export is assumed to increase from 9.6 million weaners in 2012 to 14 million in 2035, which increase the number of produced weaners from 29.7 million in 2012 to 34.4 in 2020, with a further increase to 38.4 in 2035. This corresponds to a 28 % increase in production of weaners from 2012 to 2035. Because of the rising export of weaners, the production of fattening pigs is expected to increase from 21.9 million in 2012 to 24.4 million in 2035, corresponding to 11 %.

Table 6.3 Number of produced sows, weaners and fattening pigs.

Swine, million produced	2012	2013	2015	2020	2025	2030	2035
Sows	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Weaners	29.7	30.9	31.9	34.4	36.4	38.4	38.4
Fattening pigs	21.9	21.1	21.7	23.4	23.4	24.9	24.4

6.4.5 N-excretion – swine

Due to improvements of feed efficiency a decrease in nitrogen excretion is expected. The assumptions applied in the projection are based on information from the Knowledge Centre for Agriculture. For sows the assumptions are based on a report from 2008 (Aaes et al., 2008) and the N-excretion for sows in 2020 is expected to be 22.81 kg N per sow per year, which corresponds to 11 % reduction compared to 2012.

The assumptions applied for weaners and fattening pigs are based on estimations made by Tybirk (2013). N-excretion for fattening pigs is expected to decrease from 2.84 to 2.71 kg N per pig produced per year, which corresponds to a reduction of 4 %. For weaners the N-excretion is expected to decrease from 0.51 in 2012 to 0.47 in 2020.

In Table 6.4, the figures for N-excretion used in the projection are given.

Table 6.4 N-excretion for swine – figures used in the projection to 2035

N-excretion for swine	2012	2013	2015	2020	2025	2030	2035
	kg N per pig per year						
Sows	25.56	25.22	24.53	22.81	22.81	22.81	22.81
Weaners	0.51	0.51	0.50	0.48	0.47	0.46	0.46
Fattening pigs	2.84	2.82	2.79	2.71	2.73	2.74	2.74

6.4.6 Housing system - swine

In 2012 more than 50 % of the fattening pigs are housed in systems with fully slatted floor. These systems and systems with solid floor and with deep layer of bedding are assumed to be phased out. Thus, all fattening pigs are expected to be housed in systems with partially slatted or drained floor in 2035. For sows, systems with fully slatted floor are expected to be phased out in 2020 and almost all sows are expected to be housed in systems with partly slatted floor in 2035.

6.5 Implementation of emission reducing technology

Emission reducing technology is in this projection defined as biogas treatment of animal manure, implementation of ammonia reducing technology in housing, in storage and sulphuric acid treatment of the slurry during the application to the soil. As mention before, the ammonia reducing technology is also important when it comes to emission of greenhouse gases, because reduction of ammonia has an indirectly impact on the N_2O emission.

6.5.1 Biogas treatment of animal manure

Biogas treatment leads to a lower CH_4 emission from animal manure. In 2012, approximately 2.5 million tonnes slurry was treated in biogas plants which are equivalent to approximately 6 % of all slurry. The energy production is by the Danish Energy Agency estimated to 3.0 PJ.

Assessment from the Danish Energy Agency shows an expected energy production from biogas plant by 8.9 PJ in 2020 and 12.9 PJ in 2035 and the major part of the energy production origins from biogas treated slurry. Thus, in 2020 approximately 7 million tonnes slurry is expected to be biogas treated, which correspond to around 16% of the total amount of slurry and further extended to around 22 % in 2035 (10.2 million tonnes treated slurry).

Table 6.5 Expected development in biogas treated slurry.

	Pct. of biogas treated slurry	Million tonnes slurry biogas treated
2012	6	2.5
2015	10	4.0
2020	16	7.0
2025	19	8.6
2030	21	9.5
2035	22	10.2

IPCC 2006 includes guidelines for estimation of emission reduction caused by the biogas treatment of manure. However, this is not consistence with the methodology Denmark until now has used to estimate the reduced emission of CH_4 and N_2O.

Guidelines use a specific methane conversions factor (MCF) for the biogas treated slurry. Following the IPCC 2006 Guidelines Denmark use a MCF of 10.4 % for dairy cattle slurry. This is a weighted value depending on covering of slurry tanks and the temperature zone. Logically, the MCF has to be lower for biogas treated slurry compared to non-treated slurry, but it is difficult to quantify how much lower. Currently very few data is available to estimate a MCF corresponding to the Danish agricultural conditions. Because of the lack of data the reduction of CH_4 emission is not estimated in the current projection. The IPCC 2006 mentioned that no reduced N_2O emission is expected for biogas treated slurry.

To indicate the reduction potential the sensitivity analysis chapter includes an estimation of the greenhouse gas reduction by using the old calculation methodology (Sommer et al., 2001). A project designed to provide a national MCF for biogas treated slurry is in progress and results from this work will be implemented in the inventory and projection.

6.5.2 NH_3 reducing technologies

At present, one of the most important requirements, regarding implementation of ammonia reducing technology in housing is the Danish Law on environmental approval of animal holdings (Statutory Order no. 1572 of 20/12/2006). While, the main focus of previous regulation was on a general reduction, this legislation opens up for a more specific regulation depending on the geographical location and the size of the livestock production. The consolidation Statutory Order of 2011 (Statutory Order no. 1280 of 08/11/2013) requires a minimum 30 % reduction of the ammonia emission from housing and storage when new housing are constructed or renovated. This means, that if a farmer will expand the animal production or for other reasons need to build new housing, he will be met with a requirement of 30 % reduction compared to a defined reference housing system. The 30 % requirement is the basic level, but for larger farms (more than 250 animal units) the requirement level is higher and for some livestock- or manure types the requirement level is lower. The current projection does not specify which technological solution the farmers choose to achieve the 30% reduction. A percentage of the livestock production is assumed to be exposed to a requirement of 30 % reduction in 2020 and 2030. This is heavily dependent on expectations to extension of the livestock production and the needs of new housing.

In the current projection a relatively conservative estimate of housing replacement is assumed. The current economic conditions makes it is very difficult for farmers to expand the livestock production. In the projection an expansion of livestock production for cattle, swine, mink and broilers is assumed, which indicates a need for new barns. In any case, the barns will be outdated over time and need to be replaced.

A more detailed description and explanation of the provided assumptions regarding the expectations to implementation of ammonia reducing technology refer to Nielsen et al. (2013b). Below, the assumption for each production sector, is listed. Values coloured with red indicate that the value is based on interpolation. In 2020, a share of 25 % is placed in housing with technology that reduces the ammonia emission from housing and storage by 30 %. In 2030, all dairy cattle are place in housing with 30 % reduction of the ammonia emission.

For weaners the ammonia reduction requirements are 20 %. However, a further reduction of 30% in 2035 is expected as a consequence of new environmental requirements or as a consequence of economic benefits for the farmer. Pig farms with a production higher than 250 animal units are met with higher environmental requirements. That is why the projection works with two categories of reduction requirement – the general requirement of 30 % reduction and another category with 60 % reduction requirements.

A new technology in broiler housing can reduce the ammonia emissions by 41 % by establishment of a heat exchanger, which uses the thermal energy of the air leaving the broiler housing to heat and dry the incoming air (ETV). Besides the reduction of ammonia, the heat exchange is very energy efficient and improves of the air quality in housing. The heat exchanger can be established in existing housing.

Table 6.6 Percentage of the livestock production which are exposed to a requirement of 30 % ammonia reduction from housing and storage.

Livestock category		2012	2015	2020	2025	2030	2035
Cattle							
Dairy cattle	Reduction requirement; 30%	0	11	25	63	100	100
Heifer	Reduction requirement; 30%	0	11	25	63	100	100
Swine							
Sows	Reduction requirement; 30%	0	5	29	53	76	100
Weaners	Reduction requirement; 20%	0	5	20	23	27	30
Fattening pigs	Reduction requirement; 30%	0	5	21	38	54	70
Fattening pigs	Reduction requirement; 60%	0	5	11	18	24	30
Fur bearing animal							
Mink	Reduction requirement; 30%	0	0	50	75	100	100
Poultry							
Broilers	Reduction rate; 40% (heat exchange)	0	25	50	75	100	100
Hens	Reduction requirement; 30%	0	29	64	100	100	100

Note: Red numbers are interpolated.

6.5.3 Sulphuric acid treatment during application of manure

Expectations to the use of slurry acidification during application of manure are based on information from the Knowledge Centre for Agriculture, Department for Cattle (Westergaard, 2013). The technology use today is still relatively limited, but is expected to increase in future. In 2030 it is assumed that 30 % of the cattle slurry is acid treated and 50 % of the pig slurry. From 2030 to 2035 no changes are expected.

Table 6.7 Assumed part of the slurry which is treated with sulphur acid.

Cattle slurry	2011	2030
	%	
Injected/incorporated direct	76	70
Trailing hoses	24	-
Sulphuric acid treatment	< 1	30
Pig slurry	2011	2030
	%	
Injected/incorporated direct	37	37
Trailing hoses	63	13
Sulphuric acid treatment	< 1	50

A VERA verifications show that the acid treated cattle and pig slurry reduces the ammonia emission by 49 % (VERA, 2010) compared with use of application by trailing hoses.

6.6 Other agricultural emission sources

Besides the livestock production, the most important variables regarding the emission of the greenhouse gases are use of inorganic N fertilizer on agricultural area.

6.6.1 Agricultural area

The most important variable concerning the total greenhouse gas emission is whether the areas are cultivated or not, while the crop type is less important and thus not taken into account.

Historical data indicate a decrease in the agricultural area, which is expected to continue. The current projection assumes a decrease by 55 000 ha from 2012-2020, which correspond to 0.26 % per year. This decrease covers 15 000 ha converted to urban development and infrastructure, 15 000 ha to afforestation and 25 000 ha set aside from cultivation near water streams with the purpose to reduce the nitrogen loss to the aquatic environment as described in the Agreement on Green Growth (2009 and 2010).

From 2020-2035 a lower reduction rate is assumed; 52 500 ha, which correspond to 0.14 % per year.

Table 6.8 Agricultural land area in the projection.

	2012	2013	2015	2020	2025	2030	2035
Agricultural land area, 1 000 ha	2 645	2 628	2 608	2 590	2 572	2 555	2 537

6.6.2 Use of inorganic N fertilizers

The nitrogen need in crops is covered by nitrogen in animal manure and inorganic fertilizers. The total agricultural area is assumed to be 2590 ha in 2020 and 2537 ha in 2035 and it is assumed that 1,5% is not fertilized. The historical data (2007-2011) shows an average nitrogen need of 130 kg N per ha. Based on knowledge of nitrogen content in manure (N ex Storage) and the nitrogen which has to be included in the farmers fertilizers account, the need for nitrogen in inorganic fertilizer can be calculated (see Table 6.9).

Table 6.9 Consumption of inorganic N fertilizers.

	2012	2013	2015	2020	2025	2030	2035
				Gg N			
N in animal manure (N ex storage)	207	208	211	220	227	234	236
N which is included in the farmers' fertilizer accounts	141	142	144	149	155	162	163
N in inorganic N fertilizers	192	195	190	183	174	166	162

The use of nitrogen in inorganic N fertilizers is assumed to decrease from 192 Gg in 2012 to 162 Gg in 2035, which is a 16 % reduction. The two main reasons for this reduction are a decrease in the agricultural area and implementation of ammonia reduction technology. The technology reduces the ammonia emission from the housings and thereby increases the content of N in the animal manure (N ex storage).

6.7 Results

In Table 6.10-6.12 the historical greenhouse gas emission 1990-2012 is listed, followed by the projected emissions 2013-2035. The greenhouse gas emission is expected to increase from 10.06 million tonnes CO_2 equivalents in 2012 to 10.40 million tonnes CO_2 equivalents in 2020. Until 2035 a further increase to 10.83 million tonnes CO_2 equivalents is assumed. Thus, the projection indicates an increased emission by 8 % from 2012 to 2035. The increased emission is mainly a result of an increase in the CH_4 emission due to increase of the dairy cattle production.

Table 6.10 Total historical (1990-2012) and projected (2013-2035) emission, given in CO_2 eqv.

CO_2 equivalents, million tonnes	1990	2000	2012	2013	2015	2020	2025	2030	2035	Average 2010/14
CH_4	5.45	5.63	5.65	5.69	5.78	6.00	6.18	6.42	6.51	5.68
N_2O	5.82	4.83	4.21	4.25	4.23	4.22	4.19	4.18	4.14	4.23
CO_2	0.63	0.27	0.19	0.19	0.18	0.18	0.18	0.18	0.18	0.17
Agriculture, total	11.90	10.73	10.06	10.12	10.19	10.40	10.56	10.78	10.83	10.08

6.7.1 CH_4 emission

The overall CH_4 emission has increased from 218 Gg CH_4 in 1990 to 260 Gg CH_4 in 2035 corresponding to an increase of 15 % (Table 6.11).

The decrease in emission from enteric fermentation 1990–2012 is due to a decrease in the number of dairy cattle, as a consequence of higher milk yield. Because the EU milk quota system does not continue from 2014, the number of dairy cattle is expected to increase from 2014 – 2035. The increase in number of dairy cattle and a continued increase in milk yield and feed intake lead to an increase of the enteric emission.

The CH_4 emission from manure management has increased from 1990- 2012, which is a result of change in housing systems towards more slurry based systems. In future this trend is assumed to continue but mainly due to increase in number of animals.

Table 6.11 Historical (1990-2012) and projected (2013-2035) CH_4 emission.

CH_4 emission, Gg	1990	2000	2012	2013	2015	2020	2025	2030	2035	Average 2010/14
Enteric fermentation	154.7	143.8	147.3	147.5	150.3	157.6	164.8	172.9	177.1	146.9
Manure management	63.1	81.4	78.8	79.9	80.6	82.4	82.3	83.8	83.2	80.3
Field burning	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total CH_4, Gg	217.9	225.4	226.2	227.5	231.0	240.1	247.3	256.8	260.5	227.3

6.7.2 N_2O emission

The N_2O emission is reduced from 1990 to 2012 but in the projected period 2013-2035 the emission is almost unaltered, corresponding to an emission in 2013 of 14.26 Gg N_2O and in 2035 of 13.88 Gg N_2O. This is a reduction of only 1.8 % (Table 6.12). Even though the total N_2O emission is almost unaltered, the different sources changes in the period 2013-2035.

Due to an increased number of animals the amount of manure applied to soil increases. The emission from the use of inorganic N fertilizer decreases due to an increase in utilization of manure on soil and implementation of the ammonia reducing technology, which reduces the ammonia emission in livestock houses and leads to a higher nitrogen content in manure. Given that the nitrogen is kept in the manure during the storage process, the nitrogen can be used as fertiliser. This will lower the demand of inorganic N fertilizer.

Table 6.12 Historical (1990-2012) and projected (2013-2035) N_2O emission.

N_2O emission, Gg	1990	2000	2012	2013	2015	2020	2025	2030	2035	Average 2010/14
Manure management	2.33	2.48	2.04	2.04	2.04	2.00	1.95	1.90	1.83	2.08
Inorganic N fertilizer	6.07	3.82	2.85	3.01	2.94	2.83	2.70	2.56	2.50	2.93
Animal manure applied	2.87	2.74	3.00	3.03	3.09	3.27	3.43	3.61	3.64	3.03
Sewage sludge	0.07	0.14	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11
Grazing animals	1.00	1.01	0.61	0.61	0.62	0.63	0.64	0.65	0.66	0.62
Crop residues	1.91	1.83	2.21	2.20	2.18	2.17	2.15	2.14	2.12	2.14
Mineralization	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Organic soils	1.82	1.57	1.26	1.26	1.23	1.18	1.18	1.17	1.17	1.28
Atmospheric deposition	1.60	1.21	0.95	0.90	0.89	0.86	0.81	0.77	0.76	0.94
N-leaching and run-off	1.84	1.39	1.11	1.09	1.09	1.10	1.09	1.09	1.09	1.08
Field burning	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total N_2O, Gg	19.53	16.19	14.13	14.26	14.20	14.15	14.07	14.01	13.88	14.20

6.8 Sensitivity analysis

In an attempt to foresee how the agricultural sector looks like in 20 years, it is necessary to make some assumptions. The most important variables are the livestock production and particularly the production of swine and cattle. Regarding the N_2O emission the contribution from swine and cattle is almost equal, while the cattle production is the main driver for the CH_4 emission (represent 2/3 of the emission). Therefor the development of the cattle production plays a very important role in prediction of the future greenhouse gas emission.

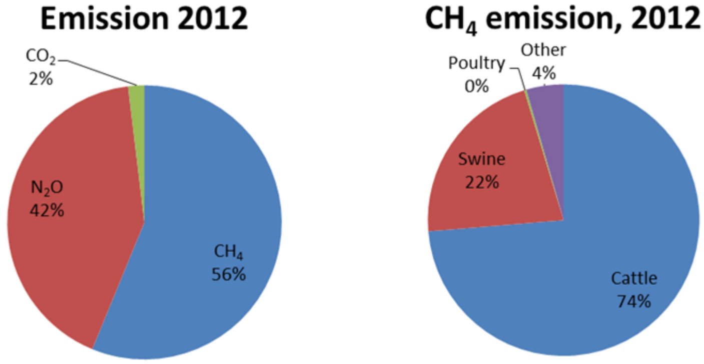

Figure 6.3 Total GHG emission and CH_4 emission 2012.

The opportunity for milk production increases after the EU quota is abolished in 2015 depending on Denmark's competitiveness. A demand on the export market and the development of the milk yield determines the number of dairy cattle. From 2012 to 2013 the number of dairy cattle has increased by 4 %, which indicate the farmer’s willingness to extend the production. Other large scale milk production countries will probably do the same, which can lower milk prices on the world market. However, EU estimates that the Danish milk production in the coming year will increase by 12.5 %, while Arla Foods, and the Danish Dairy farmers are even more optimistic and expecting an increase to 6 billion kg of milk in 2018/19, representing an increase of 20 % compared to 2012, on the assumption that financial funding can be established and the environmental approval can be achieved. In this projection are estimated an increase of 12.5 % in the total milk production in 2020 compared to 2012.

Due to the uncertainties regarding the development of the cattle production, it could be relevant to know how changes in number of dairy cattle affect the emission of greenhouse gases. The 2014 projection has been compared with two scenarios (Figure 6.3). One scenario, which include 10 % more dairy cattle than expected in the 2014 projection, in the following text mentioned as “DCE cattle+10%”. Another scenario with a lower number of dairy cattle than estimated in the 2014 projection, based on assumptions provided by the Department of Food and Resource Economics (IFRO), University of Copenhagen (Hansen et al, 2014). In the following text this scenario is mentioned as “IFRO”.

DCE 2014 projection operates with expectations of 600 thousand dairy cattle in 2020 increasing to 625 thousand in 2035. Scenario DCE cattle+10% includes a 10% production increase to 660 dairy cattle in 2020 and 688 thousand in 2035. The IFRO scenario is based on an assumption of 576 thousand dairy cattle in 2020 and 532 thousand in 2035, which is 15 % lower than the DCE 2014 projection. The result of the comparison with the DCE 2014 projection shows a difference from +500 to -700 Gg CO_2 eqv. These changes in dairy production thus affect the total greenhouse gas emission from the agricultural sector around ±5-7 %.

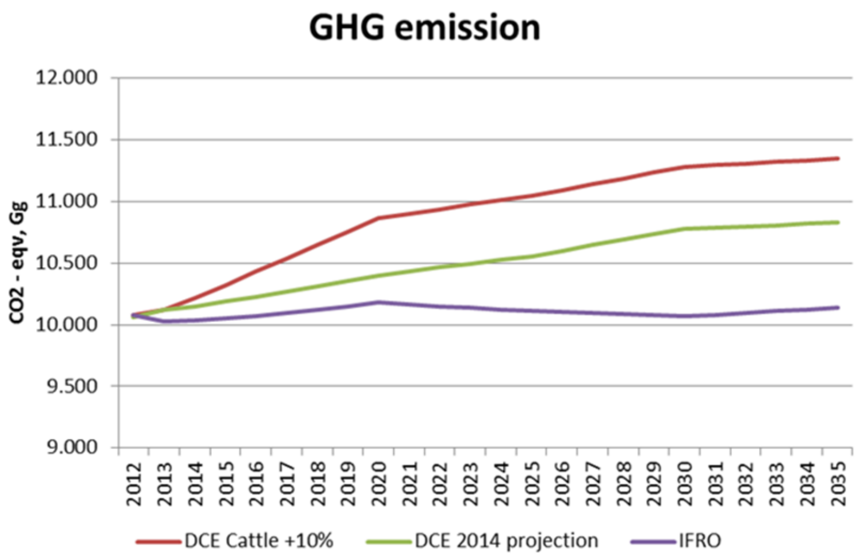

Figure 6.4 Projected emission scenarios.

A similar assessment regarding the swine production is not provided. However, it has to be mentioned that the greenhouse gas emission also will be affected if considerable changes in production takes place. The major part of the pig meat is exported (around 90%) and the market conditions in main export countries as Germany, United Kingdom, Japan, Russia and Poland is extremely crucial for the Danish production. Besides, factors such as feedstuff prices, environmental requirements, disease pressure and requirements to animal welfare also impact the possibilities for the future production.

As mentioned the IPCC 2006 Guidebook now includes guidelines for estimation of the reduced emission caused by biogas treated slurry. This methodology description does not match the calculation used in the Danish emission inventory. Therefore, the reduced emission from biogas treated slurry is not included in current projection. It is planned to re-include the reduced emission as soon as new data from an ongoing project are available. Table 6.13 indicate the reduced emission if the methodology in the previous inventory is used. In 2012, the reduced emission is estimated to 0.044 million tonnes of CO_2 eqv. increasing to 0.197 million tonnes of CO_2 eqv. in 2035, which correspond to 0.4 % of the total GHG emission in 2012 and 1.8 % in 2035.

Table 6.13 Reduced GHG emission due to biogas treated slurry compared with total GHG emission.

Emission, M tonnes CO_2-eqv.	2012	2013	2015	2020	2025	2030	2035
2014 projection	10.058	10.123	10.190	10.401	10.558	10.775	10.828
Reduced emission (methodology used in previous inventory)							
CH_4	0.024	0.035	0.047	0.081	0.100	0.111	0.118
N_2O	0.020	0.023	0.032	0.055	0.067	0.074	0.079
Total reduced emission	0.044	0.058	0.078	0.136	0.167	0.185	0.197

6.9 References

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7 Waste

7.1 Solid waste disposal on land

The CRF source category *6.A Solid waste disposal sites,* gives rise to CH_4 emissions.

CH_4 emissions are calculated by means of a first order decay (FOD) emissions model, where activity data is annual data for the amount of waste deposited and where emissions factors, which are the amounts of CH_4 emitted per amount of waste deposited, result from model assumptions about the decay of waste and release of CH_4 as described in Nielsen et al., 2014.

7.1.1 Emissions model

The model has been developed and used in connection with the historic emissions inventories prepared for the United Nation Climate Convention. As a result, the model has been developed in accordance with the guidelines found in the IPCC Guidelines (1996) and IPCC Good Practice Guidance (2001). Based on the recommendation in these reports, a so-termed Tier 2 method, a decay model, has been selected for the model. The model is described in the National Inventory Report which is prepared for the Climate Convention, the latest being the 2014 NIR report (Nielsen et al., 2014). In short, the degradation and release of methane is modelled according waste type specific content of degradable organic matter and degradation rates assuming first order decay (FOD) kinetics. For a detailed description of the model and input parameters the reader is referred to Nielsen et al., 2014.

7.1.2 Activity data

The general development for solid waste at disposal sites is a result of action plans by the Danish government called the "Action plan for Waste and Recycling 1993-1997" and "Waste 21 1998-2004" (The Danish Government, 1999). The latter plan had, inter alia, the goal to recycle 64 %, incinerate 24 % and deposit 12 % of all waste. The goal for deposited waste was met in 2000. Further, in 1996 a municipal obligation to assign combustible waste to incineration was introduced. In 2003, the Danish Government set up targets for the year 2008 for waste handling in a “Waste Strategy 2005-2008” report. According to this strategy, the target for 2008 is a maximum of 9 % of the total waste to be deposited. In the waste statistics report for the year 2004, data shows that this target was met, since 7.7 % of total waste was deposited in 2004. Waste Strategy 2009-12, part I was the sixth waste management plan or strategy adopted by the successive governments dating back to 1986. Waste Strategy 2009-12 set up targets for 2012 according to which a maximum of 6 % of the total waste produced is to be deposited; a target that was met already in 2009, where 5.6 % of all produced waste was deposited. Data at the above level of information may be obtained from the ISAG database/waste statistics (1994-2009).

Deposited amounts of waste

The amount of waste deposited at landfills has been dramatically reduced over the past 20 years as shown in Figure 7.1.

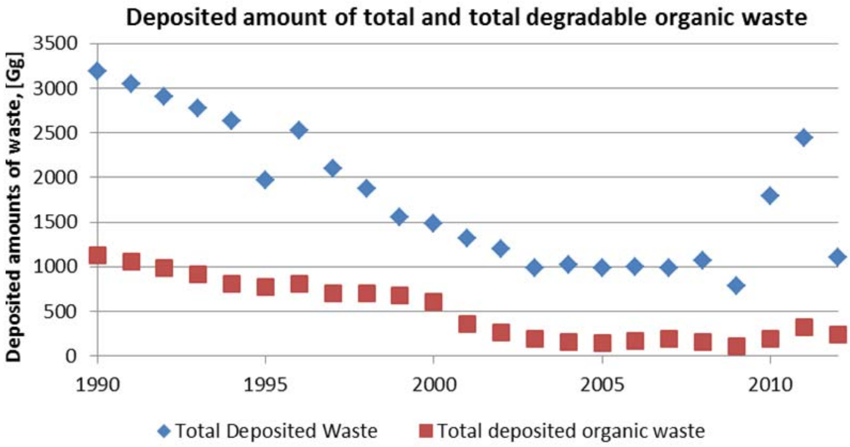

Figure 7.1 Historical data on the total amount of waste, i.e. organic/degradable and inert/non-degradable waste, and total organic waste disposed of at solid waste disposal sites.

According to DEPA (DEPA, 2011), the amount of waste deposited of at solid waste disposal sites (SWDSs) is expected to stay at a fairly constant level in the future, in spite of a future increase in the total amount of waste (DEPA, 2011; DEPA, 2014). For the year 2010 one quarter of the reporting year is missing and likewise for 2011 data are associated to increased level of uncertainty at the time of preparation of the current report. In the present projection of methane emissions from SWDSs, the characteristics and total amounts of waste have been set constant and equal to the 2012 data throughout the projection period 2013-2035.

For details regarding the fractional distribution of the 18 waste types of which 11 fractions have been identified as inert, the reader is referred to Nielsen et al., 2014 and Thomsen & Hjelgaard, 2014, in prep.

Amount of recovered methane

The amount of recovered methane was estimated based on information from the Danish Energy statistics stating that the amount of recovered methane has reached a constant level of 0.2 PJ per year from 2011 and forward. A correlation analysis between historical data on the annual generated, i.e. gross methane emission, and collected amounts of methane shows that a future projected constant amount of recovered methane requires increased recovery efficiency. As such a yearly recovery of 3.7 Gg methane corresponds to an increase in the efficiency from 9 to 20% recovery of the gross methane emission in 2011 to 2035.

7.1.3 Historical and projected activity data and emissions

The emission projection uses the same CH_4 emission model used for calculation of the historic emissions. The resulting projections of the generated, recovered and net CH_4 emissions can be seen in Table 7.1.

Table 7.1 Historical and projected amounts of deposited waste: total and organic amounts of waste, accumulated decomposable organic waste, annual deposited methane potential, gross emission, recovered methane, net methane emission at Danish landfill sites, Gg.

Year	Total Deposited Waste	Total deposited organic waste	Accumulated amount of decomposable DDOCm Eqv. 8.2.4	Annual amount of degraded DDOCm Eqv. 8.2.5	Annual deposited CH_4 potential	Annual Gross CH_4 emission Eqv. 8.2.6	Recovered methane	Annual net emission after oxidation	Implied Emission Factor
1990	3190	1128	2546	122.86	98.24	72.78	0.51	65.04	0.020
1995	1969	776	2553	122.78	61.99	71.60	7.61	57.60	0.029
2000	1489	601	2490	116.58	64.76	66.66	11.25	49.87	0.033
2005	983	147	2086	98.81	10.26	55.58	9.95	41.07	0.042
2010	1786	189	1734	80.10	6.41	44.53	6.42	34.30	0.019
2011	2439	325	1690	76.92	12.63	42.68	3.99	34.82	0.014
2012	1107	234	1634	74.44	18.60	41.23	4.30	33.24	0.030
2013	1107	234	1582	71.50	10.90	39.54	3.74	32.22	0.029
2015	1107	234	1486	66.11	10.90	36.47	3.34	29.82	0.027
2020	1107	234	1287	55.11	10.90	30.29	2.66	24.87	0.022
2025	1107	234	1136	46.88	10.90	25.72	2.24	21.13	0.019
2030	1107	234	1020	40.68	10.90	22.30	1.97	18.29	0.017
2035	1107	234	930	35.99	10.90	19.72	0.84	17.00	0.015

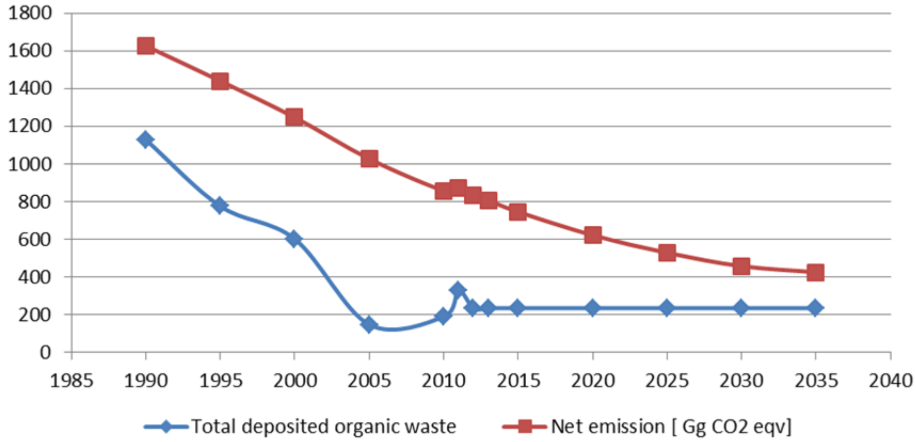

Figure 7.2 Historical and projected amounts of waste deposited at landfill and net CH_4 emissions. Historic data: 1993-2009. Projections: 2010-2035.

Due to a combination of the Danish waste strategies and goals of minimising the amount of deposited waste in favourof an increased reuse and combustion for energy production, the sharp decrease in historical data on the deposited amounts of waste is observed.

7.2 Biological Treatment

In Denmark, biological treatment of solid biological waste includes composting of:

- garden and park waste (GPW),
- organic waste from households and other sources,
- sludge and,
- home composting of garden and vegetable food waste.

The future activity of each category has been projected individually while the emission factors are kept constant throughout the time series.

7.2.1 Emission factors

By assuming that the process of compost production will not significantly change over the next 23 years, the emission factors known from Nielsen et al. (2014) are used for this projection.

Table 7.2 Emission factors for compost production, Mg per Gg.

	Garden and Park waste (GPW)	Organic waste	Sludge	Home composting
CH_4	4.20	4.00	0.41	5.63
N_2O	0.12	0.30	1.92	0.11
Source	Boldrin et al., 2009	EEA, 2009	MST, 2013	Boldrin et al., 2009

7.2.1 Activity data

Garden and park waste is for 1995-2009 determined based on the Danish waste statistics (DEPA, 2011) and on the two statistical reports Petersen (2001) and Petersen & Hansen (2003). The projection of this waste category is made from the linear regression of the 1999-2009 activity data. The 1995-1998 data is not used for the projection because the strong increase for these years does not match the 1999-2009 trend.

Activity data for both waste-categories; *organic waste from households and other sources* and *sludge*, are for the historical years 1995-2009 based on data from the Danish waste statistics. The projection of *organic waste from households and other sources* is carried out as an average of the activity data from 1995-2009 and *sludge* as an expert judgement.

Home composting of garden and vegetable food waste is for 1990-2012 determined based on data from Statistics Denmark and on Petersen & Kielland (2003). The 1990-2012 data is used in a linear regression to project home composting for 2013-2035.

Table 7.3 Projected activity data for compost production, Gg.

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Garden and park waste	954	980	1005	1031	1056	1082	1108	1133	1159	1184	1210	1235
Organic waste	55	55	55	55	55	55	55	55	55	55	55	55
Sludge	150	155	160	165	170	175	180	185	190	195	200	205
Home composting	23	23	23	23	24	24	24	24	24	24	24	25
Total	1182	1212	1243	1274	1304	1335	1366	1397	1427	1458	1489	1519
Continued	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	
Garden and park waste	1261	1286	1312	1338	1363	1389	1414	1440	1465	1491	1516	
Organic waste	55	55	55	55	55	55	55	55	55	55	55	
Sludge	210	215	220	225	230	235	240	245	250	255	260	
Home composting	25	25	25	25	25	25	25	26	26	26	26	
Total	1550	1581	1611	1642	1673	1703	1734	1765	1795	1826	1857	

7.2.1 Historical and projected emissions

Calculated emission projection is shown in Table 7.4.

Table 7.4 Projection of overall emission of greenhouse gases from biological treatment of solid waste, Gg.

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015
CH_4 emission from	1.4	1.9	3.2	3.4	4.1	4.2	4.3	4.4	4.5	4.6
N_2O emission from	0.04	0.1	0.5	0.2	0.4	0.4	0.4	0.4	0.4	0.4
CO_2-eqvivalents	46.9	68.0	233.6	144.7	207.5	218.0	228.8	234.9	241.4	247.9
Continued	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
CH_4 emission from	4.7	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7
N_2O emission from	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6
CO_2-eqvivalents	254.4	260.9	267.4	273.9	280.4	286.9	293.4	299.9	306.4	312.9
Continued	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
CH_4 emission from	5.9	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8
N_2O emission from	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7
CO_2-eqvivalents	146.4	149.2	152.0	154.7	157.5	160.2	163.0	165.7	168.5	171.3

7.3 Waste Incineration

The CRF source category *5.C Waste Incineration,* includes cremation of human bodies and cremation of animal carcasses.

Incineration of municipal, industrial, clinical and hazardous waste takes place with energy recovery, therefore the emissions are included in the relevant subsectors under CRF sector 1A. For documentation please refer to Chapter 2. Flaring off-shore and in refineries are included under CRF sector 1B2c, for documentation please refer to Chapter 3. No flaring in chemical industry occurs in Denmark.

7.3.1 Human cremation

It is assumed that no drastic changes are made in the subject of human cremation that will influence greenhouse gas emissions.

The projection of greenhouse gas emissions from human cremation is performed based on a projection of population done by Statistics Denmark and on known developments from the last two decades. The development in the total number of cremations and the cremation fraction in relation to the total number of deceased are shown in Figure 7.3 for 1990-2012.

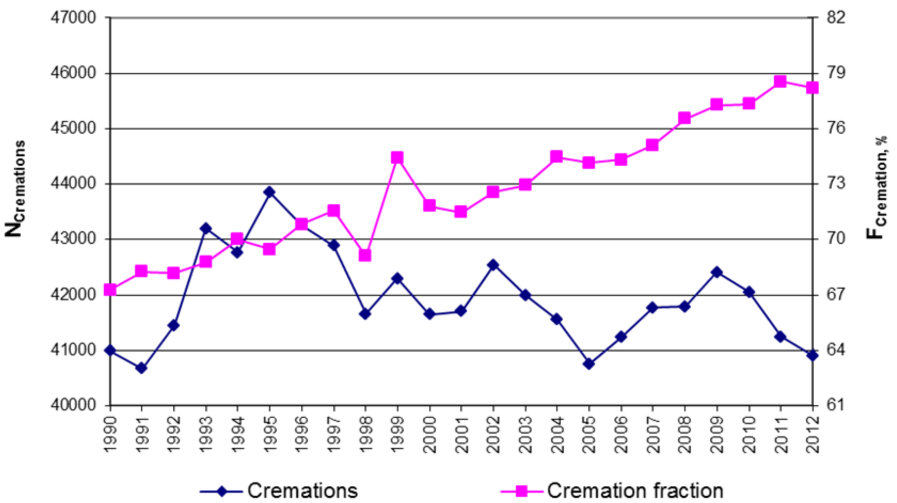

Figure 7.3 The development in the number of annual cremations.

Based on this historical development, it is assumed that the increase of the cremation fraction will continue, and that the increase can be described by the linear regression based on 1990-2010 data. By comparing data for population with the annual number of deceased for the years 1901-2012, the fraction of deaths is found to be 1 %.

Table 7.5 Projection of the population, number of deaths, cremation fraction and number of cremations.

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Population	5602628	5627235	5648580	5668253	5687089	5705758	5725204	5746161	5768823	5792613
Deaths	52471	56272	56486	56683	56871	57058	57252	57462	57688	57926
Cremation fraction	80.70%	78.8%	79.3%	79.8%	80.3%	80.7%	81.2%	81.7%	82.2%	82.6%
Cremations	42349	44361	44797	45222	45643	46064	46492	46936	47395	47865

Continued

	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Population	5816931	5841292	5865324	5888879	5911715	5933696	5954748	5974766	5993782	6011772
Deaths	58169	58413	58653	58889	59117	59337	59547	59748	59938	60118
Cremation fraction	83.1%	83.6%	84.1%	84.5%	85.0%	85.5%	86.0%	86.4%	86.9%	87.4%
Cremations	48342	48822	49302	49779	50253	50722	51184	51640	52089	52531

Continued

	2033	2034	2035
Population	6028756	6044770	6059816
Deaths	60288	60448	60598
Cremation fraction	87.9%	88.3%	88.8%
Cremations	52966	53394	53814

The projection of greenhouse gas emissions from human cremation shown in Table 7.7 is calculated by multiplying the estimated activity data from Table 7.5 with the emission factors known from Nielsen et al. (2014).

7.3.2 Animal cremation

Historically, the development in the amount of cremated animal carcasses is difficult to explain. It is therefore also difficult to predict the future development. Figure 7.4 shows historical data from 1998-2012.

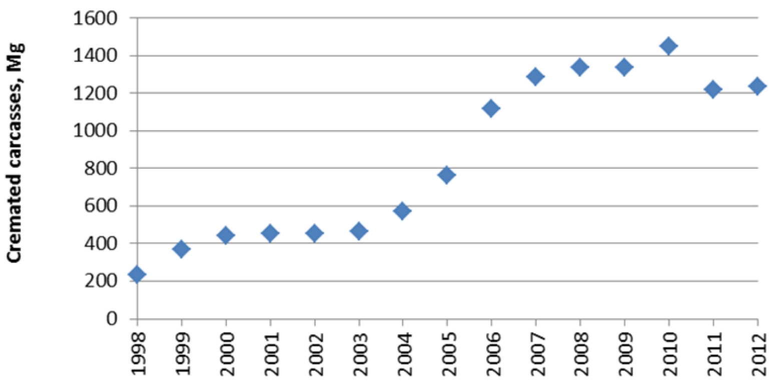

Figure 7.4 Cremated amount of carcasses, 1998-2012.

It is assumed that the 2013-2035 projection of activity data for animal cremation can be described by the constant average of the years 2008-2012.

Table 7.6 Amount of incinerated carcasses.

	2008	2009	2010	2011	2012	Average
Cremated carcasses, Mg	1338	1339	1449	1219	1238	1316

The projection of greenhouse gas emissions from animal cremation shown in Table 7.7 are calculated by multiplying the estimated activity data from Table 7.6 with the emission factors known from Nielsen et al. (2014).

7.3.3 Historical and projected emissions

Table 7.7 gives an overview of the projections of the Danish greenhouse gas emissions from the CRF source category *5.C Waste Incineration*.

CO_2 emissions from cremations of human bodies and animal carcasses are biogenic and therefore not included.

Table 7.7 Projection of greenhouse gas emissions from the incineration of human bodies and animal carcasses.

	Unit	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015
CH_4 emission from											
Human cremation	Mg	0.48	0.52	0.49	0.48	0.49	0.49	0.48	0.50	0.52	0.53
Animal cremation	Mg	0.03	0.04	0.08	0.14	0.26	0.22	0.22	0.24	0.24	0.24
Total	Mg	0.51	0.55	0.57	0.62	0.76	0.71	0.70	0.74	0.76	0.76
N_2O emission from											
Human cremation	Mg	0.60	0.64	0.61	0.60	0.62	0.61	0.60	0.62	0.65	0.66
Animal cremation	Mg	0.03	0.05	0.10	0.17	0.33	0.28	0.28	0.30	0.30	0.30
Total	Mg	0.64	0.69	0.71	0.77	0.95	0.88	0.88	0.92	0.95	0.96
5C. Waste incineration											
CO_2-eqvivalents	Gg	0.20	0.22	0.23	0.25	0.30	0.28	0.28	0.29	0.30	0.30
Continued											
	Unit	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
CH_4 emission from											
Human cremation	Mg	0.53	0.54	0.54	0.55	0.55	0.56	0.56	0.57	0.57	0.58
Animal cremation	Mg	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
Total	Mg	0.77	0.77	0.78	0.78	0.79	0.80	0.80	0.81	0.81	0.82
N_2O emission from											
Human cremation	Mg	0.66	0.67	0.68	0.68	0.69	0.70	0.70	0.71	0.72	0.72
Animal cremation	Mg	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	Mg	0.96	0.97	0.97	0.98	0.99	0.99	1.00	1.01	1.02	1.02
5C. Waste incineration											
CO_2-eqvivalents	Gg	0.31	0.31	0.31	0.31	0.31	0.32	0.32	0.32	0.32	0.33
Continued											
	Unit	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
CH_4 emission from											
Human cremation	Mg	0.59	0.59	0.60	0.60	0.61	0.61	0.62	0.62	0.63	0.63
Animal cremation	Mg	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
Total	Mg	0.82	0.83	0.83	0.84	0.85	0.85	0.86	0.86	0.87	0.87
N_2O emission from											
Human cremation	Mg	0.73	0.74	0.75	0.75	0.76	0.77	0.77	0.78	0.78	0.79
Animal cremation	Mg	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	Mg	1.03	1.04	1.04	1.05	1.06	1.06	1.07	1.08	1.08	1.09
5C. Waste incineration											
CO_2-eqvivalents	Gg	0.33	0.33	0.33	0.33	0.34	0.34	0.34	0.34	0.34	0.35

7.4 Wastewater handling

The CRF source category *5.D Waste water handling,* constitutes emission of CH_4 and N_2O from wastewater collection and treatment.

7.4.1 Emission models and Activity Data

Methane emission

Methane emissions from the municipal and private wastewater treatment plants (WWTP) are divided into contributions from 1) the sewer system, primary settling tank and biological N and P removal processes, 2) from anaerobic treatment processes in closed systems with biogas extraction and combustion for energy production and 3) septic tanks. For a detailed description of the model equations and input parameters (process-specific emissions factors and activity data) the reader is referred to Nielsen et al., 2014. Below, a short overview of historical and projected key activity data is provided.

A key parameter is the influent degradable organic matter at the wastewater treatment plants, measured in units of biological oxygen demand (BOD), as presented in Table 7.8.

Table 7.8 Total degradable organic waste (TOW) inclusive the contribution from industry to the influent TOW [tonne BOD per year].

1990	1995	2000	2005	2010'	2015	2020	2025	2030	2035
97	116	136	141	145	144	147	149	152	153

Historical data: 1999-2012, Projected data: 2013-2035.

Projection from 2013 and forward is based on the assumption of the industrial contribution to the influent BOD having reached a constant level of 40.3% since 2004 (Nielsen et al., 2014), while the contributions the BOD in the influent wastewater originating from households are based on population projections (Danish statistics, cf. Table 10.2) using the default person equivalent BOD value of 50 g BOD/person/day (IPCC, 1996). It should be mentioned that the new guidelines uses a default BOD value of 62 g BOD/ person/day. This value is yet to be verified by monitoring data on BOD reported by the Danish Nature Agency (Thomsen & Lyck, 2005), which seems in some cases to be underestimated according to plant level data reported in the green accounts (Thomsen et al., 2014).

Emission from 1) the sewer system, primary settling tank and biological N and P removal processes, 2) from anaerobic treatment processes in closed systems with biogas extraction and combustion for energy production are derived from the projected TOW data and population statistics.

The fugitive emissions from the sewer system, primary settling tank and biological N and P removal processes originates from the fraction of organic matter that is anaerobically converted in sewers and at the primary and secondary treatment steps at the WWTPs. According to expert judgement (personal communication: Jes Vollertsen), a conservative estimate of the fugitive methane emission from the primary settling tanks and biological treatment processes is well below 0.1 % of influent BOD, while the fugitive emission from the sewer system is judged to be negligible or zero (DANVA, 2008). The fraction of the influent organic matter (measured as BOD) experiencing anaerobic conditions during the primary and secondary treatment step is quantified by the methane correction factor (MCF) set equal to 0.003 (3%) based on an expert judgement (personal communication: Professor Jes Vollertsen). Using the default maximum methane producing capacity, B_o, of 0.6 kg CH_4/kg influent BOD result in an emission factor, $EF_{sewer+MB}$, of 0.0018 kg CH_4 per kg BOD (Nielsen et al., 2014). As such the fugitive emission for the sewer, primary and secondary treatment are projected by multiplying the $EF_{sewer+MB}$ with data on population statistics adding a constant contribution from industry to the inlet BOD as described below.

The methane emission from anaerobic digestion of sludge is estimated from national statistics on the fraction of wet weight sewage sludge treated anaerobic, multiplied by the default methane correction factor for anaerobic sludge digesters of 0.8 (IPCC, 2006) multiplied by the default maximum methane producing capacity, B_o, of 0.6 kg CH_4/kg BOD. The methane emission factor from anaerobic digestion is as such equal to 0.48 kg CH_4/kg BOD, which should be multiplied by the amount of sludge treated by anaerobic digestion.

The statistics on sludge amount are of low quality and incomplete (DEPA, 2011). Furthermore, some of the centralised WWTPs receives external carbon being co-digested with sludge produced at the plant, which are only taken into account to the extent such that carbon have been reported in the sludge database. For the present, the fraction of sludge treated in anaerobic digesters is set equal to the 2009 level of 34 % wet weight, which is the latest reported data (DEPA, 2013). From the projection of influent TOW data according to population statistics the gross emission is derived. The methane emission from anaerobic digestion of sludge with energy production equals 1 % of the gross methane emissions (Nielsen et al., 2014).

The projection of methane emissions from septic tanks are estimated from the population statistics and the assumption of ten per cent of the population not being connected to the sewerage system (Nielsen et al., 2014).

Methane emission projections are provided in Chapter 7.4.2, Table 7.12. For details regarding the methodology for estimating the methane emissions from the Danish WWTPs, the reader is referred to Nielsen et al., 2014 and Thomsen et al., 2014).

Remarks to the presented projection of methane emissions from wastewater handling:

As mentioned in the beginning of this section influent BOD data are a key parameter for estimating the methane emission from the Danish wastewater treatment plants. In this respect, it should be highlighted that an ongoing data collection from the green accounts shows indication that the plant-level BOD reported by the Danish Nature Agency is lower than the reported BOD data in the green accounts. The reason for the difference in plant level BOD data reported by the Danish Nature Agency and the BOD data reported in the green account reports may be explained by a lower number of measurements included in the national monitoring program, which include around 12 yearly measurements, compared to the green account reports in which BOD data are based on 70-100 measurements per year (personal communication: Kim Rindel, Biofos). Using the default Danish BOD value of 62 g BOD/ person/day according to the IPCC, 2006 guidelines confirms the opinion of Biofos; an underestimation of around 20% (Thomsen et al., 2014, in prep.). Furthermore, plant level data form Ejby Mølle WWTPs indicated that the methane emission from biological treatment may in some cases be underestimated (Andersen, 2009).

Collected plant level data on methane emissions from venting indicates that a fugitive emission of 1% of the produced biogas may be slightly underestimated as an average of 1.3% has be documented (Nielsen et al., 2014). Plant level data is needed to be able to take into account the external carbon upon subtracting the amount of biogas being flared.

To be able to take into account external carbon in the carbon mass balance of the plants, information on the amount of co-digested organic material measured in units of BOD or NVOC is needed (DEPA,2003; Sckerl, 2012).

The presented projections of methane emission from wastewater handling should be read with these reservations, having in mind that the whole time series will be reported using the default Danish BOD value of 62 g BOD/ person/day according to the IPCC, 2006 guidelines to be replaced by a plant-level emission inventory upon realisation of a complete data set as recommended by the expert review team.

Nitrous oxide

Both the direct and indirect N_2O emission from wastewater treatment processes is calculated based on country-specific and process specific emission factors (Nielsen et al., 2014) and the amount of nitrogen in the influent and effluent wastewater, respectively. The influent total N was projected based on the average influent N per person per year for the years 2005-2012 and projected according to population statistics. A person equivalent (PE) value of 5.5 kg total N per year was obtained compared to the value of 4.4 for normal household wastewater defined in the Executive Order No. 1448, 2007, which may be explained by the Danish influent wastewater being a mix of industrial, household and rainwater conditioned influent wastewater flows. As such, a PE cannot be taken as a measure of how much a person discharges into the treatment plant as substances from industrial, road, rain, infiltration, etc.is also fed to the WWTP via the sewer system. Population statistics are provided in Table 7.9 and direct N_2O emissions in Table 7.13.

Table 7.9 Population statistics (Statistics Denmark).

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
Population-Estimates (1000s)	5135	5216	5330	5411	5535	5633	5723	5821	5911	5984

Historical data: 1990-2012, Projected data: 2013-2035.

Table 7.10 Total N in the influent waste water [Mg].

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
Total N, influent, [Mg]	14679	26952	26952	32288	27357	30862	31357	31890	32387	32783

Historical data: 1990-2012, Projected data: 2013-2035.

For the total N in the effluents, the contribution from separate industries, rainwater conditioned effluents, scattered settlements and mariculture and fish farming, a decreasing trend followed by a close to constant level are observed and the 2012 emission data is kept constant throughout the projection period. The total N content in the effluent from WWTPs is increasing according to population statistics using the average of the effluent total N load for the period 2005-2012; 0.7 Mg N/person/year for the years 2005-2012. Historical and projected influent N is shown in Table 7.11.

Table 7.11 Total N in the effluent waste water [Mg].

Years	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
Total effluent N	16884	8938	4653	3831	4025	4001	4065	4134	4199	4250

Historical data: 1990-2012, Projected data: 2013-2050.

Implied emission factors, calculated as average emissions for the period 2005-2012 assuming constant industrial influent N load, and the population statistics have been used for projecting emissions from WWTPs. The emission projection for the total N_2O emission is provided in Table 7.13.

Remarks to the presented projection of nitrous oxide from wastewater handling:

The default IPCC emission factor for N_2O emissions from domestic wastewater nitrogen effluent is 0.005 6 (0.0005 - 0.25). kg N_2O-N/kg N in the new guidelines compared to the former value of 0.1. The new EF has not been used in the historical data, nor in the projected estimations of the indirect N_2O emissions due to indications of influent organic matter reported by the Danish Nature Agency being underestimated compared to the amounts reported in plant level green accounts which is expected to influence the whole N balance at the Danish WWTPs (see above).

For the direct N_2O emissions a value of 4.99 kg N_2O/tonnes influent total N are used in the estimated historical and projected direct N_2O emissions; the value is within the range reported by Danish research in the area (e.g. Ni et al., 2011). However, very little has so far been available from the scientific literature about the size of the direct N_2O emissions (Nielsen et al., 2014; Thomsen et al., 2014) and novel data indicates that the N_2O emissions from secondary treatment processes may be underestimated for some plants (Andersen, 2012; Ni et al., 2011).

7.4.2 Historical emission data and projections

Historical and projected methane emissions are shown in Table 7.12.

Table 7.12 Gross, recovered, emissions for sewer system, anaerobic treatment, septic tanks and total net CH_4 emission, Gg.

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
$CH_{4,\ produced}$	13.3	16.0	29.0	22.9	23.6	24.3	24.7	25.1	25.5	25.8
$CH_{4,\ Recovered}$	13.2	15.9	28.8	22.7	23.4	24.0	24.4	24.8	25.2	25.5
$CH_{4,\ sewer\ system\ and\ MB}$	0.17	0.2	0.27	0.25	0.26	0.26	0.26	0.27	0.27	0.28
$CH_{4,\ septic\ tanks}$	2.81	2.86	2.92	2.96	3.03	3.08	3.13	3.19	3.24	3.28
$CH_{4,\ anaerobic\ treatment}$	0.13	0.16	0.29	0.23	0.24	0.24	0.25	0.25	0.25	0.26
$CH_{4,\ net\ emission}$	3.12	3.23	3.48	3.45	3.53	3.59	3.64	3.71	3.76	3.81

Historical data: 1990-2012, Projected data: 2013-2035.

The total N_2O and net CH_4 emission figures converted to CO_2 equivalents and the sum up result for emissions from wastewater in total is given in Table 7.13.

Table 7.13 Net CH_4, Indirect and direct N_2O emission and the sectoral total emission, Gg CO_2 eqv.

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
$N_2O_{,\ indirect}$	79.1	71.0	46.9	33.0	32.6	32.7	33.0	33.4	33.7	33.9
$N_2O_{,direct}$	21.8	33.2	40.1	48.0	40.7	39.7	40.4	41.1	41.7	42.2
$CH_{4,net}$	78.0	80.6	86.9	86.1	88.2	89.7	91.1	92.7	94.1	95.3
$CO_{2eqv.,total}$	178.9	184.8	173.8	167.1	161.4	162.1	164.5	167.1	169.5	171.4

Historical data: 1990-2012, Projected data: 2013-2035.

7.4.3 Further measures

The Green Growth (2009 and 2010) focus on e.g. improved treatment efficiency of rainwater and wastewater and green N-regulation, the Resource strategy focus on increased extraction and recycling of phosphorous at WWTPs (DEPA, 2014) and the Energy Strategy have influenced the carbon management strategy at the WWTPs (Thomsen et al., 2014). An example of green regulation alternative instruments, such as cultivation and harvest of mussels and other marine organisms, for improved water quality have been initiated within the Regions of Denmark (e.g. NordJyllands Amt, 2006; Region North Jutland, 2011; Seghetta et al., 2015).

WWTPs

Ongoing development project for the restructuring and optimisation of wastewater treatment technologies for optimised conversion of COD into CH4 for energy production, while lowering the energy consumption and loss of BOD prior to anaerobic digestion may led to an increased amount of recovered methane (e.g. Johansen, R., Beyer, T., 2014). Likewise, optimised COD and N removal technologies may lead to a decreased N_2O emission; e.g. by introduction of biosorption technologies at the primary treatment step with increased allocation of primary sludge to the digester tank and struvite precipitation (Jensen et al. 2014; Thomsen et al. 2014; http://www.udviklingssamarbejdet.dk/prioriterede-omr%C3%A5der).

Scattered houses

Reduced emissions from scattered settlements may be included as knowledge of 1) a reduction in the fraction of the population not connected to the municipal sewer system and 2) alternative solutions to the treatment of wastewater from scattered houses is obtained from the Danish Nature Agency (NA, 2014).

Indirect emissions from mariculture and fishfarming

As part of the water plan of the 23 water districts in Denmark cultivation of mussels and other marine species on lines are mentioned as instruments (NA, 2013). Furthermore a general plan to improve conditions in aquaculture and marine fish farms are ongoing. The deduced N amount to streams from aquaculture is approximately 800-1000 tonnes N/year. However, it is unknown how big an impact the Green regulation (Green Growth, 2009) will have on the indirect emission from mariculture and fish farming and therefore the expected increased N effluent from these activities has not been included this in the projection.

7.5 Other

This category is a catch up for the waste sector. Emissions in this category could stem from accidental fires, sludge spreading, biogas production and other combustion. Currently, the projections in this section cover accidental building and vehicle fires.

7.5.1 Sludge spreading

Sludge from waste water treatment plants is only spread out in the rural areas with the purpose of fertilising crop fields. Any greenhouse emissions that might derive from this activity are estimated in Chapter 6 (CRF Sector 4).

7.5.2 Biogas production

Emissions from biogas production are divided and reported in different sections according to use.

For the biogas production from organic waste with the purpose of energy production, see Chapter 2, Stationary Combustion.

Biogas production from manure is included in Chapter 8, Agriculture.

Emissions from wastewater handling are described in Chapter 10, Wastewater Treatment.

7.5.3 Other combustion

Other waste types under the "Waste Other" category are the open burning of yard waste and bonfires.

Occurrence of wild fires and crop burnings are categorised under Chapter 8 LULUCF and 6 Agriculture, respectively.

In Denmark, the open burning of private yard waste is under different restrictions according to the respective municipality. These restrictions involve what can be burned but also the quantity, how, when and where or in some cases a complete ban (DEPA, 2012). There is no registration of private waste burning and the activity data on this subject are very difficult to estimate. People are generally incited to compost their yard waste or to dispose it through one of the many waste disposal/-recycling sites.

The occurrence of bonfires at midsummer night and in general are likewise not registered, therefore it has not been possible to obtain historical activity data or to predict the development of this activity.

7.5.4 Accidental building fires

Activity data for building fires are classified in four categories: full, large, medium and small. The emission factors comply for full scale building fires and the activity data is therefore recalculated as a full scale equivalent (FSE). Here it is assumed that a full, large, medium and a small scale fire makes up 100 %, 75 %, 30 % and 5 % of a FSE, respectively.

Calculations of greenhouse gas emissions for 1990-2006 are based on surrogate data and on detailed information for 2007-2012 given by the Danish Emergency Management Agency (DEMA). Because of the very limited amount of detailed historical information available, it has been difficult to predict the future development of this activity. Activity data for accidental building fires are therefore chosen as the average of 2008-2012 data.

Table 7.14 Number of accidental building fires 2008-2012.

	2008	2009	2010	2011	2012	Average
Container FSE fires	962	799	594	729	584	733
Detached house FSE fires	886	876	833	818	742	831
Undetached house FSE fires	278	208	194	206	181	213
Apartment building FSE fires	433	413	348	362	327	377
Industrial building FSE fires	346	344	281	334	298	321
Additional building FSE fires	523	466	429	740	610	553
All building FSE fires	3428	3106	2678	3189	2741	3028

By assuming that building compositions and sizes will not significantly change over the next 25 years, the emission factors known from Nielsen et al. (2014) are used for this projection.

7.5.5 Accidental vehicle fires

The Danish Emergency Management Agency (DEMA) provides data for the total number of accidental vehicle fires 2007-2012 divided into the categories; passenger cars, light duty vehicles, heavy duty vehicles, buses, motorcycles/mopeds, other transport, caravans, trains, ships, airplanes, bicycles, tractors, combined harvesters and machines.

DTU transport (Jensen & Kveiborg, 2014) provides the national population of vehicles in these same categories for historical years as well as a projection of the 2013-2035 vehicle population. These data are shown in Table 7.15.

Table 7.15 Population of vehicles.

	Passenger cars	Buses	Light duty vehicles	Heavy duty vehicles	Motorcycles /Mopeds	Caravan	Train	Ship	Airplane	Tractor	Combined harvester
2013	2296253	13176	335764	43500	296094	146184	2763	1757	1112	98872	17564
2014	2255398	13174	347453	44074	296359	148967	2763	1757	1114	94666	16429
2015	2210396	13173	363353	44706	296628	151749	2763	1757	1117	89087	14857
2020	2188820	13169	426724	48111	300906	165662	2763	1757	1128	75879	13996
2025	2301824	13166	462698	51626	307915	179574	2763	1757	1140	73075	11923
2030	2415081	13163	496761	55448	315257	193487	2763	1757	1151	67106	11234
2035	2534453	13161	533221	59685	322631	207399	2763	1757	1163	65021	10636

The data quality for vehicle fires for 2007-2012 is of a very high standard. These data are, like the data for building fires, divided into four damage rate categories; full, large, medium and small. A full, large, medium and small scale fire, leads to 100, 75, 30 and 5 % burnout, respectively. From these data, an average full scale equivalent (FSE) is calculated for each vehicle category.

Table 7.16 Average number of full scale vehicle fires relative to the total number of nationally registered vehicles for 2008-2012.

Category	Fraction, %
Passenger cars	0.03
Buses	0.13
Light duty vehicles	0.01
Heavy duty vehicles	0.13
Motorcycles/Mopeds	0.03
Caravan	0.03
Train	0.11
Ship	1.05
Airplane	0.06
Tractor	0.06
Combined harvester	0.16

There is no data for the population of the categories; other transport, bicycles and machines. For these categories the average FSE fires for 2008-2012 is used in the projection 2013-2035.

By assuming that the average number of FSE fires from 2008-2012 (shown in Table 7.16), is applicable for describing the risk of accidental fires in the future vehicle population, activity data for the projection 2013-2035 can be calculated.

Table 7.17 Projection of number of full scale equivalent accidental vehicle fires.

	2013	2014	2015	2020	2025	2030	2035
Passenger cars	643	632	619	613	645	676	710
Buses	17	17	17	17	17	17	17
Light duty vehicles	38	39	41	49	53	56	61
Heavy duty vehicles	58	59	60	64	69	74	80
Motorcycles/mopeds	99	99	99	101	103	105	108
Other transport	70	70	70	70	70	70	70
Caravan	38	38	39	43	46	50	54
Train	3	3	3	3	3	3	3
Ship	18	18	18	18	18	18	18
Airplane	1	1	1	1	1	1	1
Bicycle	3	3	3	3	3	3	3

Tractor	64	61	57	49	47	43	42
Combined harvester	27	26	23	22	19	17	17
Machine	113	113	113	113	113	113	113

It is assumed that no significant changes in the average vehicle weight will occur during the next 25 years. The average weight of passenger cars, light duty vehicles, trucks, busses and motorcycles/mopeds are known for 2012 (Statistics Denmark, 2013). The average weight of the units from the remaining categories is estimated by an expert judgement.

Table 7.18 Average vehicle weight in 2012, kg.

Passenger cars	1160
Buses	11625
Light duty vehicles	4150
Heavy duty vehicles	10844
Motorcycles/Mopeds	136
Combined harvester	12800

It is assumed that the average weight of a bus equals that of a ship. That vans and tractors weigh the same and that trucks have the same average weight as trains and airplanes.

Bicycles, machines and other transport can only be calculated for the years 2007-2012 due to the lack of surrogate data (number of nationally registered vehicles). The average weight of a bicycle, caravan, machine and other transport is set as 12 kg, 90 % of a car, 50 % of a car and 40 % of a car respectively.

By multiplying the number of full scale fires with the average weight of the vehicles respectively, the total amount of combusted vehicle mass can be calculated. The results are shown in Table 7.19.

Table 7.19 Activity data for accidental vehicle fires.

	Burnt mass of vehicles, Mg
2013	2780
2014	2748
2015	2705
2020	2731
2025	2793
2030	2879
2035	2985

By assuming that vehicle compositions will not significantly change over the next 25 years, the emission factors known from Nielsen et al. (2014) are used for this projection.

7.5.6 Historical emission data and projections

Table 7.20 gives an overview of the Danish non-biogenic greenhouse gas emission from the CRF source category *5.E Waste Other*.

Buildings have a high content of wood both in the structure and in the interior; this leads to 82 % of the CO_2 emission from accidental building fires to be biogenic.

Table 7.20 Projection of overall emission of greenhouse gases from the accidental building and vehicle fires.

	Unit	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015
CO_2 emission from											
Building fires	Gg	11.41	13.05	11.53	11.29	11.09	12.15	10.79	12.07	12.07	12.07
Vehicle fires	Gg	6.13	6.54	6.87	6.86	7.26	6.30	5.56	6.67	6.59	6.49
Total non-biogenic	Gg	17.54	19.60	18.40	18.14	18.35	18.45	16.36	18.75	18.67	18.57
CH_4 emission from											
Building fires	Mg	64.15	73.35	64.87	63.77	64.61	68.46	61.67	68.74	68.74	68.74
Vehicle fires	Mg	12.77	13.64	14.32	14.29	15.12	13.12	11.59	13.90	13.74	13.52
Total	Mg	76.92	86.99	79.19	78.06	79.74	81.58	73.27	82.64	82.48	82.27
5E. Waste Other											
CO_2-eqvivalents	Gg	19.46	21.77	20.38	20.10	20.34	20.49	18.19	20.81	20.73	20.62

Continued

	Unit	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
CO_2 emission from											
Building fires	Gg	12.07	12.07	12.07	12.07	12.07	12.07	12.07	12.07	12.07	12.07
Vehicle fires	Gg	6.44	6.43	6.49	6.52	6.55	6.58	6.61	6.63	6.66	6.70
Total non-biogenic	Gg	18.51	18.50	18.56	18.60	18.63	18.66	18.68	18.71	18.74	18.78
CH_4 emission from											
Building fires	Mg	68.74	68.74	68.74	68.74	68.74	68.74	68.74	68.74	68.74	68.74
Vehicle fires	Mg	13.42	13.39	13.51	13.59	13.66	13.71	13.77	13.82	13.88	13.97
Total	Mg	82.16	82.13	82.26	82.34	82.40	82.45	82.51	82.56	82.62	82.71
5E. Waste Other											
CO_2-eqvivalents	Gg	20.57	20.55	20.62	20.66	20.69	20.72	20.74	20.77	20.80	20.85

Continued

	Unit	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
CO_2 emission from											
Building fires	Gg	12.07	12.07	12.07	12.07	12.07	12.07	12.07	12.07	12.07	12.07
Vehicle fires	Gg	6.74	6.77	6.81	6.85	6.91	6.95	7.00	7.04	7.10	7.16
Total non-biogenic	Gg	18.81	18.84	18.89	18.93	18.98	19.03	19.07	19.11	19.17	19.24
CH_4 emission from											
Building fires	Mg	68.74	68.74	68.74	68.74	68.74	68.74	68.74	68.74	68.74	68.74
Vehicle fires	Mg	14.03	14.10	14.19	14.28	14.39	14.48	14.58	14.67	14.79	14.93
Total	Mg	82.77	82.84	82.93	83.02	83.14	83.22	83.32	83.41	83.53	83.67
5E. Waste Other											
CO_2-eqvivalents	Gg	20.88	20.91	20.96	21.00	21.06	21.11	21.15	21.20	21.26	21.33

7.6 Source specific recalculations

7.6.1 Biological Treatment

The implementation of the 2006 Guidebook has led to "composting" being moved from source category *Other* to the new category *Biological Treatment*.

Emissions from composting has increased with 9-15 % due to an update in the calculations of activity data and 10 % due to the new global warming potentials (GWPs) also introduced by the 2006 Guidebook. However, the largest increase in emission is caused by an update of emission factors for sludge and household waste.

The joint effect of these recalculations is an increase of between 100 Gg and 200 Gg CO_2 eqv. corresponding to 90-106 %.

7.6.2 Waste Incineration

Emissions from cremation have generally increased. Changes were made in the activity data for this year's submission. Activity data for human cremation is based on a projection of population made by Statistics Denmark; this projection is updated each year. The projection of population has increased with 0.2 - 1-3 %.

The 2013 emission is 3.4 % lower than in last submission because the 2013 are now actual data and not projections.

Activity data for animal cremation was also updated. In last year's submission animal cremation was estimated as the average of 2007-2010 data, this year's submission uses the average of 2008-2012. This caused a drop of 2.7 % in emission because 2012 is lower than 2007-2010.

No changes were made to emission factors or methodology in the waste incineration category.

All together the changes made have given recalculations lower than 1 % with the exception of 2013.

Table 7.21 Recalculations in CO_2 equivalents.

	2013	2014	2015	2016	2020	2025	2030	2035
Human cremation, Mg	-5.8	1.7	1.9	2.0	2.2	3.2	4.1	4.7
Animal cremation, Mg	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0
Total 5C, Mg	-7.8	-0.2	-0.1	0.0	0.3	1.2	2.1	2.7
Fraction, %	-2.6	-0.08	-0.03	0.00	0.08	0.37	0.62	0.80

7.6.1 Waste Other

Emissions from accidental building fires have decreased with just below 5 % because of the new data year 2012.

For accidental vehicle fires, this year's submission presents a 1-6 % decrease in the time series 2013-2035. The recalculation is a result of changes in the forcast of vehicle population done by DTU transport (Jensen & Kveiborg, 2014)

The update of the 2006 Guidebook global warming potentials (GWPs) result in an increase of 2 %.

The joint effect of these three recalculations is a decrease in the projected emissions of 20-21 Gg CO_2-eq (4-5 %).

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8 LULUCF

The emission of GHGs from the LULUCF sector (Land Use, Land Use Change and Forestry) includes primarily the emission of CO_2 from land use and small amounts of N_2O from disturbance of soils not included in the agricultural sector.

The LULUCF sector is subdivided into six major categories:

- Forest
- Cropland
- Grassland
- Wetlands
- Settlements
- Other Land

The projections are made on best available knowledge on the past development in the land use in Denmark and expectations for the future. Regarding the methodology for estimation of the sources/sinks from the different sectors, see Chapter 7 in Nielsen et al. (2014). Furthermore has the new IPCC 2006 Guidelines (IPCC 2006) been taken into account and the 2013 Wetlands Supplement (IPCC 2014).

Approximately two thirds of the total Danish land area is cultivated and 13.4 per cent is forest, Figure 8.1. Intensive cultivation and large numbers of animals exerts a high pressure on the landscape, and regulations have been adopted to reduce this pressure. The adopted policy aims at doubling the forested area within the next 80-100 years, restoration of former wetlands and establishment of protected national parks. In Denmark almost all natural habitats and all forests are protected. Therefore only limited conversions from forest or wetlands into cropland or grassland has occurred and is expected to occur in the future.

Figure 8.1 shows the land use in 1990, 2010 and the expected land use in 2035. A decrease in cropland is expected. The conversion is mainly from Cropland to Forest, Grassland and Settlements. It should be noted that the definition of the LULUCF-sectors differs slightly from the normal Danish land use definitions and the shown distribution will therefore differ from other national statistics.

The type of land use conversions decides whether a category is a sink or a source. In the following, emissions by sources are given as positive values (+) and removals by sinks are given as negative values (-).

Under the Kyoto protocol, Denmark has selected Forest Management, Cropland Management and Grazing Land Management under article 3.4 to meet its reduction commitments besides the obligatory Afforestation, Reforestation and Deforestation under article 3.3. Since land, which is converted from one category to another (e.g. from Cropland to Settlements), cannot be omitted from the reporting obligation under the Kyoto Protocol, the actual estimates in each category reported under the Convention, may not be the same as accounted for under the Kyoto Protocol, see Section 13.11.

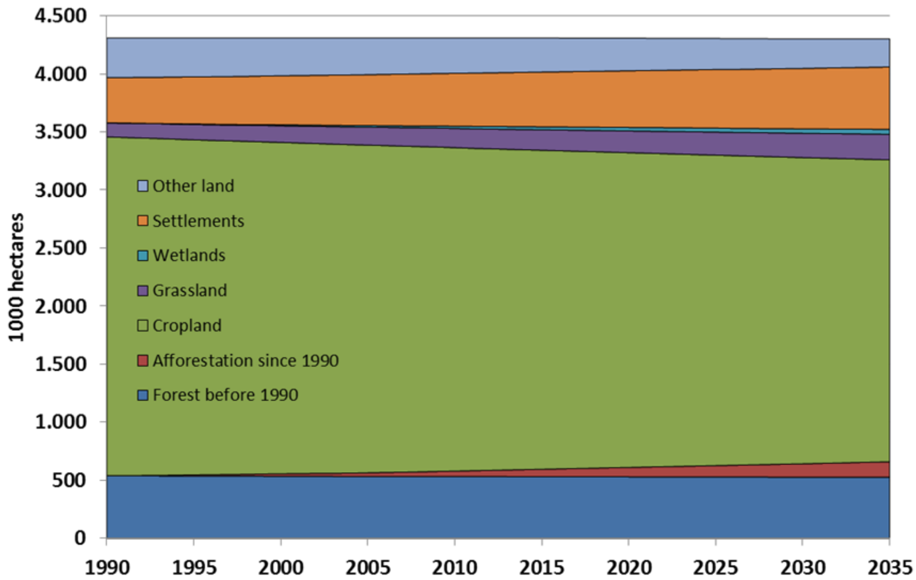

Figure 8.1 Land area use 1990-2035.

Table 8.1 shows the foreseen average land use changes between the different land use categories.

Table 8.1 The general annual land use change in hectares per year.

	Settlement	Lake	Forest	Grassland	Other land	Wetland	Cropland	Total, ha per year
Settlement		0	0	0	0	0	0	0
Lake	0		0	0	0	0	0	0
Forest	13	15		74	0	93	55	251
Grassland	669	67	899		0	93	0	1728
Other land	0	0	0	0		0	0	0
Wetland, partly water covered	3	0	1	0	0		24	29
Cropland	670	67	1000	2157	0	285		4178
Total, ha per year	1355	149	1900	2231	0	471	80	6186

The most important emission factors are given in Table 8.2.

Table 8.2 Emission factors used in the projection until 2035.

		Carbon stock
Default amount of living biomass	Cropland	11.875 tonnes C/ha
	Grassland	8.360 tonnes C/ha
	Wetlands	13.680 tonnes C/ha
	Settlement	4.400 tonnes C/ha
Default amount of C in soils	Forest	158 tonnes C/ha
	Cropland	151 tonnes C/ha
	Grassland	150 tonnes C/ha
	Wetlands	No changes assumed when converted from other land uses
	Settlements	120 tonnes C/ha
		Emissions
Soil	Crop in rotation: Organic soils >12% OC	11.5 tonnes C/ha/yr 13 kg N_2O-N/ha/yr
	Crop in rotation: Organic soils 6-12 % OC	5.75 tonnes C/ha/yr 6.25 kg N_2O-N /ha/yr
	Permanent Grassland: Organic soils >12% OC	8.4 tonnes C/ha/yr 16 kg CH_4/ha/yr 8.2 kg N_2O-N /ha/yr
	Permanent Grassland: Organic soils 6-12 % OC	4.2 tonnes C/ha/yr 4.1 kg N_2O-N /ha/yr
	Forest land, drained: Organic soils >12% OC	2.6 tonnes C/ha/yr 2.5 kg CH_4/ha/yr 2.8 kg N_2O-N /ha/yr
	Forest land, drained: Organic soils 6-12 % OC	1.3 tonnes C/ha/yr 1.25 kg CH_4/ha/yr 1.4 kg N_2O-N /ha/yr
	Wetlands, >12 kg OC	0 kg C/ha/yr 0 kg N_2O-N/ha/yr 288 kg CH_4/ha/yr
	Peat extraction areas	Excavated peat + 2.8 C/ha/yr 6.1 CH_4/ha/yr 0.3 kg N_2O-N /ha/yr

8.1 Forest

Department of Geosciences and Natural Resource Management (IGN) at Copenhagen University is responsible for the reporting of GHG emission from the Danish forest. For this projection IGN has not provided new emission data. Therefore, no emission estimates are provided for living, dead biomass and emission from organic soils in the forest in this projection. It is assumed that a continuous afforestation rate of 1900 ha per year is taking place and a deforestation of 251 ha per year. Changes in soil mineral carbon stocks in the forest due to land use conversion are included.

Due to changed accounting rules under the Kyoto protocol in the second commitment period, it is not possible to indicate the consequences of changed afforestation, deforestation and forest management on the Danish reduction commitments before a new Forest Management Reference Level has been estimated.

Since 1990 the forested area has increased. This is expected to continue in the future as Danish policy aim is to double the forest area from 1980 to 2080.

Afforestation is expected to take place on 1 900 hectares per year in the future. No estimates are provided for the accumulated carbon storage in the afforested area.

The Danish forests are well protected and only limited deforestation is expected to occur in connection with new settlements and building of new infrastructure. It is assumed that deforestation will take place on a limited area of 251 hectares per year until 2035. This deforestation is mainly due to an opening of the state forest where small forest areas are turned into open spaces. These spaces are converted into grassland. Only limited deforestation on land converted to Settlements is assumed. No estimates are given for the carbon stock in the deforested areas.

The amount of living and dead biomass in the Danish forests has not been estimated. The changes given in Table 8.2 thus derives only from changes in the carbon stock in mineral soils due to land use conversion. The mineral forest soils in afforested areas are expected to have total net build-up. The forested soils at equilibrium are expected to have a C content of 158 t per ha (0-100 cm) which is a higher carbon stock than the soils on which afforestation has taken place (for cropland an average of 151 t per ha is used). No changes in the carbon stock are expected in mineral forest soils for forests existing before 1990. The organic forest soils are expected to have a continuous emission associated with drainage. As no new information on how the organic forest soils are treated in future is available, no estimates has been given.

Table 8.3 Annual changes in area and carbon stock in forest (inclusive N_2O emission from forest soils) until 2035. It is currently not possible to provide a projection on living, dead biomass in the forest and emissions from the organic forest soils. Data until 2012 are reported data to UNFCCC.

	1990	2000	2005	2010	2012	2015	2020	2025	2030	2035
Area, Ha	548.0	588.7	608.7	627.4	632.5	640.8	649.0	657.2	665.5	673.7
Living biomass	77.8	-846.0	196.6	-1845.4	-3456.6	35.6[a]	35.6[a]	35.6[a]	35.6[a]	35.6[a]
Dead Organic Matter and litter	0.0	56.0	405.3	-2202.5	-996.1	NE	NE	NE	NE	NE
Soil, mineral soils	-2.1	-22.6	-32.9	-43.3	-46.2	-50.5	-55.1	-59.8	-64.4	-69.1
Soils, organic soils	192.9	185.5	177.6	171.0	174.0	NE	NE	NE	NE	NE
CH_4, CO_2 eqv. from soils	1.7	2.0	2.1	2.2	2.3	2.3	2.4	2.5	2.5	2.6
N_2O, CO_2 eqv. from soils	26.5	25.5	24.4	23.5	23.9	NE	NE	NE	NE	NE
Wildfires	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO_2 eqv. Total	298.0	-599.6	773.1	-3894.5	-4298.8	-12.6[a]	-17.1[a]	-21.7[a]	-26.3[a]	-30.9[a]

Note: removals by sinks are given as negative values (-) and emission by sources are given as positive values (+).
NE = Not estimated

[a] The values do not include estimates from changes in living biomass in the forest. When land use conversion from other land uses to forest land takes place an initial loss of living biomass it taking place from the converted land. This is included in the emission estimates.

The CH_4 emission is primarily due to CH_4 emission from organic forest soils and to a small extends to wild fires in the forests.

A very high variability in the emission estimates for forests established before 1990 is noted for the year 2008 to 2012. The high variability is primarily due to the National Forest Inventory, which was established in 2002 and introduced in the GHG inventory but still needs a couple of years of monitoring before a stabilisation in the C stock estimates can be expected.

8.2 Cropland

Agriculture occupies the major part of the Danish territory. In total approximately 2.7 million hectares are utilised for agricultural activities of which crops in rotation cover the majority of the area.

Cropland is subdivided into four types: Agricultural cropland which is the area defined by Statistics Denmark, Wooden agricultural crops which are fruit trees, willow etc., Hedgerows and small biotopes and "other agricultural land". The latter is defined as the difference between the area in the national statistics and the Cropland area defined by satellite monitoring and cadastral information. This area varies slightly between years due to annual differences in agricultural area reported by Statistics Denmark.

In Cropland five different carbon pools are accounted for: Above ground living biomass, below ground living biomass, dead wood, litter and soil organic carbon (SOC). The major part of the cropland area is covered with annual crops. Approximately 60 000 hectares are covered with hedgerows or small biotopes that do not meet the definition of forest.

8.2.1 Agricultural cropland

The area with Cropland has decreased over the last 20 years primarily due to urbanisation and afforestation. This is expected to continue in the future. The area with agricultural crops has declined with 141 000 hectares from 1990 to 2000 or 14 100 hectares per year. From 2000 to 2010 the reduction in the area with agricultural crops was only 23 000 hectares or 2 500 hectares per year. The reduced loss of agricultural land to other land uses can be attributed to less need of land for settlements and other infrastructure, but more importantly, the EU subsidiary system has changed and as a result more agricultural cropland is reported to Statistics Denmark than previously. Because of this irregularity it is assumed that the average loss is 6 500 hectares of agricultural land every year. This loss is split on Cropland and Grassland.

The Danish government has planned that 25 000 hectares along water courses shall be unmanaged grassland by the end of 2014 (Ministry of the Environment, 2014). This is implemented by September 1st 2014 as a 9 meter buffer strips along all water courses and ponds. The buffer zones will be grassland and must not be ploughed, fertilised or sprayed with pesticides. No changes in the drainage in the zones are expected. Maps with the buffer strips have been combined with the latest soil map and the latest field map for 2013 to find their current land use. As organic soils are often found around the streams there is a high frequency of organic soils in the buffer strips. Out of the 25 000 ha, 2382 ha organic soils were found to be grown with crops allocated to cropland. The area with organic soils in rotation is therefore reduced accordingly and converted into grassland.

8.2.2 Methodology

The amount/change of living biomass in Cropland is by default estimated as the amount of living biomass at its peak, e.g. just before harvest. This peak is estimated as the average barley yield for the 10 year period 1999 to 2008.

As a consequence of the loss of agricultural cropland the amount of living biomass will be reduced according to the conversion and thus reported as a loss. Due to the reduced area with agricultural cropland an average loss of biomass of approx. 55 Gg C per year is expected. This is partly counteracted by an increase in the amount of living biomass in the land class to which it is converted.

The change in Soil Organic Carbon (SOC) in mineral agricultural soils is estimated with C-TOOL version 2.0 (www.agrsci.dk/c-tool) in reporting to the UNFCCC. C-TOOL is a dynamic 3-pooled soil carbon model, which uses annual carbon input and carbon stock in soil as driving parameters. The input to C-TOOL is the amount of straw and roots returned to soil based on actual crop yield, areas with different crop types and applied animal manure divided in untreated and biogas treated manure. Based on this, C-TOOL estimates the degradation of Soil Organic Matter (SOM) and returns the net annual change in carbon. In the projection C-TOOL has been used. The average crop yield for the last 10 years is used as input, combined with a linear increasing temperature regime according to estimation of temperature increase in Denmark by the Danish Meteorological Institute (DMI, 2012) scenario A1B.

Hence, an annual loss of approximately 900 Gg CO_2 per year is included from the mineral soils in the future. This annual value is of course very dependent on the actual temperature, harvest yield and removal of animal manure and straw components for other purposes.

The emission from organic soils in cropland is based on high organic soils with an organic carbon content >12 % organic carbon (OC) and soils having a medium soil OC, 6-12 % OC. The 6 % limit is the traditional limit for organic soils in the Danish soil classification system from 1975. Soils having 6-12 % OC is given emission factors which are half of what have been measured in soils having > 12 % OC. Few measured values can be found for these soils but as they are drained they will have a continuous degradation of their OC until they reach the equilibrium state between input and degradation which is around 2-3 % OC as in most Danish mineral soils.

The area of organic soils with annual crops or grass in rotation is based on data from the EU subsidy register and the new soil map for organic soils. It is considered to be very precise. The new soil map has shown a dramatic decrease in the area with organic soils in Denmark. Using the 2010 boundary of agricultural land on the soil map from 1975, an area of 70 107 hectares with >12 % organic carbon is present. In 2010 only 41 817 hectares with organic soils could be found within this area. The area of soils with 6-12 % organic C in 1975 were > 40 000 hectares, and in 2010 it has decreased to 30 174 hectares. The dramatic change is attributed to the fact that the Danish organic soils are very shallow, and due to the high losses of CO_2 caused by drainage and cultivation, they are rapidly depleted of organic matter.

When looking on the data for recently established wetlands it can be found that 13.4% of the established cropland area is on organic soils (> 12 % OC). This fraction has been used for all land use conversions from cropland to other land uses.

In the future, it is assumed that the area with organic soils in rotation will decrease with 38 ha per year until 2035 due to a general establishment of wetlands on cropland, a reduction of 2 383 hectares in 2013 due to establishment of buffer strips where cropland are converted to permanent grassland and a conversion of 2 451 ha cropland to wetlands in the period 2014-2017 due to special targeted political initiative for taking organic soils out of rotation and convert it to wetlands (KEBMIN 2014).

The applied emission factor for CO_2 from organic soils is 11 500 kg C per ha for annual crops and for grass in rotation. Drained grass land on organic soils outside annual rotation has a lower emission factor of 8 400 kg C per ha per year combined with a CH_4 emission of 16 kg per ha per year.

A new source in the new IPCC 2006 Guidelines is N_2O from mineral agricultural soils if they are losing carbon as this also release nitrogen from the organic matter. This will subsequently form N_2O. It can be questioned if this is a double counting, as the agricultural sector includes N_2O emissions from crop residues, which is the origin of the organic matter in the soil. If an agricultural soil is losing OM (Organic Matter) and if instant oxidation of all applied organic matter is included in the agricultural sector, it is very likely a double counting. This should be investigated further. However, in this projection this source is included, so the projection is in accordance with the latest guidelines.

The overall result is a decrease in the annual emission from the organic soils reported in Cropland from 2 835.8 Gg CO_2 in 2012 to 2 593 Gg CO_2 in 2035 as shown in Table 8.4.

8.2.3 Perennial wooden crops

Perennial wooden crops in Cropland covers fruit trees, fruit plantations and energy crops. Christmas trees are reported under forest. Fruit trees are marginal in Denmark and covers only around 7 800 hectares. No changes in the area with fruit trees are expected. The area with willow as energy crop is expected to increase from 6 400 hectares in 2013 by 300 hectares per year until 2035. The increase in this area has only very marginal effect on the emission estimates as the area is harvested every 2-3 year and thus no larger amounts of C in living biomass is present in the willow plantations. Overall, an increase in living biomass of 9.5 Gg CO_2 per year until 2035 is estimated for Perennial wooden crops (not shown).

8.2.4 Hedgerows and small biotopes

The area with hedgerows and small biotopes not meeting the definition of forest is today around 60 000 hectares in the defined Cropland area. Analysis has shown that the area has not changed significantly over the last 20 years although there is very high dynamic in the landscape as old hedgerows are removed and replaced with new ones to facilitate new farming technologies. Establishing hedgerows and small biotopes are partly subsidised by the Danish government. It is assumed that the subsidy system combined with legal protection of the existing hedgerows will not change in the future. Therefore, the area is expected to be maintained at the same level, but due to changes in the composition of the hedgerows towards higher carbon densities, a small increase in the total carbon stock in hedgerows is estimated with an average annual increase of 15-25 Gg C per year (not shown).

N_2O emissions from cultivated croplands are reported in the agricultural sector.

The overall expected emission trend for Cropland is shown in Table 8.4 from an emission of 3 635.7 Gg CO_2 eq in 2012 to 3 459.7 Gg in 2035. Overall, a decreasing trend in the emission from Cropland is expected. This is both due to mineral soils and organic soils. The likely reason for the decrease in the emission from mineral soils is that the soils are approaching the equilibrium state between input and degradation. However, a zero emission from the mineral soils is not expected for the next couple of centuries unless initiatives to increase annual carbon input is taken. For the organic soils the main reason is a steady decrease in the area due to conversion into grassland and wetlands.

Table 8.4 Overall emission trend for Cropland from 1990 to 2035.

	1990	2000	2005	2010	2012	2015	2020	2025	2030	2035
Area, 1000 Ha	2714.0	2670.5	2654.4	2661.1	2666.8	2653.0	2632.5	2612.0	2591.5	2571.0
Living biomass	-73.5	59.1	-0.4	-40.9	193.0	6.9	0.1	26.4	10.7	32.6
Dead Organic Matter (from deforestation)	2.9	2.9	0.4	0.5	12.2	0.0	0.0	0.0	0.0	0.0
Soil, mineral soils	1415.3	913.7	968.3	1150.0	576.1	939.8	888.0	812.3	779.5	706.5
Soils, organic soils	4115.8	3542.1	3255.2	2968.3	2835.8	2709.6	2616.9	2608.9	2600.8	2592.8
N_2O, CO_2 eqv. (from deforestation and mineral soils)	0.2	23.1	92.1	240.2	18.6	137.9	122.2	129.2	126.3	127.8
CO_2 eqv. Total	5460.8	4540.9	4315.6	4318.1	3635.7	3794.1	3627.3	3576.7	3517.4	3459.7

8.3 Grassland

Grassland is defined as permanent grassland and areas without perennial vegetation meeting the forest definition. Grass in rotation is reported under Cropland.

A total of 311 592 hectares has been reported in the Grassland sector in 2012. The area is expected to increase until 321 275 in 2035 (Table 8.5) primarily due to regulation for more environmental friendly farming. It should be mentioned here that the Grassland definition differs from the one used by Statistics Denmark for permanent Grassland and among others include heath land and other marginal areas which are not reported in the other land use categories.

The amount of living biomass in Grassland is limited and only minor changes are foreseen. The observed loss is primarily due to conversion from cropland to grassland where a lower default amount of living biomass is found.

No changes in SOC in mineral soils are expected except for a small change in SOC in areas converted from other land use categories into Grassland. As the major change is from Cropland, which has a slightly higher SOC than Grassland, a small loss of carbon is estimated.

For drained organic soils in Grassland > 12 % OC, which can be found inside geographically located fields in the field maps, an average emission of 8 400 kg C per ha per year is assumed combined with a CH_4 emission of 16 kg CH_4 per ha per year.

N_2O emissions from cultivated grasslands are reported in the agricultural sector.

The small amount of CH_4 from grassland results from the new 2013 Wetlands Supplement, which indicate an emission of 16 kg CH_4 per ha per year, and from burning of heath land.

It is expected that the emission from Grassland will stabilize around 175 Gg C per year or equivalent to 650 Gg CO_2 equivalents per year. The major source here will be drained organic grassland.

Table 8.5 Overall emission trend for Grassland from 1990 to 2035.

	1990	2000	2005	2010	2012	2015	2020	2025	2030	2035
Area, 1000 Ha	400.8	385.6	371.4	330.8	311.6	311.2	313.7	316.2	318.8	321.3
Living biomass	75.3	63.9	144.6	162.3	463.2	39.2	39.2	39.2	39.2	39.2
Dead Organic Matter (from deforestation)	1.6	1.6	3.2	3.8	7.0	0.0	0.0	0.0	0.0	0.0
Soil, mineral soils	0.2	1.7	2.5	3.4	4.5	5.0	6.0	7.0	8.0	9.0
Soil, organic soils	716.2	616.4	566.5	516.5	528.9	601.1	599.2	597.2	595.3	593.4
CH_4, organic soils	9.3	8.0	7.4	6.7	6.9	7.8	7.8	7.8	7.8	7.7
Wildfires and Controlled burning	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1
CO_2 eqv. Total	802.6	691.6	724.2	692.8	1010.6	653.3	652.3	651.4	650.4	649.4

8.4 Wetlands

Wetlands are defined as peat land, where peat extraction takes place, and restored wetlands. Emissions from wetlands occurring before 1990 are not reported. Due to the long-time intensive utilisation of the Danish area for farming purposes wetland restoration has taken place for many years.

8.4.1 Peat land

Peat extraction is taking place at three locations in Denmark. The sites are managed by Pindstrup Mosebrug A/S (www.pindstrup.dk). In total it is estimated that 1 596 hectares are under influence of peat excavation although the actually open area for peat excavation is around 400 hectares. Pindstrup Mosebrug A/S is operating under a 10 year licence. Recently the license has been renewed (Pindstrup Mosebrug, pers. com). It is therefore not expected that any major changes will take place until the new licence expire in 2022. From then on no peat extraction is expected in Denmark.

The emission is estimated as a degradation of peat on the soil surface and an immediate oxidation of the extracted peat which is mainly used for horticultural purposes.

In 2012 152 000 m^3 of peat were extracted. The total emission from this is estimated at 8.64 Gg C and 0.000377 Gg N_2O per year. In the inventory is it assumed an instant oxidation of excavated peat.

8.4.2 Re-established wetlands

Only re-established wetlands are included in the Wetland category. Naturally occurring wetlands are included under Other Land where no emission estimates are made. Some larger wetland restoration projects were carried out in the 1990's. Lately, only smaller areas have been converted. Previous GIS analysis of restored wetlands has shown that only a part of the re-established wetland is located in areas where agricultural fields could be identified. The major part of the established wetlands is allocated to unmanaged Grassland and the impact on the emission estimates from establishing wetlands is therefore sometimes limited. The same is true if the wetlands are established on mineral soils because large changes only occur if the wetlands are established on drained organic soils.

There has been a large variation in the area converted to restored wetlands within the past years. The Danish Green Growth plan estimate a conversion of total 15 000 ha within the coming years. In the projection, it is assumed that 285 hectares of Cropland, 93 hectare of Grassland and 93 hectares of Forest land are converted to wetland per year. In total 471 ha per year. In the projection is this rate used for the whole period 2013-2035.

When establishing wetlands on agricultural soils one of the important factors is that the degradation on the agricultural land is halted by re-wetting the soils, and not the build-up of organic matter.

The new wetlands are divided into fully covered water bodies (lakes) and partly water covered wetlands. Based on historical figures is it assumed that 24% of all new wetlands are converted to lakes.

The new partly water covered wetlands are assumed to be in a zero balance with the environment in terms of the carbon stock. This means that no losses or gains are assumed in the soil carbon stock. Only emissions of CH_4 occurs. The new 2013 Wetlands Supplement assumes a net emission of 288 kg CH_4 emission from the wetlands. This has been implemented in the projection for partly water covered wetlands but not for lakes and other fully water covered areas.

The overall expected emission trends for Wetlands are shown in Table 8.6. From 1990 to 2022, the emission is dominated by emissions from the eextracted peat and at around 80-90 Gg CO_2 equivalents. From 2022 and onwards the dominating emission is CH_4 emission from the water saturated areas. Because of the assumed closure of the peat extraction areas the expected emission is around 20-22 Gg CO_2 eqv. per year in the future (Table 8.6).

Table 8.6 Overall emission trend for Wetlands from 1990 to 2035.

	1990	2000	2005	2010	2012	2015	2020	2025	2030	2035
Area, 1000 Ha	129.8	139.3	144.3	150.3	151.5	152.6	155.6	158.5	161.5	164.4
Living biomass	2.6	2.8	45.8	47.8	-0.2	-1.7	-1.7	-1.7	-1.7	-1.7
Peat extraction areas (incl. N_2O and CH_4)	100.0	68.3	84.2	52.9	48.5	45.2	45.2	0.0	0.0	0.0
Dead Organic Matter (from deforestation)	0.2	0.2	6.2	7.2	0.0	0.0	0.0	0.0	0.0	0.0
Soils	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CH_4 from land converted to Wetlands	0.7	8.2	12.0	16.1	16.9	17.8	20.1	22.4	24.6	26.9
CO_2 eqv. Total	103.6	79.5	148.2	124.0	65.2	61.3	63.5	20.7	22.9	25.2

8.5 Settlements

The need for areas for housing and other infrastructure has resulted in an increase in the Settlement area from 1990 to 2012 of 31 169 hectare or 1 417 hectare per year. In 2011 the Danish Nature Agency estimated that the need for settlement areas in the vicinity of Copenhagen is 1 250 hectares per year for the period 2013 to 2025 (Danish Nature Agency, 2011). To this should be added the remaining part of Denmark as well as areas for roads and other purposes. It is assumed that the historic increase of 1 355 hectares per year will continue in the future and mainly result from conversion of Cropland.

The overall expected emission trend is shown in Table 8.7. As the carbon stock in other land use categories other than settlement, is higher than in settlement areas, land converted to settlement is a CO_2 source. In forest land and cropland the general C stock in mineral soils is 151-158 tonnes C per ha. In settlements it is assumed that a new equilibrium of 120 tonnes C per ha is established. It is assumed that it takes 100 years to reach this new equilibrium stage. As a consequence the emission from converted soils will continue for the next many years and because of the expected increase in the settlement area the emission from the designated settlement areas will increase in the future.

Table 8.7 Overall emission trend for Settlements from 1990 to 2035.

	1990	2000	2005	2010	2012	2015	2020	2025	2030	2035
Area, 1000 Ha	486.4	495.0	500.3	509.6	516.7	521.6	528.4	535.1	541.9	548.7
Living biomass	11.4	11.6	22.1	22.2	56.0	14.0	14.0	14.0	14.0	14.0
Dead Organic Matter (from deforestation)	0.6	0.5	0.4	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Soils	1.0	10.6	16.5	26.9	34.8	40.3	47.9	55.5	63.0	70.6
Other N_2O, CO_2 eqv.	0.1	1.3	2.1	3.4	4.5	5.1	6.1	7.1	8.1	9.0
CO_2 eqv. Total	13.0	24.1	41.1	53.0	95.3	59.4	68.0	76.5	85.1	93.6

8.6 Other Land

Other Land is defined as sandy beaches and sand dunes without or with only sparse vegetation. The total area is 26 433 hectares. No changes in the area are foreseen in the future. The carbon stock in these soils is very low and almost absent in terms of living biomass. No emissions are expected from these areas.

8.7 Fires

Forest fires are rare in Denmark and only occur as wild fires. In general, between 0 and 2 hectares are burned per year. Controlled burning of heathland to maintain the heath is made by the Danish Nature Agency. Previously around 300 hectares were burned every year. In recent years an intensified burning has taken place, resulting in around 700 hectares burnt area every year. These very small areas are not assumed to have any influence on the carbon stock of living biomass as regeneration is very quickly taking place. The emissions from these fires are for clarification also included in table 8.3 (Forest) and 8.5 (Grassland).

Table 8.8 Emission from forest fires and burning of heath land.

	1990	2000	2005	2010	2012	2015	2020	2025	2030	2035
Forest area burned, ha	150.0	0.0	0.0	0.0	0.0	2.0	2.0	2.0	2.0	2.0
Heathland area burned, ha	47.0	121.6	638.4	359.0	709.0	700.0	700.0	700.0	700.0	700.0
Total burned area, ha	197.0	121.6	638.4	359.0	709.0	702.0	702.0	702.0	702.0	702.0
Emission, CH_4, Gg	150.0	0.0	0.0	0.0	0.0	2.0	2.0	2.0	2.0	2.0
Emission, N_2O, Gg	47.0	121.6	638.4	359.0	709.0	700.0	700.0	700.0	700.0	700.0
Total, Gg CO_2 eqv.	197.0	121.6	638.4	359.0	709.0	702.0	702.0	702.0	702.0	702.0

8.8 Total emission

The total emission from the LULUCF is shown in Table 8.10. For all land categories except Forest land is assumed an overall emission of around 4 500 Gg CO_2 eqv. per year in 2013, decreasing to 4 100 Gg CO_2 eqv. per year in 2035. The main drivers for this decrease is a reduction in the area with organic soil in agricultural crop production and an expected decrease in the emission from agricultural mineral soils as they approaches an equilibrium state with the annual organic matter input and the annual degradation of the organic matter.

Major changes have been made in the emission factors in the LULUCF sector. New sources such as N_2O from mineral soils in cropland, CH_4 sources in Forests, Grassland and Wetlands, movement of liming from LULUCF to Agriculture etc. is included. These changes have changed the overall emission from the LULUCF sector from being a net sink of 851 Gg CO_2 eqv. to a net source of 491 Gg CO_2 eqv. (excl. liming) compared to the reported emission in the annual 2014 submission for 2012 to UNCCC. The largest changes are found in the emission factors for organic soils, which have increased. In total the emission from Cropland is expected to increase with 22 % and from Grassland with 83 %, Table 8.9.

Table 8.9 Changes in the emission from the LULUCF in 2012 due to changes in the emission factors and other changes.

	Original submission in 2014 for 2012	Estimated new emissions in 2012	Change, Gg CO_2 eqv.	Change, %
5. Land Use, Land-Use Change and Forestry	**-851.70**	**491.3**	**-1,342.98**	
A. Forest Land	-4,453.54	-4,298.8	-154.69	3
B. Cropland	2,955.24	3,619.0	-663.81	-22
C. Grassland	553.52	1,010.6	-457.10	-83
D. Wetlands	2.27	65.2	-62.93	-2767
E. Settlements	90.81	95.3	-4.45	-5
F. Other Land	NA,NO	NA,NO	NA,NO	NA,NO

It has not been possible to get updated forest data and the projection does therefore not include living biomass in forests, dead organic matter and the organic soils in the forest. It does however include emissions from the expected land use conversions of mineral soils and loss of living biomass in the converted area. Comparing this with the historical data has little influence on the overall carbon stock changes in all forest.

Conversion of organic soils from annual crops into permanent grassland will reduce the emission to about two-third but not remove the emission totally unless the conversion includes a raised water table to prevent a degradation of the organic matter in the dry grasslands.

Another important loss factor is the conversion of cropland to other land use except forestry. The reason for this is that the current carbon stock for annual crops is defined as when the maximum carbon stock is in the field. Conversion of Cropland having a high amount of carbon in living biomass into other categories with a lower amount of living biomass like urban areas will therefore cause an overall loss of carbon.

The main driver for the increase in the emission is primarily an expected increase in the loss of carbon from agricultural soils. Increasing the input of organic matter into the agricultural soils to compensate for this loss seems very difficult as only 10-15 % of the annual input of organic matter will add to the soil organic carbon and the remaining will very rapidly be degraded and return to the air as CO_2.

Growing of energy crops will only have marginal effect on the emissions in the LULCUF sector as only small amounts of carbon will be stored temporarily in the energy crops before it is harvested.

Table 8.10 Total emission from the LULUCF sector, Gg CO_2 eqv. per year. Forestry do not include living biomass, dead organic matter and organic soils.

	1990	2000	2005	2010	2012	2015	2020	2025	2030	2035
5. Land Use, Land-Use Change and Forestry, (Gg CO_2 eqv.)	6,677.9	4,713.7	5,910.6	1,055.1	491.3	4,419.6	4,273.9	4,176.8	4,125.8	4,072.1
A. Forest Land	298.0	-599.6	773.1	-3,894.5	-4,298.8	-12.6	-17.1	-21.7	-26.3	-30.9
1. Forest Land remaining Forest Land	218.5	-573.6	1,355.8	-3,655.3	-4,380.1	1.7	1.6	1.6	1.6	1.6
2. Land converted to Forest Land	79.5	-26.0	-582.7	-239.1	81.3	-14.2	-18.8	-23.4	-28.0	-32.5
B. Cropland	5,460.8	4,518.1	4,224.2	4,079.8	3,619.0	3,658.2	3,507.2	3,450.0	3,393.8	3,334.8
1. Cropland remaining Cropland	5,450.2	4,506.8	4,259.9	4,116.6	3,688.5	3,662.5	3,511.1	3,453.5	3,396.9	3,337.5
2. Land converted to Cropland	10.6	11.4	-35.7	-36.8	-69.5	-4.3	-3.9	-3.5	-3.1	-2.7
C. Grassland	802.6	691.6	724.2	692.8	1,010.6	653.3	652.3	651.3	650.4	649.4
1. Grassland remaining Grassland	781.3	668.2	690.3	656.5	883.2	635.5	633.5	631.6	629.6	627.7
2. Land converted to Grassland	21.3	23.4	33.9	36.2	127.4	17.8	18.8	19.8	20.8	21.7
D. Wetlands	103.6	79.5	148.2	124.0	65.2	61.3	63.5	20.7	22.9	25.2
1. Wetlands remaining Wetlands	100.0	68.3	84.2	52.9	48.5	45.2	45.2	0.0	0.0	0.0
2. Land converted to Wetlands	3.6	11.2	64.0	71.1	16.7	16.1	18.4	20.7	22.9	25.2
E. Settlements	13.0	24.1	41.1	53.0	95.3	59.4	68.0	76.5	85.1	93.6
1. Settlements remaining Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2. Land converted to Settlements	13.0	24.1	41.1	53.0	95.3	59.4	68.0	76.5	85.1	93.6
F. Other Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

8.9 Uncertainty

The general uncertainty in the emission estimates is very high as the LULUCF sector is dealing with biological processes where the general uncertainty in the emission factors is high. If the emission factors are kept constant for the whole time series the uncertainty are low to medium. Generally, the conversion of one land use category to another (except for Forestry) has a low effect on the emission estimates.

The highest inter-annual uncertainty relates to the use of the dynamic model for estimating the degradation of SOM, C-TOOL, where the input data depends on actual harvest yields, and the degradation on future temperature regimes in combination with a low annual change compared with a very large carbon stock in the soil. The total carbon stock in the agricultural mineral soils has been estimated to approximately 420 Tg C, which is equivalent to 1 540 million tonnes of CO_2. Even small changes in the parameters may change the emission prediction substantially. The average temperature in Denmark was very high in 2006-2008 whereas in 2009 and 2010 the average temperature decreased, Figure 8.2. This difference in temperature has an impact on the modelled outcome from C-TOOL. The effect of the cold winter in 2009 could be seen directly in the reported inventory on the emission from agricultural soils. The difference between the reported emission from the agricultural soils from 2008 to 2009 is 990 Gg CO_2. A high uncertainty should therefore be expected for the emission estimate from especially mineral agricultural soils. The uncertainty for the organic soils mainly relate to the uncertainty on the estimate of the absolute emission factor used for these soils. Changes between years are therefore due to actual changes in how the land is utilized and temperature differences.

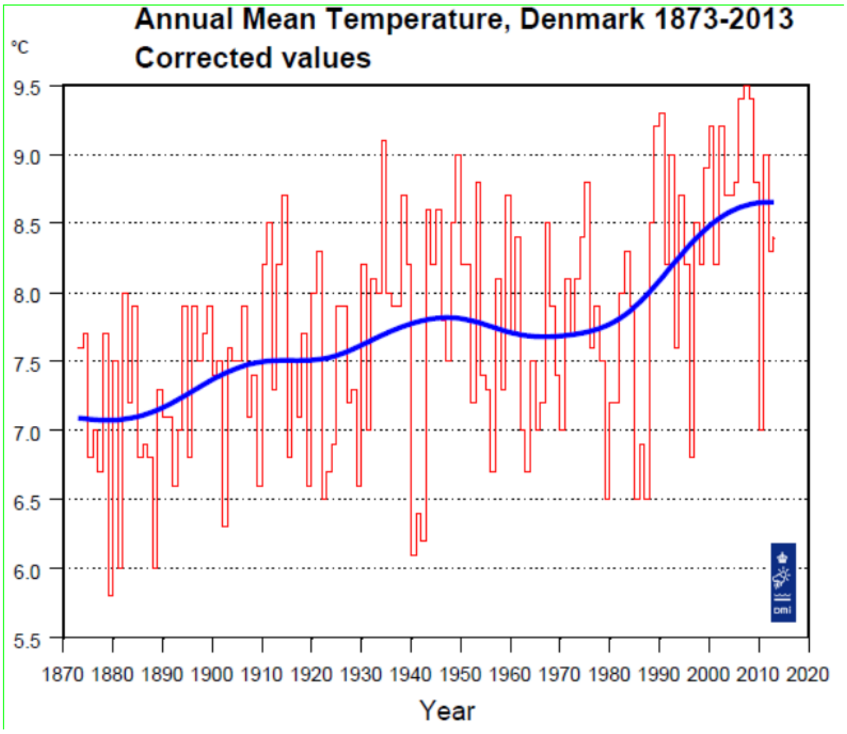

Figure 13.2 Average temperature in Denmark 1873 to 2013 (DMI 2013).

For Forestry there is a high variability in the projected carbon stock change in 2008 to 2012. This is due to the incorporation of the National Forest Inventory (NFI) in 2002 into the Danish GHG inventory. In the first year of the NFI a large variability in the collected data was found. It is expected that the variability will decrease so that the data after 2012 will be much more stable.

A conservative uncertainty estimate for the overall LULUCF estimate will be in the range of ± 500 Gg CO_2 eqv. or ±0.5 million tonnes CO_2 eqv. per year.

8.10 The Danish Kyoto commitment

Denmark has elected Forest Management (FM), Cropland Management (CM) and Grazing Land Management (GM) under article 3.4 to meet its reduction commitment, besides the obligatory inclusion of Afforestation/Reforestation and Deforestation (article 3.3). Although, the reduction commitment is based on the national inventory to UNFCCC there are several differences. The major differences are that for CM and GM the reduction is estimated based on the net-net principle. Furthermore, a land elected for any activity in 1990 cannot leave the commitment and shall therefore be accounted for in the future. It means that land converted from Cropland to e.g. Settlements shall still be accounted for in the reduction commitment in the first and all subsequent commitment periods.

The first commitment period is from 2008 to 2012. In this the current submitted GHG inventory to UNFCCC in 2014 shows that CM would add a net benefit to the Danish reduction commitment in the first commitment period of 8 247 Gg CO_2 eqv. or 1 650 Gg CO_2 eqv. per year. The election of GM would add negatively to the Danish reduction commitment of 552 Gg CO_2 eqv. or 110 Gg CO_2 eqv. per year.

The accounting rules in Cropland Management and Grassland Management is net-net accounting. As it is expected that the emission will be reduced further in the future an increase is expected in the amount that CM and GM will add to future reduction commitments.

For the second commitment period, 2013-2020 Cropland Management and Grazing Land Management is projected to contribute to the Danish reduction commitment by 1 765 Gg CO_2 eqv. per year or 14 122 Gg CO_2 eqv. in total for the second commitment period. Cropland and Grassland will still be net sources of CO_2 but due to an increased incorporation of plant debris, animal manure, a reduced area with organic soil under cultivation and establishment of wetlands, the change in the agricultural activities will contribute positively to further Danish reduction commitments.

Table 8.11 Projected emission estimates for article 3.3 and 3.4 activities 1990 to 2035.

	1990	2000	2005	2010	2012	2015	2020	2025	2030	2035
Cropland Management	5451.4	4536.9	4336.1	4361.6	3643.4	3853.5	3701.3	3665.5	3620.8	3577.8
Grassland Management	796.3	689.3	712.0	659.8	980.2	652.6	655.1	657.7	660.2	662.8

a) N_2O emission associated with deforestation is reported under Cropland in the convention reporting but for clarification in the accounting under KP given here under Deforestation

b) In the first commitment period (2008-2012) there is a cap (a maximum) on the amount stored in forest remaining forest, which can be included in the Danish reduction commitment. The Danish cap for 2008-2012 is 916.7 Gg CO_2. For the second commitment period (2013-2020) a Forest Management Reference Level (FMRL) has been made of 282-573 Gg CO_2 per year in the period 2013-2020.

Table 8.12 Accounting estimates for 2013 to 2020 for Cropland Management (CM) and Grassland Management (GM) under Art. 3.4 of the Kyoto-protocol, Gg CO_2 eqv.

	Average per year, 2013-2020	Total 2nd commitment period
Cropland Management, Gg CO_2 eqv.	-1615.8	-12926.6
Grassland Management, Gg CO_2 eqv.	-149.5	-1196.2
CM+GM, Gg CO_2 eqv.	-1765.3	-14122.7

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9 Conclusions

In assessing the projection it is valuable to separate the emissions included in the EU ETS and hence the current projection provides a separate projection of the CO_2 emissions covered by the EU ETS. The CO_2 emissions covered by EU ETS are shown for selected years in Table 9.1. Detailed tables containing the projected emissions are available at:
http://envs.au.dk/videnudveksling/luft/emissioner/emissioninventory/

The historic and projected greenhouse gas (GHG) emissions are shown in Figure 9.1. Projected GHG emissions include the estimated effects of policies and measures implemented until September 2014 and the projection of total GHG emissions is therefore a so-called 'with existing measures' projection.

The main sectors for GHG emission in 2013 are expected to be Energy Industries (34 %), Transport (23 %), Agriculture (19 %) and Other Sectors (10 %). For the latter sector the most important sources are fuel combustion in the residential sector. GHG emissions show a decreasing trend in the projection period from 2013 to 2035, with decreasing emissions from 2013 to 2020 and fairly constant emissions from 2020 to 2035. In general, the emission share for the energy industries sector is decreasing while the emission share for the transport sector is increasing. The total emissions in 2013 are estimated to be 53.4 million tonnes CO_2 equivalents and 39.8 million tonnes in 2035, corresponding to a decrease of 25.5 %. From 1990 to 2012 the emissions are estimated to have decreased by 23 %.

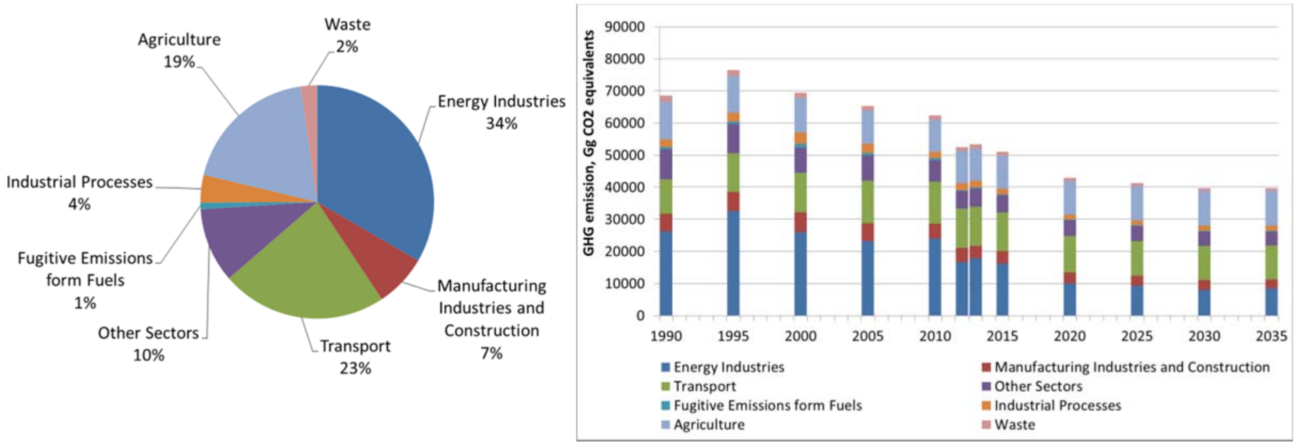

Figure 9.1 Total GHG emissions in CO_2 equivalents. Distribution according to main sectors (2013) and time series for 1990 to 2035.

9.1 Stationary combustion

Stationary combustion includes Energy industries, Manufacturing industries and construction and Other sectors. Other sectors include combustion in commercial/institutional, residential and agricultural plants. The GHG emissions in 2013 from the main source, which is public power (63 %), are estimated to decrease significantly in the period from 2013 to 2025 due to a partial shift in fuel type from coal to wood and municipal waste. From 2025 to 2035 the emission is projected to decrease but at a lower rate. Also, for residential combustion plants and combustion in manufacturing plants a significant decrease in emissions is projected. The emissions from the other sectors remain almost constant over the period except for energy use in the offshore industry (oil and gas extraction), where the emissions are projected to increase.

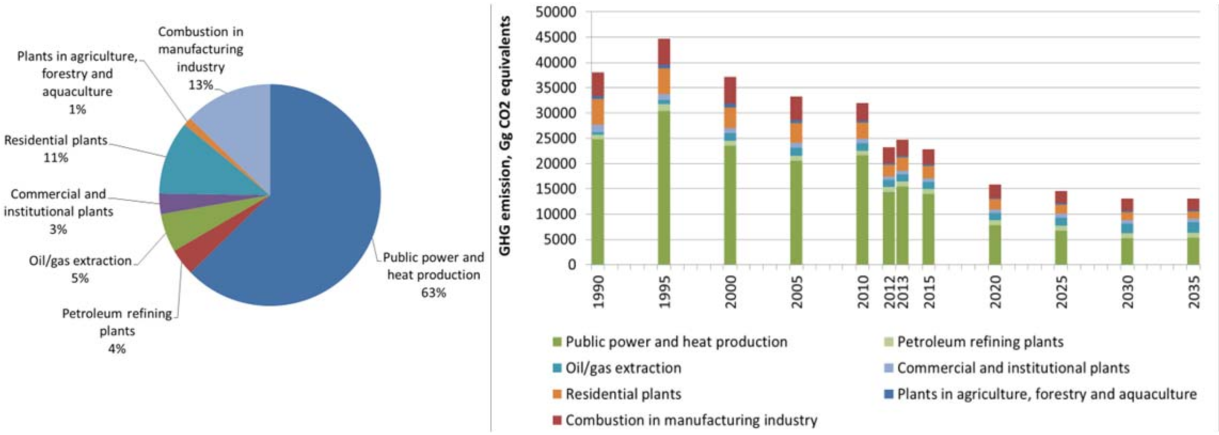

Figure 9.2 GHG emissions in CO_2 equivalents for stationary combustion. Distribution according to sources (2013) and time series for 1990 to 2035 for main sources.

9.2 Fugitive emission

The GHG emissions from the sector Fugitive emissions from fuels increased in the years 1990-2000 when a maximum was reached. The emissions are estimated to decrease in the projection years 2013-2035, mainly from 2013-2015. The decreasing trend mainly owes to decreasing amounts of gas being flared at offshore installations. Further, the decrease owes to technical improvements at the raw oil terminal and thereby a large decrease in the emissions from storage of oil in tanks at the terminal and to a lesser degree from onshore loading of ships. Emissions from extraction of oil and gas are estimated to decrease in the period 2013-2035 due to a decreasing oil and natural gas production. The GHG emissions from the remaining sources show none or only minor changes in the projection period.

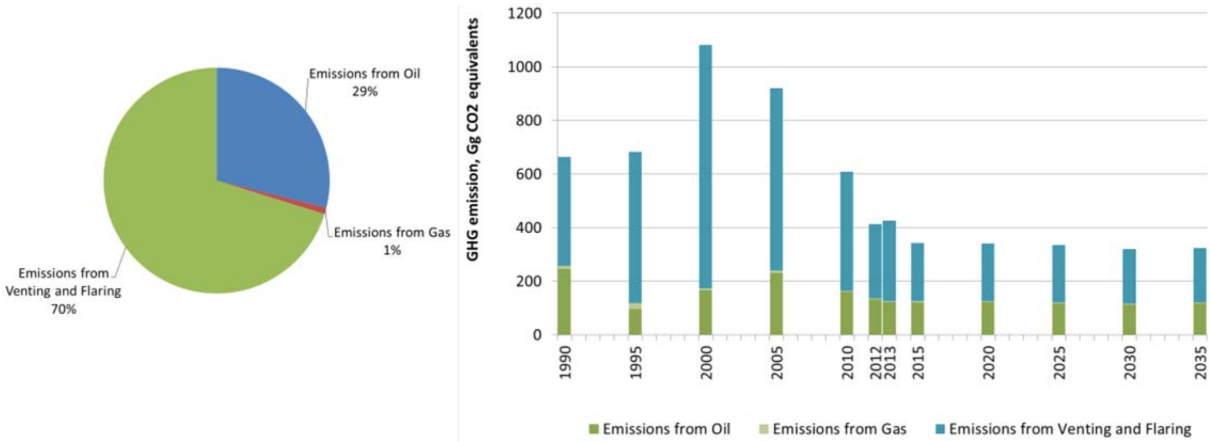

Figure 9.3 GHG emissions in CO_2 equivalents for fugitive emissions. Distribution according to sources for 2013 (average for the years 2008-2012) and time series for 1990 to 2035 for main sources.

9.3 Industrial processes

The GHG emission from industrial processes increased during the nineties, reaching a maximum in 2000. Closure of the nitric acid/fertiliser plant in 2004 has resulted in a considerable decrease in the GHG emission. The most significant source is cement production. Consumption of limestone and the emission of CO_2 from flue gas cleaning are assumed to follow the consumption of coal and waste for generation of heat and power. The GHG emission from this sector will continue to be strongly dependent on the cement production at Denmark's only cement plant.

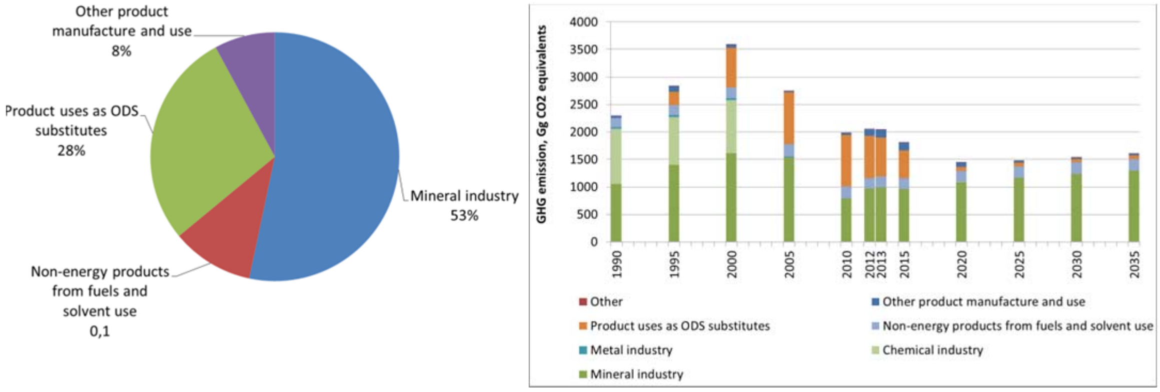

Figure 9.4 Total GHG emissions in CO_2 equivalents for industrial processes. Distribution according to main sectors (2013) and time series for 1990 to 2035.

9.4 Transport

Road transport is the main source of GHG emissions accounting for 68 % in 2013 and the share is projected to remain relatively stable. The emission shares for the remaining mobile sources are small compared with road transport, and the largest contribution derives from non-road machinery in industry.

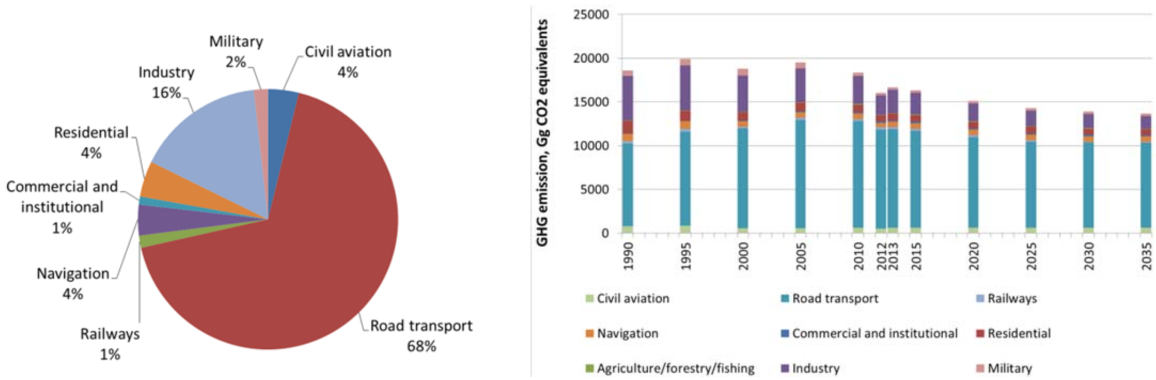

Figure 9.5 GHG emissions in CO_2 equivalents for mobile sources. Distribution according to sources (2013) and time series for 1990 to 2035 for main sources.

9.5 Agriculture

From 1990 to 2012, the emission of GHGs in the agricultural sector has decreased from 11.9 million tonnes CO_2 equivalents to 10.1 million tonnes CO_2 equivalents, which corresponds to a 15 % reduction. This development continues and the emission to 2035 is expected to increase slightly to 10.8 million tonnes CO_2 equivalents. The reduction in the historical years can mainly be explained by improved utilisation of nitrogen in manure and a significant reduction in the use of fertiliser and a lower emission from N-leaching. Uptake of technologies to reduce ammonia emissions in stables and expansion of biogas production are taken into account in the projections. An increase in the number of animals and ensuing emission increase is assumed in the projection.

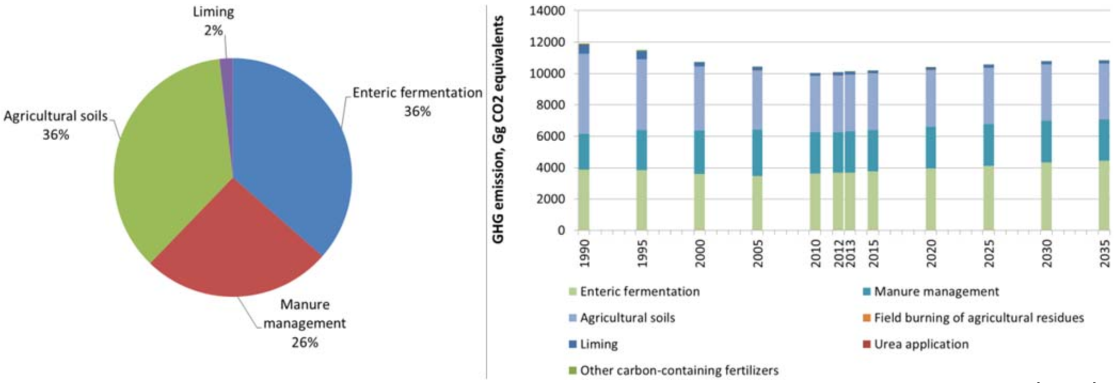

Figure 9.6 GHG emissions in CO_2 equivalents for agriculture sources. Distribution according to sources (2013) and time series for 1990 to 2035 of main sources.

9.6 Waste

Solid waste disposal on land (SWDS) is by far the largest source of GHG emissions from the waste sector. The projection of the contribution of CH_4 from landfill to the sector total in 2013 is 66 %, Figure 9.7. Due to the decrease in waste deposited to landfills the emission has been decreasing during the later historical years and this trend is expected to continue in the projection timeframe.

The predicted GHG emission from wastewater is 13 %. The estimated increase in the total amount of organic material in the influent wastewater is assumed to be a function of an increase in the population size alone, while the contribution from industry is assumed to stay at a constant level.

The category other waste, which covers cremations of corpses and carcasses and accidental fires, contributes with 2 % of the total GHG emission from the waste sector. The category biological treatment of solid waste covers emissions from composting and accounts for 19 % in 2013. The emission is expected to increase due to increasing use of composting as waste disposal.

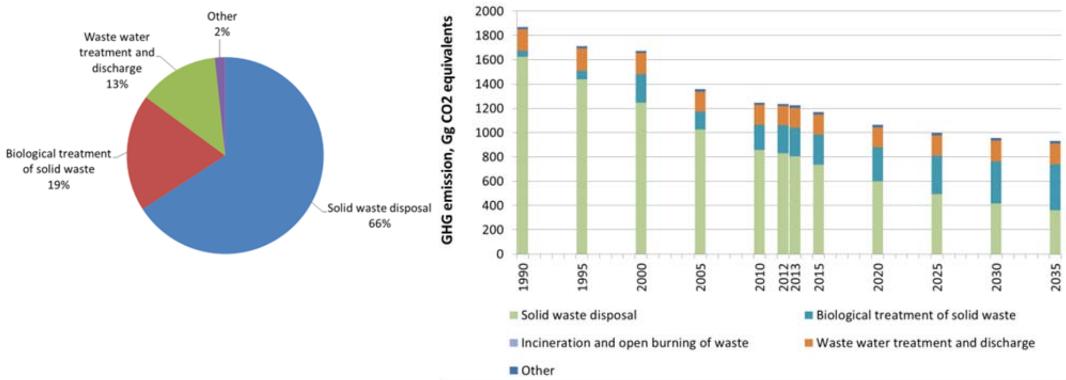

Figure 9.7 GHG emissions in CO_2 equivalents for Waste. Distribution according to main sources (2013) and the time series for 1990 to 2035.

9.7 LULUCF

The LULUCF sector without forestry is a net source of 6 380 Gg CO_2 eqv. in 1990, 4790 Gg CO_2 eqv. in 2012 and further decreasing to 4 135 Gg CO_2-eqv. in 2035. The major reason for this decrease is that agricultural organic soils are being depleted for degradable organic matter and that the agricultural mineral soils are expected to reach an equilibrium state. Afforestation is expected to continue to take place in Denmark with an estimated rate of 1 745 hectare per year. Together with a very small deforestation rate, the C-stock in the Danish forest is expected to increase in the future. Cultivation of organic soils is a major steady source. Agricultural regulations will reduce the area with cultivated agricultural organic soils further in the future, but there will still be a large net emission from these soils.

9.8 EU ETS

CO_2 emissions covered by EU ETS are from the energy sector and from industrial processes. From 2012 aviation is included in EU ETS, but otherwise only CO_2 emissions from stationary combustion plants are included under fuel combustion, hence the category 'Agriculture, forestry and aquaculture' refers to stationary combustion within this sector. The major part of industrial process CO_2 emissions are covered by EU ETS. It is dominated by cement production and other mineral products. The results of the projection for EU ETS covered emissions are shown in Table 9.1.

Table 9.1 CO_2 emissions covered by EU ETS.

	2015	2020	2025	2030	2035
Public electricity and heat production	12946	6755	6090	4691	4892
Petroleum refining	964	964	964	964	964
Other energy industries (oil/gas extraction)	1407	1352	1601	1888	2128
Combustion in manufacturing industry	2337	1977	1874	1806	1690
Civil aviation	145	147	149	150	151
Commercial and institutional	10	9	9	9	9
Agriculture, forestry and aquaculture	123	122	120	119	118
Fugitive emissions from flaring	214	212	212	201	201
Mineral industry	963	1086	1167	1231	1291
Chemical industry	2	2	2	2	2
Other	2	2	2	2	2
Total	19113	12628	12190	11063	11447
Civil Aviation, international	2667	2826	2939	3017	3054

PROJECTION OF GREENHOUSE GASES 2013-2035

This report contains a description of models, background data and projections of CO_2, CH_4, N_2O, HFC_s, PFC_s and SF_6 for Denmark. The emissions are projected to 2035 using a scenario combined with the expected results of a few individual policy measures. Official Danish forecasts of activity rates are used in the models for those sectors for which forecasts are available, i.e. the latest official forecast from the Danish Energy Agency. The emission factors refer to international guidelines and some are country-specific and refer to Danish legislation, Danish research reports or calculations based on emission data from a considerable number of industrial plants. The projection models are based on the same structure and method as the Danish emission inventories in order to ensure consistency.

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