PROJECTION OF GREENHOUSE GASES 2014-2025

Scientific Report from DCE – Danish Centre for Environment and Energy No. 194 2016

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Data sheet

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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 2025 using a baseline scenario, which includes the estimated effects of policies and measures implemented by November 2015 on Denmark's greenhouse gas (GHG) emissions ('with existing measures' projections). For other sectors than fuel combustion, emissions have also been projected for 2030.

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

The authors would like to thank:

The Danish Energy Agency (DEA) - for providing the energy consumption forecast and for valuable discussions during the project.

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Danish Centre for food and Agriculture (DCA) and the Knowledge Centre for Agriculture, the Danish Agricultural Advisory Service (DAAS) for providing data for the agricultural sector.

The Danish Environmental Protection Agency (DEPA) for financial support on the solvent projection.

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. At the time of making this projection, some sectors had the latest historic year of 2014, while other sectors had 2013 as the latest historic year. This is reflected in the projection. Whenever possible the latest available historic year was used as a basis for the projection. The emissions are projected to 2025 using a scenario, which includes the estimated effects of policies and measures implemented by November 2015 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 (2014-2025) in the models for those sectors for which these forecasts are available. For other sectors than fuel combustion, emissions have also been projected for 2030. 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 shown both as actual emissions and corrected for electricity trade.

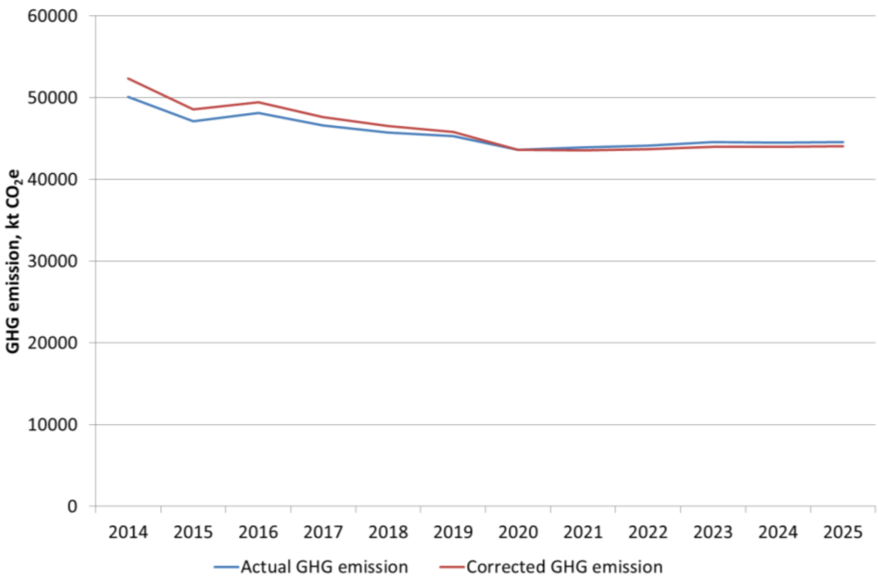


Figure S.1 Actual GHG emissions in CO_2 equivalents compared with the GHG emission corrected for electricity trade.

The emission corrected for electricity trade, follows the general trend in emissions. For the first years of the time series the actual emission is lower than the corrected emission, i.e. there is an import of electricity. Around 2020 the import/export is close to zero, where after there is an electricity export and hence the actual emissions become larger than the corrected.

The main emitting sectors in 2015 are Energy Industries (27 %), Transport (27 %), Agriculture (21 %) and Other Sectors (10 %). For the latter sector the most important sources are fuel combustion in the residential sector. GHG emissions show a slight decrease in the projection period from 2015 to 2025.

The total emissions in 2015 are estimated to be 47.1 million tonnes CO_2 equivalents and 44.6 million tonnes in 2025, corresponding to a decrease of 5 %. From 1990 to 2013 the emissions decrease by 21 %.

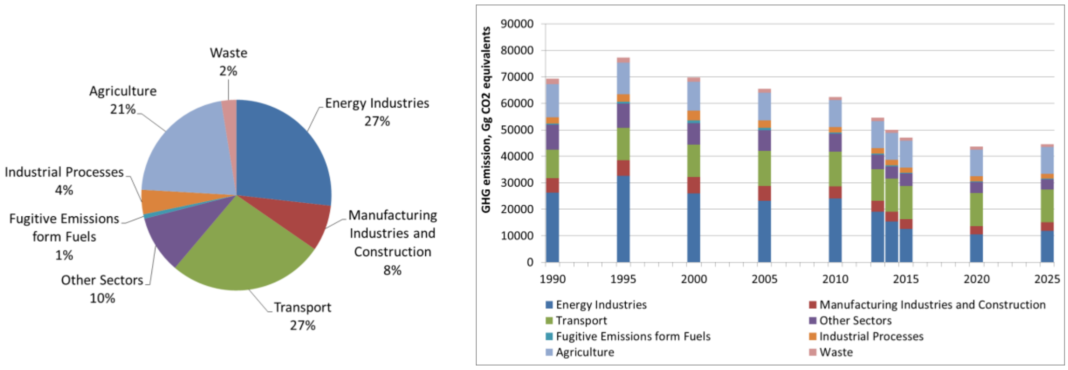


Figure S.2 Total GHG emissions in CO_2 equivalents. Distribution according to main sectors in 2015 and time series for 1990 to 2025.

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 2015 from the main source, which is public power and heat production (56 %), are estimated to decrease in the period from 2015 to 2025 (9 %) due to a partial shift in fuel type from coal to wood and municipal waste as well as a decrease in fuel use following from the increase in wind power and photovoltaics in electricity production. Also, for residential combustion plants and combustion in manufacturing plants a significant decrease in emissions is projected; the emissions decrease by 28 % and 18 % from 2015 to 2025 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 increased by 145 % from 1990 to 2013 and projected to increase further by 14 % from 2015 to 2025. The reason for the increasing energy use in the offshore sector is the depletion of the oil and gas fields that make the extraction more energy intensive.

Fugitive emissions from fuels

The greenhouse gas emissions from the sector "Fugitive emissions from fuels" show large fluctuations in the historical years 1990-2013, 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 2015-2030 by 12 %. 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 projection period 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 2015 is cement production (49 %) and use of substitutes (f-gases) for ozone depleting substances (ODS) (33 %). The corresponding shares in 2030 are expected to be 77 % and 8 %, 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 from transport and other mobile sources in 2015 (86 %) and emissions from this source are expected to be almost constant in the projection period 2015 to 2025. 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 agriculture, forestry and fishing contributes 9 % of the sectoral GHG emission in 2015 and this share is expected to stay at 9 % in 2025.

Agriculture

The main sources in 2015 are enteric fermentation (36 %), agricultural soils (36 %) and manure management (26 %). The corresponding shares in 2030 are expected to be 38 %, 35 % and 25 %, respectively. From 1990 to 2013, the emission of GHGs in the agricultural sector decreased by 19 %. In the projection years 2015 to 2030 the emissions are expected to increase by 2 %. 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. 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 36 %. The decreasing trend is expected to continue with a decrease of 21 % from 2015 to 2030. In 2015, GHG emission from solid waste disposal is predicted to contribute 64 % of the emission from the sector as a whole. A decrease of 46 % is expected for this source in the years 2015 to 2030, due to less waste deposition on landfills. An almost constant level for emissions from wastewater is expected for the projection period. GHG emissions from wastewater handling in 2015 contribute with 15 %. Emissions from biological treatment of solid waste contribute 19 % in 2015 and 35 % in 2030.

LULUCF

The LULUCF sector includes emissions from forestland management (FM), cropland management (CM) and grassland management (GM). In 2015 the GHG emissions from CM and GM were 4 336.8 Gg CO_2 eqv. and 237.8 Gg CO_2 eqv., respectively. The emission from CM is expected to decrease by 33 % in the projection period 2015-2030, while the emission from GM is expected to decrease by 115 % in the same period. 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.

Projections of emissions/removals from forestry are carried out by the Department of Geosciences and Natural Resource Management, Copenhagen University. They are not included in this report.

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). På tidspunktet for udarbejdelsen af denne fremskrivning er det seneste historiske år for nogle sektorer 2014, og for andre sektorer 2013. Dette er afspejlet i fremskrivningen. Hvor det er muligt er det seneste historiske år anvendt som basis for fremskrivningen. Emissionerne er fremskrevet til 2025 på baggrund af et scenarie, som medtager de estimerede effekter på Danmarks drivhusgasudledninger af virkemidler iværksat indtil november 2015 (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 (2014-2025) anvendt. For sektorer, der ikke omfatter forbrænding, er emissionerne desuden fremskrevet for 2030 af DCE baseret på bedste tilgængelige viden. 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 vises både som faktiske emissioner og korrigeret for elhandel.

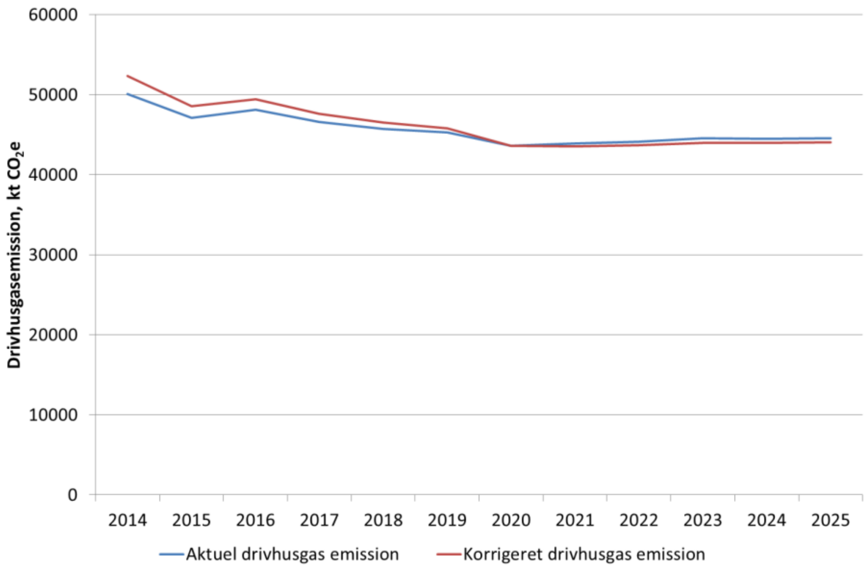
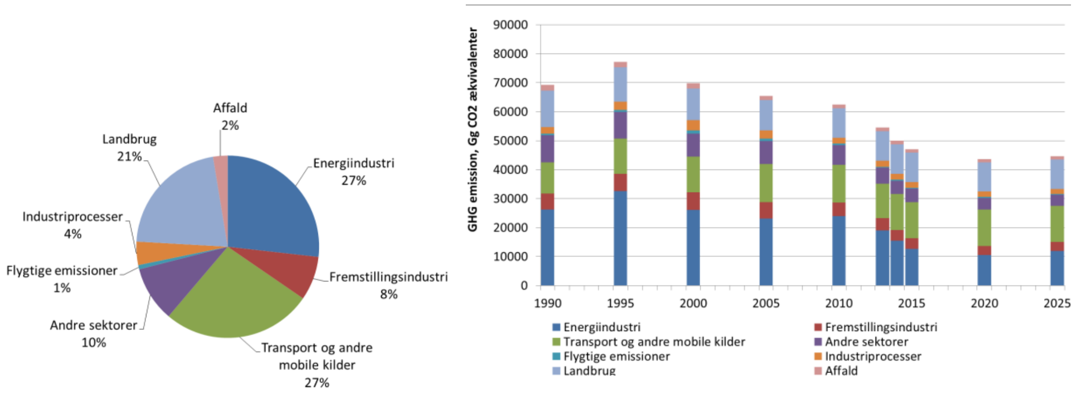


Figure R.1 Aktuelle drivhusgasemissioner i CO_2 ækvivalenter sammenlignet med drivhusgasemissionen korrigeret for elhandel.

Emissionen korrigeret for elhandel følger den generelle udvikling i drivhusgasemissionen. I de første år af tidsserien er den aktuelle emission mindre end den korrigerede emission, dvs. der er for disse år import af el. Omkring 2020 er import/eksport tæt på nul, hvorefter der er eleksport og derfor bliver de aktuelle emissioner større end de korrigerede.

De vigtigste sektorer i forhold til emission af drivhusgas i 2015 forventes at være energiproduktion og -konvertering (27 %), transport (27 %), landbrug (21 %), og andre sektorer (10 %). For "andre sektorer" er den vigtigste kilde husholdninger (Figur R.2). Drivhusgasemissionerne viser et mindre fald i fremskrivningsperioden 2015 til 2025. De totale emissioner er beregnet til 47,1 millioner tons CO_2-ækvivalenter i 2015 og til 44,6 millioner tons i 2025 svarende til et fald på 5 %. Fra 1990 til 2013 er emissionerne faldet med 21 %.



Figur R.2 Totale drivhusgasemissioner i CO_2-ækvivalenter fordelt på hovedsektorer for 2015 og tidsserier fra 1990 til 2025.

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 2015 (56 %), er beregnet til at falde i perioden 2015 til 2025 (9 %) grundet et delvis brændselsskift fra kul til træ og affald samt et mindre brændselsbehov som følge øget anvendelse af vindkraft og solenergi i elproduktionen. Emissionerne fra husholdningers og fremstillingsindustriers forbrændingsanlæg falder ifølge fremskrivningen også i perioden 2015 til 2025 (henholdsvis 28 % og 18 %). Drivhusgasemissionerne fra andre sektorer vil være næsten konstante i hele perioden med undtagelse af offshore-sektoren, hvor emissioner fra anvendelse af energi til udvinding af olie og gas steg med 145 % fra 1990 til 2013 og forventes at stige med yderligere 14 % fra 2015 til 2025. Det stigende energiforbrug skyldes den langsomme udtømning af olie/gas felterne, som medfører at udvindingen bliver mere energikrævende.

Flygtige emissioner

Emissionen af drivhusgasser fra sektoren "Emissioner af flygtige forbindelser fra brændsler" udviser store fluktuationer i de historiske år 1990-2013, 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 12 % i perioden 2015-2030. 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 2015, og anvendelse af substitutter (f-gasser) for ozonnedbrydende stoffer (ODS), der bidrager med 33 %. 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 fra sektoren transport og andre mobile kilder i 2015 (86 %), og emissionerne fra denne kilde forventes ikke at ændres væsentligt i fremskrivningsperioden 2015 til 2025. Den samlede emission for andre mobile kilder er lave sammenlignet med vejtransport.

Landbrug

Den største kilde i 2015 er emissioner fra dyrenes fordøjelse (36 %), landbrugsjorde (36 %) og gødningshåndtering (26 %). De tilsvarende andele i 2030 forventes at være hhv. 38 %, 35 % og 25 %. Fra 1990 til 2013 er emissionen fra landbrugssektoren faldet med 19 %. I fremskrivningsperioden 2015-2030 forventes emissionerne af stige med 2 %. 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 36 % i perioden 1990 til 2015. Den faldende trend forventes at fortsætte med et fald på 21 % fra 2015 til 2030. I 2015 udgør drivhusgasemissionen fra lossepladser 64 % af den totale emission fra affaldssektoren. Et fald på 46 % er forventet for denne kilde i perioden 2015 til 2030. Dette skyldes, at mindre affald bliver deponeret og at tidligere deponeret affald har afgivet meget af CH_4-potentialet. I 2015 udgør spildevandshåndtering 15 % af sektorens samlede emission. Emissionerne fra biologisk behandling af affald udgør 19 % i 2015 og 35 % i 2030.

LULUCF

LULUCF-sektoren omfatter emissioner fra skovarealer, dyrkede arealer og græsarealer. I 2015 er drivhusgas emissionerne fra dyrkede arealer og græsarealer hhv. 4.336,8 Gg CO_2-ækv og 237,8 Gg CO_2-ækv. Emissionen fra dyrkede arealer forventes at falde med 33 % i fremskrivningsperioden 2015-2030, mens der for emissionen fra græsarealer forventes et fald på 115 % for den samme periode. 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.

Fremskrivningerne af emissioner/optag fra skov udføres af Institut for Geovidenskab og Naturforvaltning ved Københavns Universitet. Fremskrivningerne er ikke inkluderet i denne rapport

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 sulphur dioxide (SO_2), nitrogen oxides (NO_x,) non-methane volatile organic compounds (NMVOC) and ammonia (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), "Projection of greenhouse gas emissions 2011 to 2035" (Nielsen et al., 2013) and "Projection of greenhouse gas emissions 2013 to 2035" (Nielsen et al., 2014). The purpose of the present project, "Projection of greenhouse gas emissions 2014 to 2025" 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 November 2015 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 2013. 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 2013 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 2013 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 21.2 % from 1990 to 2013.

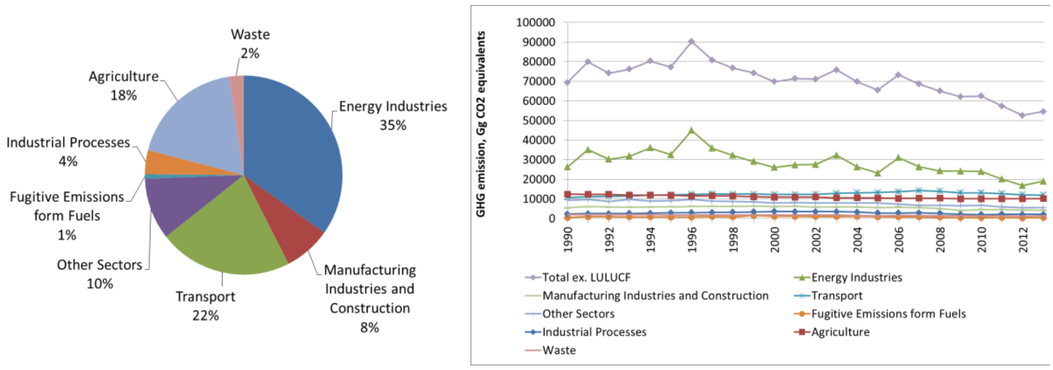


Figure 1.1 Greenhouse gas emissions in CO_2 equivalents distributed on main sectors for 2013 and time series for 1990 to 2013.

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 45 % of the emissions. About 36 % of the CO_2 emission comes from the transport sector. In 2013, the actual CO_2 emission was about 22 % lower than the emission in 1990.

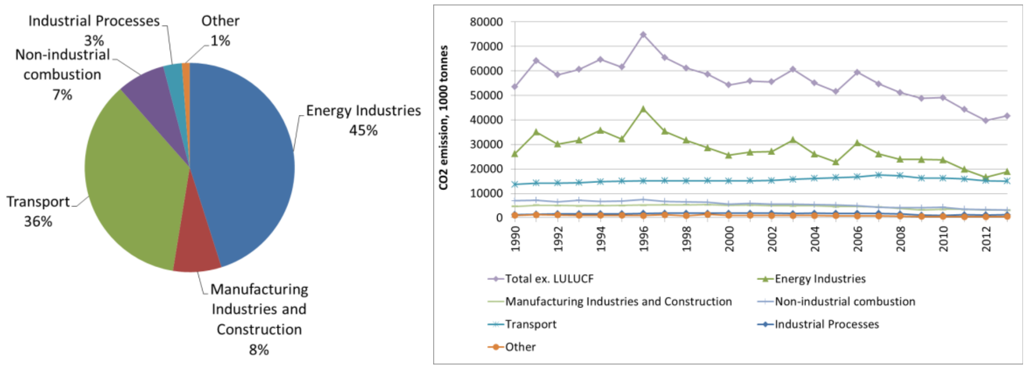


Figure 1.2 CO_2 emissions. Distribution according to the main sectors (2013) and time series for 1990 to 2013.

1.3.2 Nitrous oxide

Agriculture is the most important N_2O emission source in 2013 contributing 88.0 % (Figure 1.3) of which N_2O from soil dominates (73 % of national N_2O emissions in 2013). 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 28.8 % from 1990 to 2013 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 3.2 % in 2013. 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.

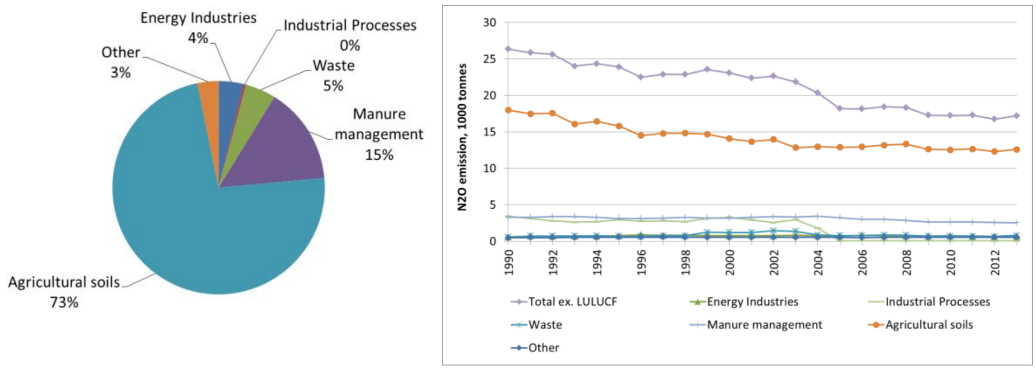


Figure 1.3 N_2O emissions. Distribution according to the main sectors (2013) and time series for 1990 to 2013.

1.3.3 Methane

The largest sources of anthropogenic CH_4 emissions are agricultural activities contributing in 2013 with 67.4 %, waste (13.6 %), and the energy sector (4.1 %). The emission from agriculture derives from enteric fermentation (50.2 % of national CH_4 emissions) and management of animal manure (27.8 % of national CH_4 emissions), and a minor contribution from field burning of agricultural residues, which are included in waste in Figure 1.4.

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 2013, the emission of CH_4 from enteric fermentation has decreased 8.7 % mainly due to the decrease in the number of cattle. However, the emission from manure management has in the same period increased 10.9 % 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 2.6 % from 1990 to 2013.

CH_4 emissions from Waste has decreased by 43.2 % from 1990 to 2013 due to a combination of decreasing emissions from solid waste disposal (52.4 %) and increasing emissions from waste water handling (13.3 %).

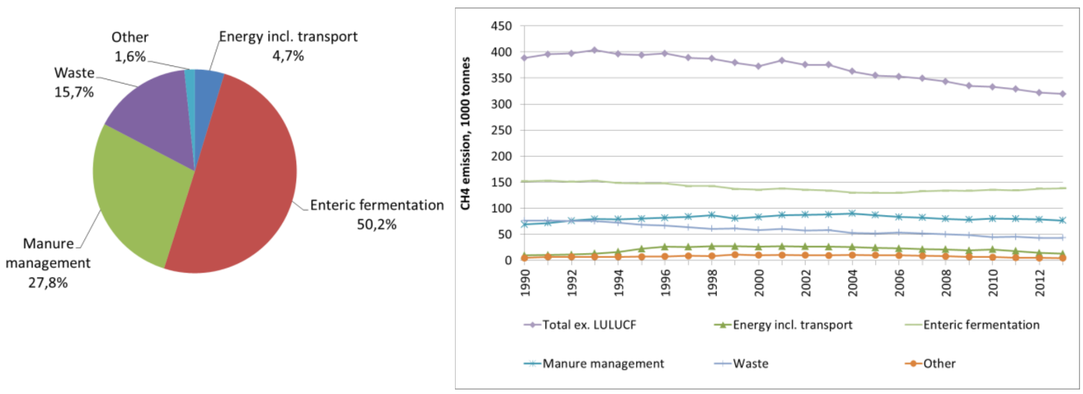


Figure 1.4 CH_4 emissions. Distribution according to the main sectors (2013) and time series for 1990 to 2013.

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 2013 the emission of F-gases expressed in CO_2 equivalents decreased. The increase in emission from 1995 to 2013 is 168 %. 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 2013 was only 14.1 %. The use of HFCs has increased several folds. HFCs have, therefore, become the dominant f-gases, comprising 70 % in 1995, but 85 % in 2013. HFCs are mainly used as a refrigerant. Danish legislation regulates the use of f-gases, e.g. since 1 January 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.

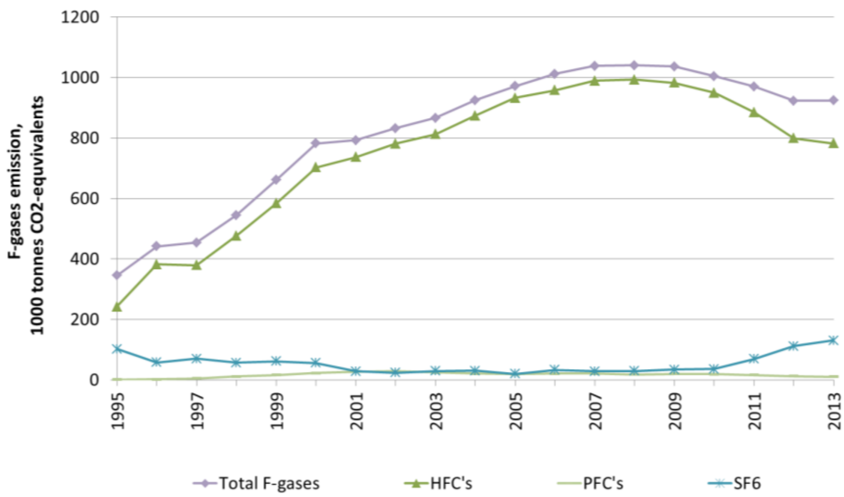


Figure 1.5 F-gas emissions. Time series for 1995 to 2013.

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:

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

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:

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

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).

1.5 References

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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 the 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 2025 (Danish Energy Agency, 2015a) and energy projections for individual plants (Danish Energy Agency, 2015b).

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 Figure 2.1. In addition, the effect of electricity trade has been calculated. This is described in Chapter 3.6.

Natural gas is the most important fuel through the beginning of the time series. After 2015, wood and similar wood wastes are expected to exceed steam coal as the second most important fuel and in 2018 it passes natural gas as the most important fuel. The largest variations are seen for coal use, biogas and wood. Coal use peaks in 2014 and decreases significantly until 2020, thereafter it increases slightly. For biogas the projected consumption increases throughout the period as a whole.

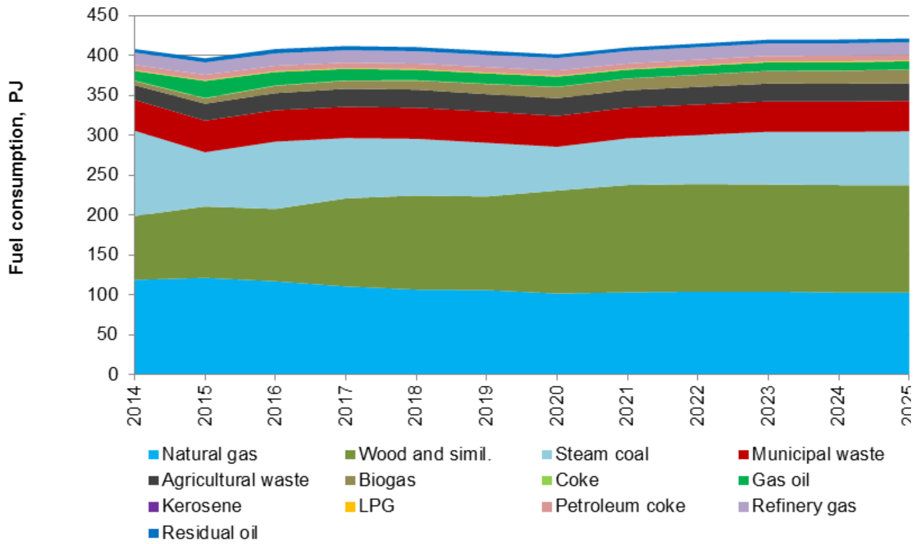

Figure 2.1 Projected energy consumption by fuel type.

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 oil/gas extraction.

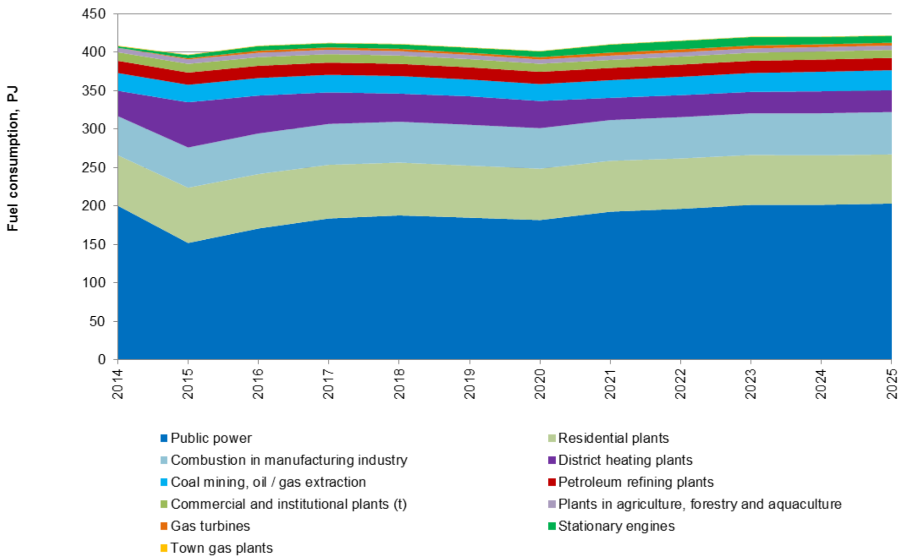

Figure 2.2 Energy use by sector.

2.4 Emission factors

2.4.1 Area sources

In general, emission factors for area sources refer to the emission factors for 2013 applied in the 2015 emission inventory (Nielsen et al., 2015).

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 2006-2013 emission factors have been applied rather than including only the 2013 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 2013 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 2013-2025.

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 2013.

SNAP	Fuel	GHG	IEF
0101	Residual oil	CH_4	2.5
0101	Gas oil	CH_4	10.5
0101	Biogas	CH_4	389
0103	Refinery gas	CH_4	1.1
0201	Biogas	CH_4	236
0203	Biogas	CH_4	366
03	Gas oil	CH_4	0.61
03	Biogas	CH_4	39
0101	Residual oil	N_2O	2.3
0101	Gas oil	N_2O	1.1
0101	Biogas	N_2O	1.4
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	1.4
03	Gas oil	N_2O	0.43
03	Biogas	N_2O	0.23

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 factors are implied emission factors for the current technology distribution for biogas fuelled plants.

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. (2015).

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 factor for CH_4, which causes the emissions from residential wood combustion to decrease substantially from 2014 to 2025.

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.

For natural gas fuelled engines the applied CH_4 emission factor is 3.5 % higher than the emission factor applied for 2013. The increase is a result of the increased NO_x tax that has resulted in changed engine settings for some plants. This will influence the CH_4 emission (Kvist, 2012; Kristensen, 2013)[1].

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*.

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

The total emission in CO_2 equivalents for stationary combustion is shown in Table 2.3.

Table 2.3 Greenhouse gas emissions, Gg CO_2 equivalents.

Sector	1990	1995	2000	2005	2010	2013	2014	2015	2020	2025
Public electricity and heat production	24 789	30 424	23 565	20 577	21 659	16 705	13 137	10 343	8283	9449
Petroleum refining plants	908	1388	1001	939	855	951	928	928	928	928
Oil/gas extraction	552	755	1479	1632	1501	1350	1369	1346	1297	1535
Commercial and institutional plants	1420	1166	928	990	884	763	423	424	359	349
Residential plants	5113	5114	4147	3825	3331	2255	2116	2232	1816	1598
Plants in agriculture, forestry and aquaculture	618	733	799	672	369	296	208	211	194	195
Combustion in industrial plants	4662	5134	5223	4656	3522	3157	3092	3093	2649	2638
Total	38 062	44 715	37 142	33 292	32 122	25 477	21 273	18 575	15 526	16 690

From 1990 to 2025, the total emission falls by approximately 21 400 Gg (CO_2 eqv.) or 56 % due to fossil fuels (mainly coal and natural gas) being partially replaced by renewable energy. The emission projections for the three GHGs are shown in Figures 2.3-2.8 and in Tables 2.4-2.6, together with the historic emissions for 1990, 1995, 2000, 2005 and 2010 (Nielsen et al., 2015).

[1] It has been assumed that the engine settings will not be changed once again after the decrease of the NO_x tax.

2.5.1 CO_2 emissions

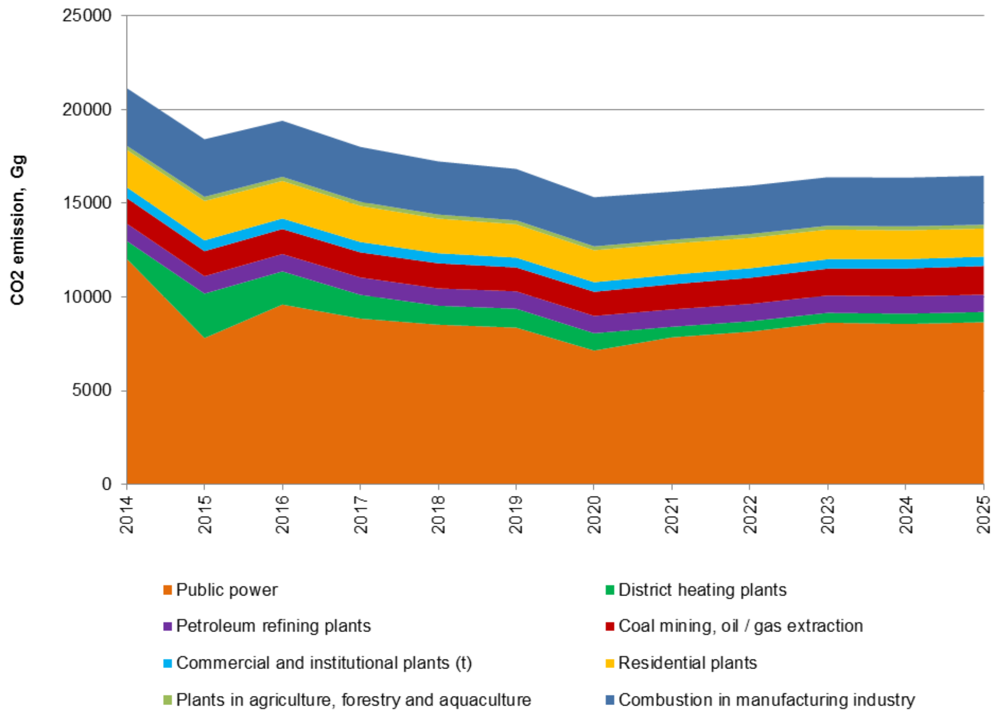

Figure 2.3 CO_2 emissions by sector.

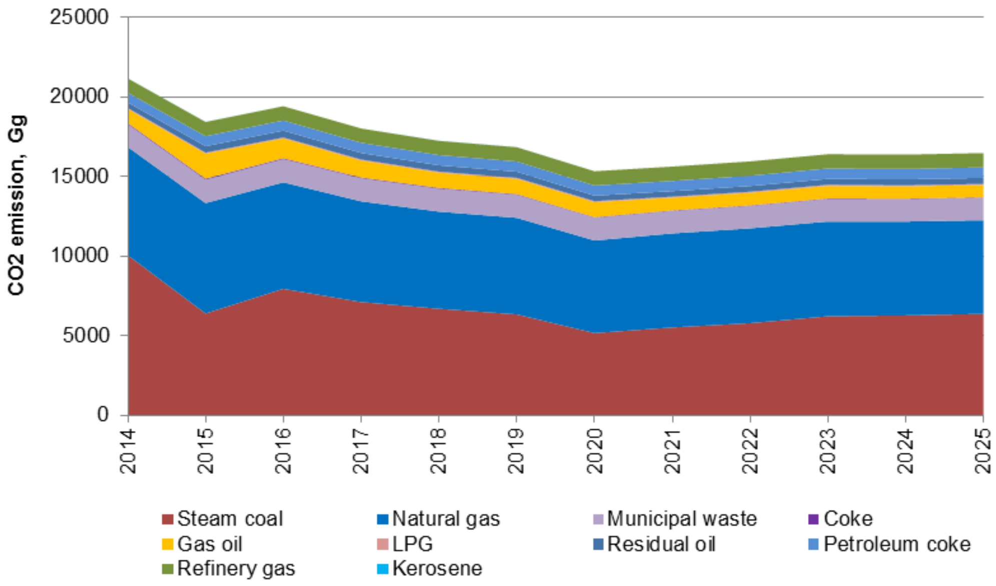

Figure 2.4 CO_2 emissions by fuel.

Table 2.4 CO_2 emissions, Gg.

Sector	1990	1995	2000	2005	2010	2013	2014	2015	2020	2025
Public electricity and heat production	24 695	30 038	23 105	20 175	21 283	16 477	13 004	10 184	8068	9205
Petroleum refining plants	906	1384	998	938	854	950	926	926	926	926
Oil/gas extraction	545	746	1461	1619	1492	1342	1361	1338	1290	1526
Commercial and institutional plants	1413	1143	901	963	861	748	416	416	349	338
Residential plants	4965	4943	3987	3622	3108	2089	1976	2079	1687	1482
Plants in agriculture, forestry and aquaculture	585	688	732	613	330	265	185	187	170	170
Combustion in industrial plants	4606	5061	5135	4583	3464	3110	3064	3063	2613	2599
Total	37 714	44 005	36 319	32 512	31 392	24 980	20 932	18 193	15 103	16 246

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 public electricity and heat production, which contributes with about 66 % in 2013 to the total emissions from stationary combustion plants. Other important sources are combustion plants in industry, residential plants and oil/gas extraction. The emission of CO_2 decreases by 22 % from 2014 to 2025 due to lower fuel consumption and a fuel shift from coal and natural gas to wood and biogas.

2.5.2 CH_4 emissions

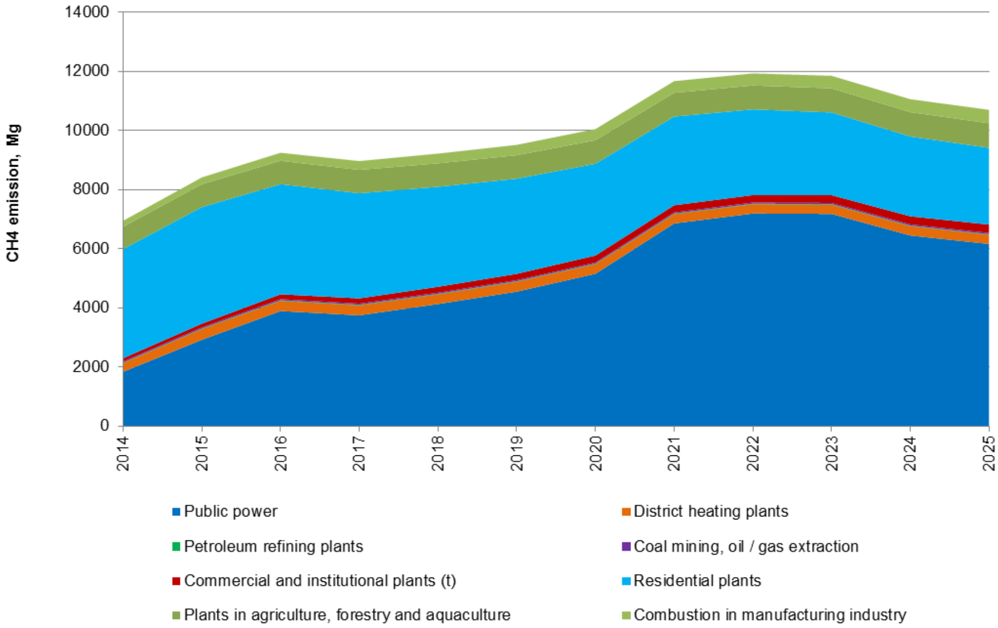

Figure 2.5 CH_4 emissions by sector.

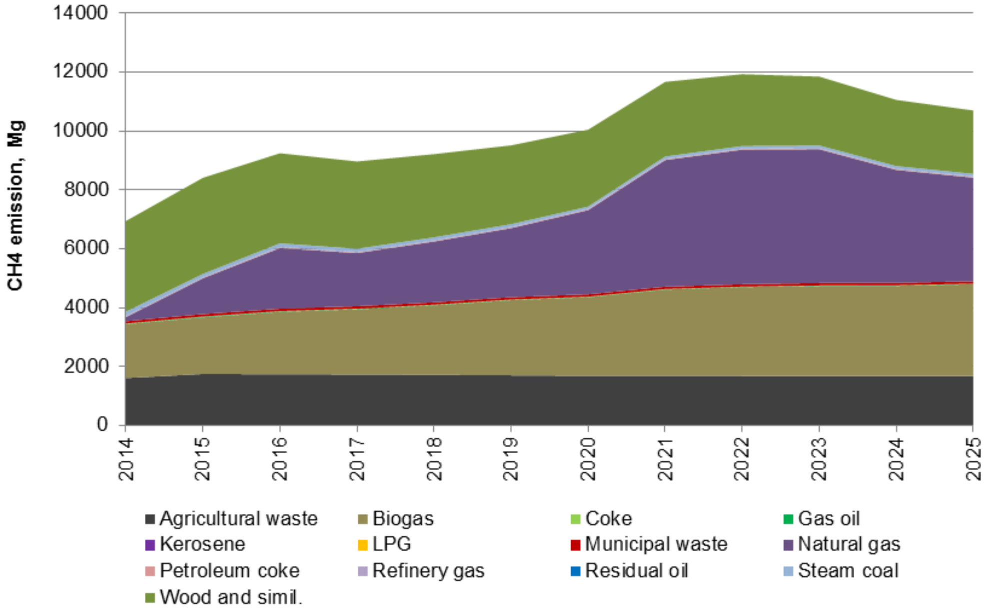

Figure 2.6 CH_4 emissions by fuel.

Table 2.5 CH_4 emissions, Mg.

Sector	1990	1995	2000	2005	2010	2013	2014	2015	2020	2025
Public electricity and heat production	596	11 369	14 632	12 376	10 945	5544	2127	3280	5478	6473
Petroleum refining plants	18	30	21	19	17	19	18	18	18	18
Oil/gas extraction	16	19	38	48	44	40	40	39	38	45
Commercial and institutional plants	114	672	905	824	691	417	108	126	234	281
Residential plants	4683	5434	5006	6213	6519	4641	3695	3944	3106	2599
Plants in agriculture, forestry and aquaculture	1085	1577	2462	2183	1380	1085	757	776	798	832
Combustion in industrial plants	273	347	1024	828	536	338	201	228	375	452
Total	6786	19 447	24 090	22 491	20 132	12 083	6945	8411	10 046	10 700

The two largest sources of CH_4 emissions are public power and residential plants. This fits well with the fact that natural gas and biogas, especially when combusted in gas engines and wood when used in residential plants are the fuels contributing 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. The 2014 emission for natural gas is underestimated due to a misallocation in the emission calculation with too much natural gas being allocated to boilers instead of 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.

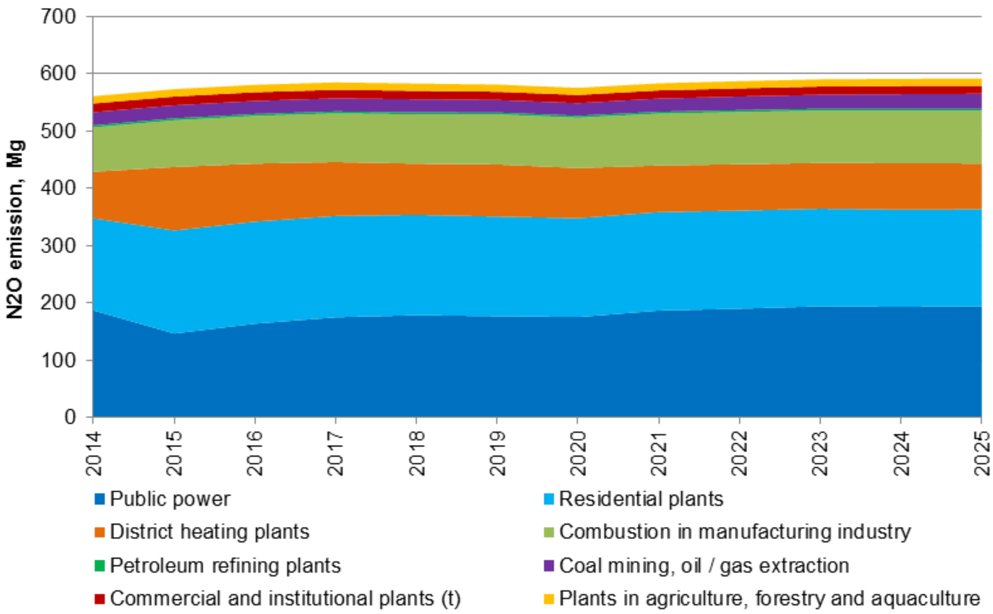

Figure 2.7 N_2O emissions by sector.

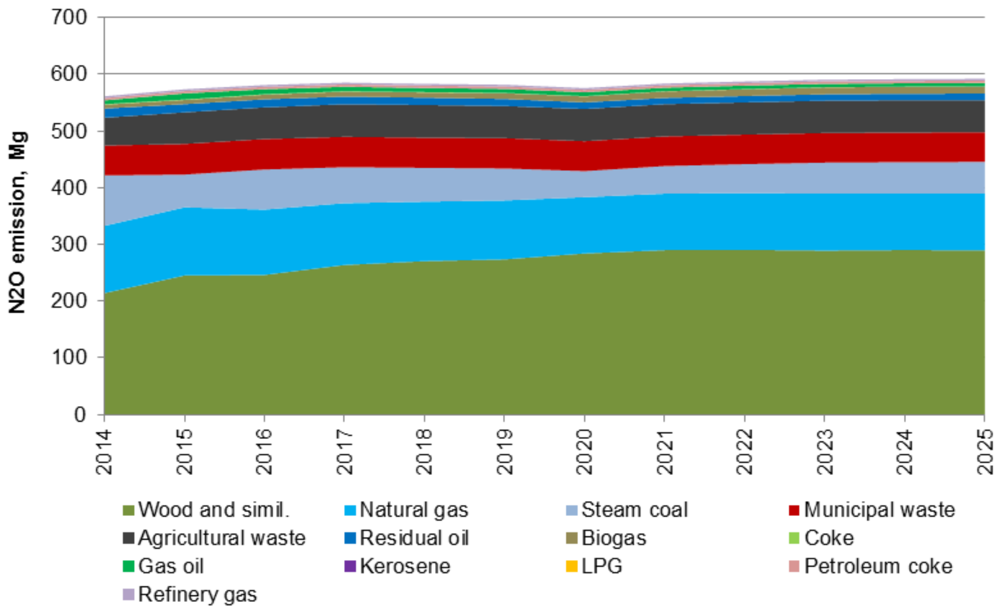

Figure 2.8 N_2O emissions by fuel.

Table 2.6 N_2O emissions, Mg.

Sector	1990	1995	2000	2005	2010	2013	2014	2015	2020	2025
Public electricity and heat production	265	343	317	312	345	301	268	258	263	274
Petroleum refining plants	2	8	7	5	3	4	3	3	3	3
Oil/gas extraction	21	29	56	39	26	23	23	23	22	26
Commercial and institutional plants	17	19	15	20	18	16	15	15	14	14
Residential plants	106	118	118	162	201	168	161	180	173	169
Plants in agriculture, forestry and aquaculture	21	18	17	16	14	14	13	13	12	13
Combustion in industrial plants	166	216	210	176	152	128	78	81	88	92
Total	598	751	740	730	760	654	561	573	575	592

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 2.9.

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 2.7.

Table 2.7. Tables in the 'Fremskrivning 2014-2025'.

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 2.8.

Table 2.8 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 2014-2025' (Figure 2.10). The outputs from the summation queries are Excel tables.

Table 2.9 Summation queries.

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

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.

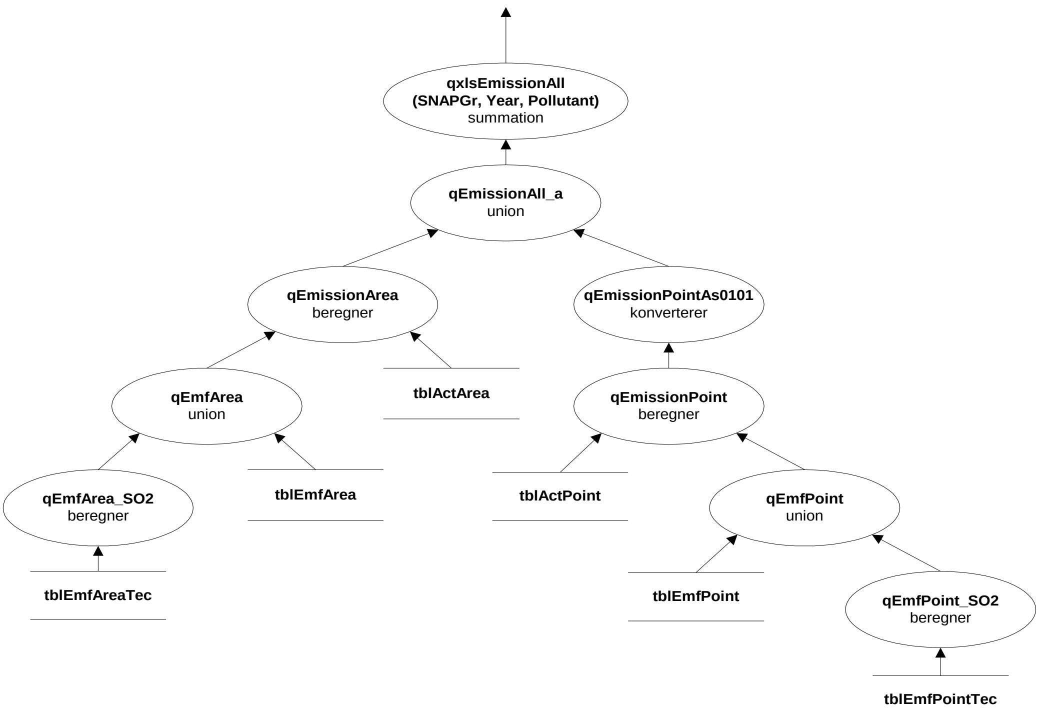

Figure 2.9 The overall construction of the database.

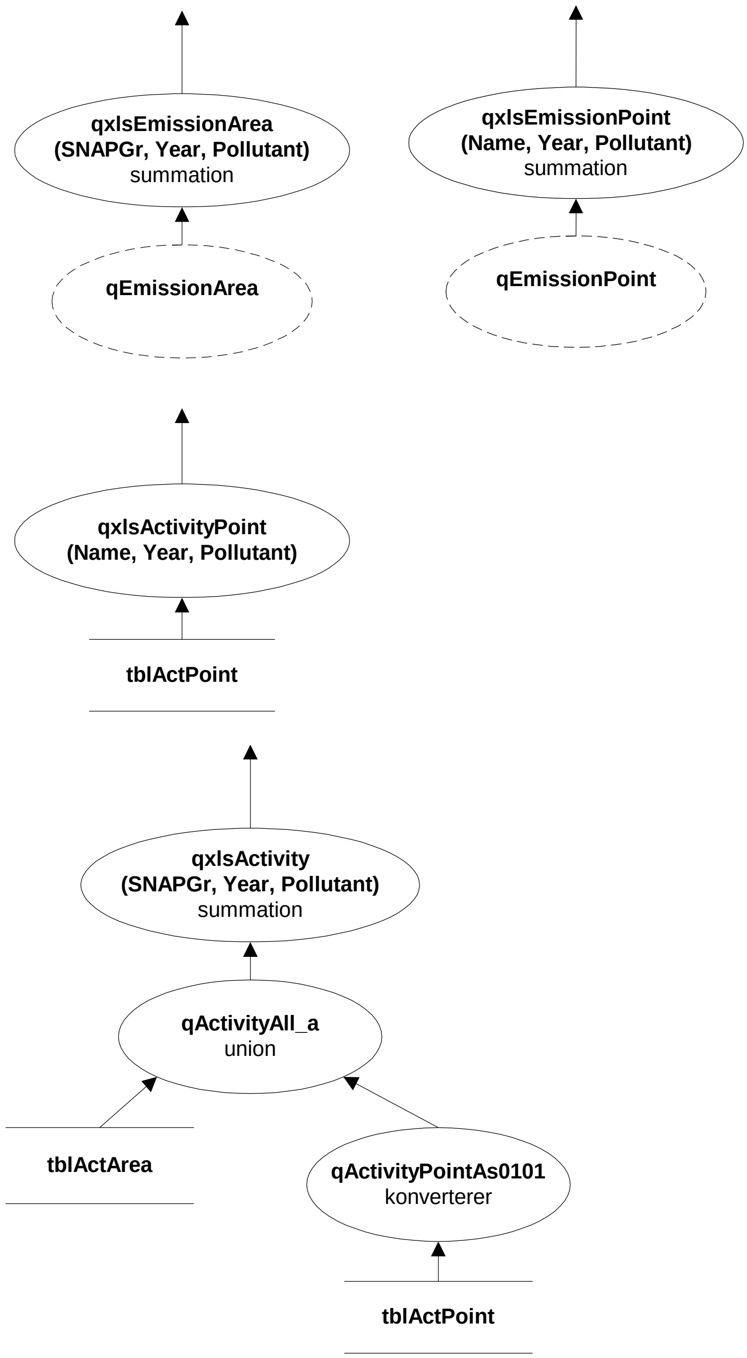

Figure 2.10 Summation queries.

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 2015. This update cause only minor recalculations.

The CO_2 emission factor for natural gas has been updated to the value for 2014.

Finally, the EU ETS data for 2013 have been implemented for coal, residual oil, refinery gas and for natural gas applied in offshore gas turbines.

2.8 Electricity trade

Due to the open electricity market, there are significant inter-annual variations in the projection of the Danish fuel consumption and hence the emissions. The development in the fuel consumption associated with electricity export is shown in Figure 2.11 below.

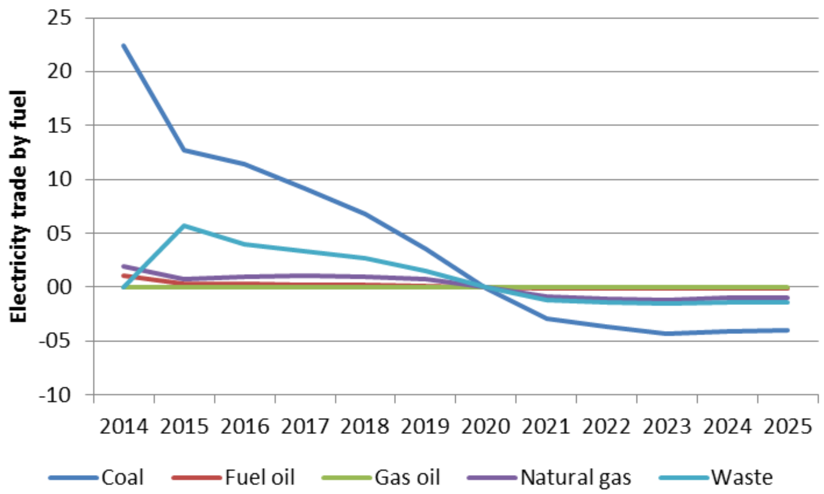

Figure 2.11 Projection of fuel consumption associated with electricity trade, PJ. Positive values indicate electricity import.

The associated CO_2 emissions are calculated based on the standard emission factors as presented in Chapter 3.3. It is not possible to distribute the fuel consumption on technology types and therefore the effect on CH_4 and N_2O has not been estimated. Figure 2.12 below shows the CO_2 emission associated with electricity trade.

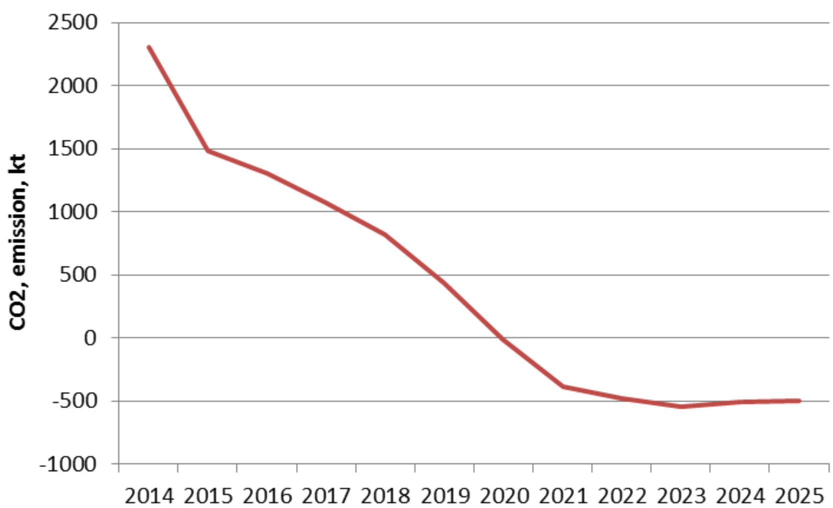

Figure 2.12 Projection of CO_2 emission associated with electricity trade.

2.9 References

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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 from fuels 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. Detailed descriptions of the emission inventory for the historical years are included in Plejdrup et al. (2009) and Nielsen et al. (2015).

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 from the fugitive emission sector.

IPCC sectors	SNAP code	SNAP name	Activity
1 B 1 a	050103	Storage of solid fuel	Coal (storage)
1 B 2 a 1	050204	Exploration of oil	Oil
1 B 2 a 2 / 1 B 2 a 3	050202	Off-shore activities	Oil
1 B 2 a 4	040101	Petroleum products processing	Oil
1 B 2 a 4	040103	Other processes in petroleum industries	Oil
1 B 2 a 4	040104	Storage and handling of petroleum produc. in refinery	Oil
1 B 2 a 5	050503	Service stations (including refuelling of cars)	Oil
1 B 2 b 1	050304	Exploration of gas	Natural gas
1 B 2 b 2	050303	Off-shore activities	Natural gas
1 B 2 b 4	050601	Pipelines	Natural gas (transmission)
1 B 2 b 5	050603	Distribution networks	Natural gas (distribution)
1 B 2 c 2 1 ii	050699	Venting in gas storage	Venting
1 B 2 c 2 i	090203	Flaring in oil refinery	Flaring
1 B 2 c 2 ii	090206	Flaring in oil and gas extraction	Flaring
1 B 2 c 2 ii	090298	Flaring in gas storage	Flaring
1 B 2 c 2 ii	090299	Flaring in gas transmission and distribution	Flaring

3.1 Methodology

The methodology for the emission projection corresponds to the methodology in the annual emission inventory, based on the IPCC Guidelines (IPCC, 2006) and the EMEP/EEA Guidebook (EMEP/EEA, 2013).

Activity data are based on official forecasts by the Danish Energy Agency on production of oil and gas, and on flaring in upstream oil and gas production (the oil and gas prognosis, DEA, 2015a), and on fuel consumption (the energy consumption prognosis, DEA, 2015b).

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, 2015b) 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 2030 as in 2015. The prognosis includes production from existing fields and discoveries based on existing technology, 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 flaring in upstream oil and gas production. According to the DEA projection, the flaring amounts are expected to show a slight decrease over the projection period. Flaring and venting related to exploration of oil and gas is not included in the oil and gas prognosis, and therefore this activity is not included in the projection.

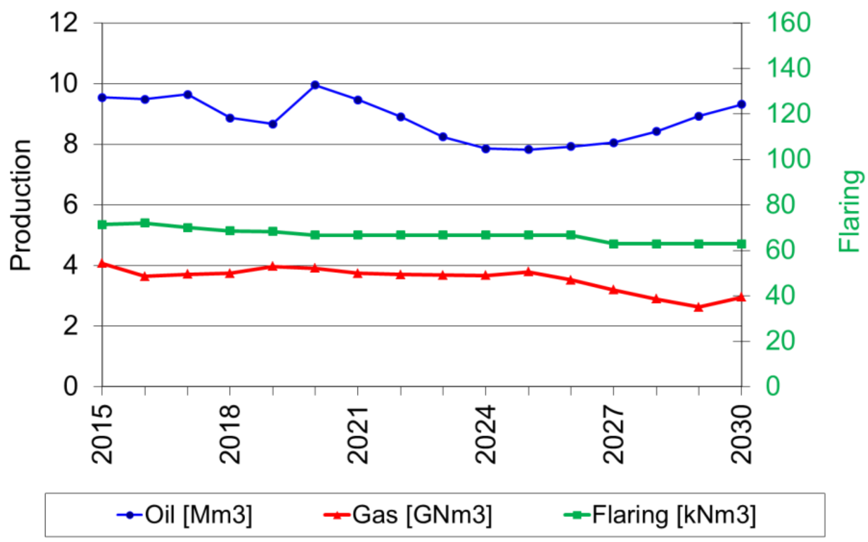

Figure 3.1 Prognosis for the production of oil and gas (DEA, 2015b).

The DEA prognosis of the productions 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 flaring in upstream oil and gas production.

Data from the energy consumption prognosis by the DEA (2015a) are applied in the projection of fugitive emissions from fuels for the sources transmission of natural gas, and distribution of natural gas and town gas. Consumption of natural gas is used as proxy to project transmission of natural gas and the consumption of town gas is used as a proxy for the fugitive losses from town gas distribution.

The fuel consumption and flaring rates for refineries are assumed to be constant for the projection period according to the DEA prognosis (DEA, 2015a).

3.3 Emission factors

For some sources the emission factors are based on the IPCC Guidelines (IPCC, 2006) and the EMEP/EEA Guidebook (EMEP/EEA, 2013). This is the case for onshore and offshore loading of oil to ships and flaring in upstream oil and gas production. For loading of ships the EMEP/EEA 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 raw oil terminal by 53 % (Spectrasyne Ltd, 2010). CH_4 emissions from the raw oil terminal in the projection period are estimated as the emission in the latest historical year scaled to the annual oil production. The standard emission factor from IPCC (2006) for CO_2 from transport of oil in pipelines is applied.

Table 3.2 Emission factors for 2011-2030.

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 in upstream oil and gas production and at refineries are based on EU-ETS for the emission inventory for historical years. For calculation of CO_2 emissions from flaring in upstream oil and gas production, the average emission factor based on EU-ETS data for 2010-2014 is applied for the projection years.

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

The N_2O emission factor is taken from the EMEP/EEA Guidelines (2013) for flaring in upstream oil and gas production and at refineries.

In the projection of emissions from refineries (processing and flaring) the emission factor for the latest historical year are applied, in correspondence with the approach in the energy consumption prognosis, where the activity and flaring rates for refineries are kept constant for the projection period, at the level for the latest historical year.

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 of natural gas, distribution of natural gas and town gas, processing and flaring at refineries, 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 five historical years (only the last historical year for refineries, see Section 3.3), 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.

Figure 3.2 include CH_4 emission on sub-sector level in selected historical years and projection years. The total fugitive CH_4 emission is expected to show a little decrease in the projection period. The decrease is mainly caused by a decrease in production of gas, which contribute to lower the CH_4 emissions from offshore extraction and offshore loading of ships.

The fuel consumption and flaring amounts for refineries are assumed to be constant for the projection period according to the DEA prognosis (DEA, 2015a), and correspondingly the emissions from fugitive emissions and flaring in refineries for 2014 are applied for the projection years 2015-2030.

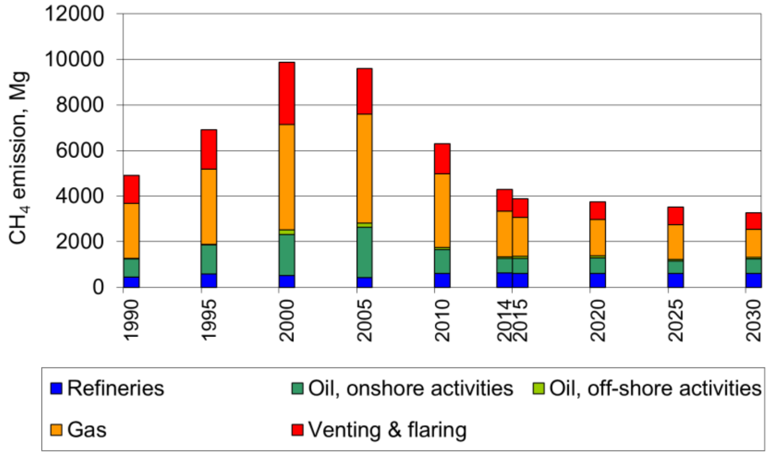

Figure 3.2 CH_4 emissions in selected historical years (1990, 1995, 2000, 2005, 2010, 2014, including exploration of oil and gas) and projection years (2015, 2020, 2025, 2030, excluding exploration of oil and gas).

By far the major source to fugitive emissions of CO_2 is flaring upstream oil and gas production (Figure 3.3). CO_2 emissions peaked in 1999 and have shown a decreasing trend over the following historical years. In the projection years the annual emission from flaring in upstream oil and gas production is rather constant. The increase from the latest historical year 2014 and the first projection year 2015 owe to the applied methodology in the projection. The CO_2 emission from offshore flaring is estimated from the projected flaring rates (DEA, 2015b) and an average emission factor for the years 2010-2014. The CO_2 emission factor in 2014 was 2.684 kg/Nm^3, while the average emission factor applied in the projection years is 2.744 kg Nm^3.

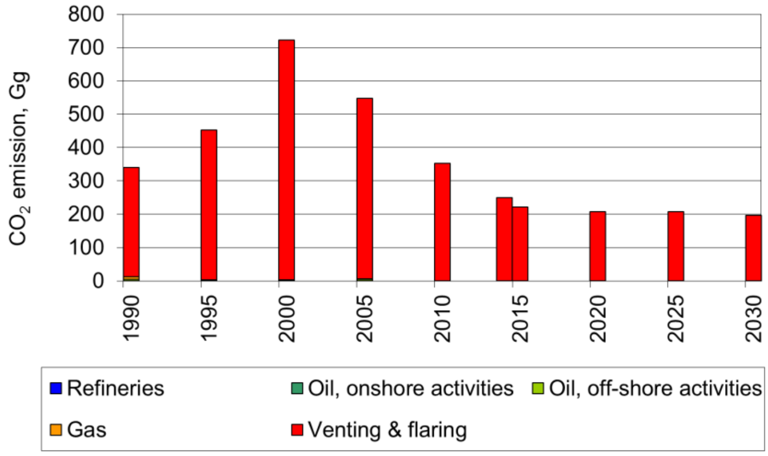

Figure 3.3 CO_2 emissions in selected historical years (1990, 1995, 2000, 2005, 2010, 2014, including exploration of oil and gas) and projection years (2015, 2020, 2025, 2030, excluding exploration of oil and gas).

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 upstream oil and gas production, 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 in upstream oil and gas production, at 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 to a less degree 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.

Emissions from exploration of oil and gas are not included in the projected emissions, but only in historical years. The maximum CH_4 emission from exploration occurred in 2002, where this source contributed 0.98 % of the total fugitive CH_4 emission (second and third highest emission occurred in 1990 and 2005 and contributed 0.63 % and 0.08 %, respectively).

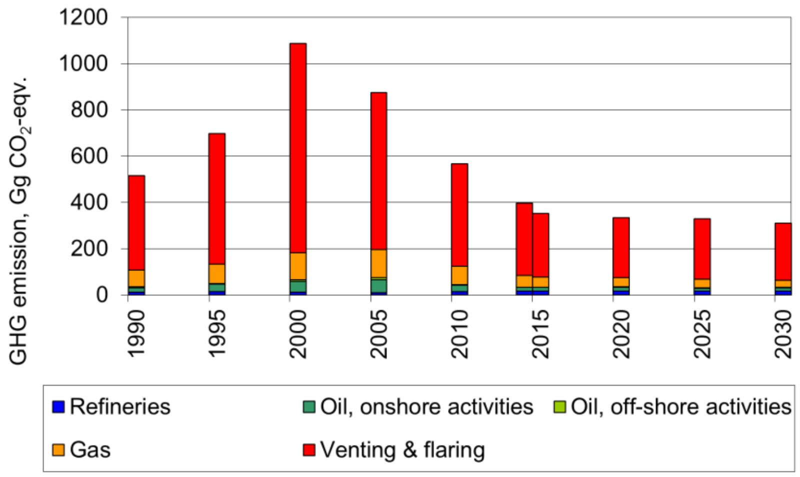

Figure 3.4 GHG emissions in selected historical years (1990, 1995, 2000, 2005, 2010, 2014, including exploration of oil and gas) and projection years (2015, 2020, 2025, 2030, excluding exploration of oil and gas).

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 3.3 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 plus prognosis and projected activity rates and emission factors for the projection years. Further, the resulting emissions for 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.
Gas losses	Activity data and emission factors for transmission and distribution of natural gas and town gas for the historical years.

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, 2015a: Energy consumption prognosis 2015-2035, November 2015.

Danish Energy Agency, 2015b: Oil and gas production prognosis 2015-2035, November 2015.

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

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Spectrasyne Ltd, 2009: Fugitive Hydrocarbon Emission Survey of 8 Crude Oil Storage Tanks at DONG, Frederica. 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, 2E Electronics Industry, 2F Product Use as Substitutes for Ozone Depleting Substances* and *2G Other Product Manufacturing and Use*. 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
		2A4b Other uses of soda ash	04 06 19
		2A4d Flue gas cleaning	04 06 18
		2A4d Stone wool production	04 06 18
2B	Chemical industry	2B10 Catalysts/fertilisers	04 04 16
2C	Metal industry	2C5 Lead production	03 03 07
2D	Non-energy products from fuels and solvent use	2D1 Lubricant use	06 06 04
		2D2 Paraffin wax use	06 06 04
		2D3 Other	06 04 00
		Solvent use	04 06 10
		Asphalt roofing	04 06 11
		Road paving with asphalt	
2E	Electronics Industry	2E5 Fibre optics	06 05 08
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
		2F5 Solvents	06 05 08
2G	Other product manufacture and use	2G1 Electrical equipment	
		2G1b Use of electrical equipment	06 05 07
		2G2 SF_6 and PFCs from product use	
		2G2c Double-glazed windows	06 05 08
		2G3 N_2O from product use	
		2G3a Medical applications	06 05 01
		2G4 Other product use	
		Fireworks	06 06 01
		Barbeques	06 06 04
		Tobacco	06 06 02

The projection of emissions from industrial processes is based on the national emissions inventory (Nielsen et al., 2015).

4.2 Methodology

The projection of greenhouse gas (GHG) emissions includes CO_2, N_2O, NMVOC, HFCs, PFCs 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, 2015a; 2015b).

For HFCs, PFCs and SF_6, also known as F-gases, emission projections are based on an F-gas projection done by Poulsen (2015).

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

The fluorinated gases 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.

For more detailed information on the methodologies and sources used within the different categories, find the relevant category descriptions in the sections 4.2.2 to 4.2.7 below.

4.2.1 F-gases

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, 2015). In this connection, projections to 2030 are also prepared. Annual reports that contain both consumption and emission data are available.

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 in this report 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.

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 Nielsen et al. (2015). As a result, the model corresponds with the guidelines produced for this purpose. For details on 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 (2015) provide 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 1 January 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 1 January 2000, building new HCFC-22-based systems has not been permitted and from 1 January 2002 substitution with HCFC-22 in existing systems has been banned.

It should be noted that the basic data for the years before 1995 are 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.

4.2.2 2A – Mineral Industry

There are nine sources of GHG emissions within the CRF category *2A Mineral Industry*; production of cement, lime, glass, glass wool, bricks/tiles, 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 4.2 Sources/processes included in *2A Mineral Industry*.

		Sources/processes
2A1	Cement production	Cement production
2A2	Lime production	Lime production (incl. lime produced in the sugar industry)
2A3	Glass production	Glass production
		Glass wool production
2A4	Other process uses of carbonates	Ceramics
		Production of bricks/tiles
		Production of expanded clay
		Other uses of soda ash
		Flue gas cleaning
		at CHPs
		at WIPs
		Mineral wool production

CHP: Central Heating Plants, WIP: Waste Incineration PlantS.

Cement production is the major CO_2 source within industrial processes. Information on the emission of CO_2 in 2014 is based on the company report to EU-ETS (Aalborg Portland, 2015). The emission for 2015-2035 is estimated by extrapolating the average value for the historical years 2010-2014 with a factor based on projected production values for "cement industry" (Danish Energy Agency, 2015b).

Table 4.3 Extrapolation factors for estimation of CO_2 emissions from industrial processes based on production and energy value projections by Danish Energy Agency (2015a; 2015b).

	Steel industry	Glass industry	Cement industry	Building and construction	Central plants CHP, Coal/coke	Decentral plants WIP, Waste
2013	1	1		1	1	1
2014	1.04	1.04	1	1.05	0.89	1.00
2015	1.09	1.09	1.01	1.06	0.87	1.00
2016	1.12	1.11	1.06	1.11	0.86	1.00
2017	1.15	1.15	1.11	1.16	0.52	1.00
2018	1.20	1.19	1.16	1.21	0.47	0.99
2019	1.25	1.24	1.21	1.26	0.44	0.99
2020	1.26	1.25	1.25	1.31	0.30	1.00
2021	1.30	1.29	1.28	1.34	0.31	1.02
2022	1.34	1.33	1.30	1.36	0.30	1.02
2023	1.35	1.34	1.32	1.38	0.29	1.00
2024	1.35	1.34	1.33	1.39	0.26	1.00
2025	1.35	1.34	1.34	1.40	0.26	1.00
2026	1.37	1.35	1.35	1.41	0.18	1.00
2027	1.38	1.37	1.36	1.42	0.16	0.99
2028	1.38	1.36	1.38	1.44	0.16	0.99
2029	1.38	1.36	1.39	1.45	0.16	0.99
2030	1.41	1.40	1.41	1.47	0.17	0.99
2031	1.40	1.39	1.43	1.49	0.19	0.99
2032	1.40	1.39	1.43	1.50	0.16	0.98
2033	1.38	1.37	1.44	1.51	0.18	0.98
2034	1.37	1.36	1.45	1.52	0.19	0.98
2035	1.43	1.42	1.47	1.54	0.19	0.98

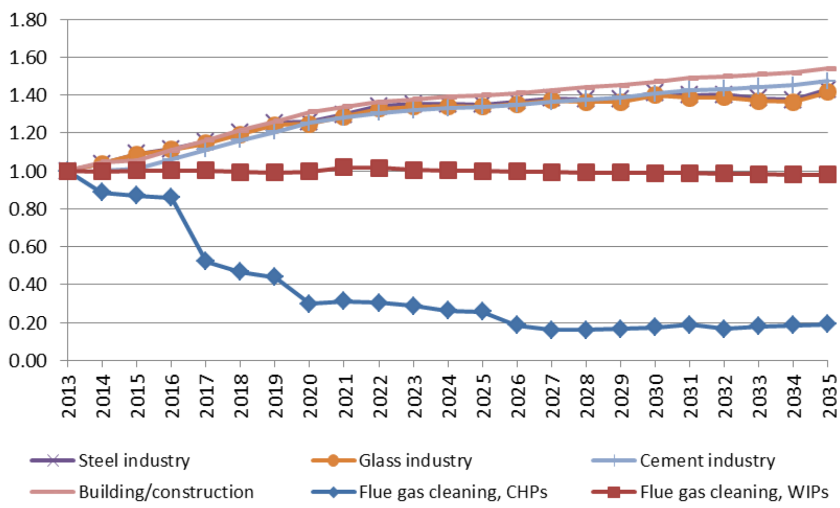

Figure 4.1 Extrapolation factors for estimation of CO_2 emissions from industrial processes based on production and energy value projections by Danish Energy Agency (2015a; 2015b).

Lime is used for a number of different applications. There are no projected production values available for lime production and the emission for 2014-2035 is therefore estimated to be the constant average value for 2009-2013. Like lime, soda ash has many applications and like lime, the category of "other uses of soda ash" is projected as the average emission for the years 2009-2013.

Glass is mainly produced for packaging. 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 "glass industry" (Danish Energy Agency, 2015b); see Table 4.3 and Figure 4.1.

Production of building materials i.e. glass wool, bricks/tiles, expanded clay products and stone wool contributes significantly to industrial process emissions. The emissions for 2014-2035 are estimated individually for the four sources by extrapolating the respective average value for the historical years 2009-2013 with a factor based on projected production values for "building and construction" (Danish Energy Agency, 2015b); see Table 4.3 and Figure 4.1.

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 2014-2035 are estimated individually for the two sources by extrapolating the average value for the historical years 2009-2013 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 4.10 and Table 4.11.

4.2.3 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*.

There are no projected production values available for the production of catalysts/fertilisers; the emission for 2014-2035 is therefore estimated to be the constant average value for 2009-2013.

Historically the emission in CO_2 equivalents declines sharply in 2004 as the production of nitric acid ceased in mid-2004 (Kemira, 2004).

Calculated emission projections are shown in Table 4.10.

4.2.4 2C – Metal Industry

There has been no production at Danish steelworks since 2006. There is also no planned reopening of these productions. There is however a small emission of CO_2 from lead production that is projected as the constant average of the years 2009-2013.

Calculated emission projections are shown in Table 4.10.

4.2.5 2D – Non-Energy Products from Fuels and Solvent Use

This category includes CO_2, CH_4, 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 and Asphalt roofing.

Table 4.4 Global Warming Potentials (GWPs) for substances in category 2D.

Substance:	Typical use	GWP CO_2 eqv.
CO_2	Lubricants, Paraffin wax use	1
CH_4	Paraffin wax use	25
N_2O	Paraffin wax use	298

The contribution to GHG emissions from NMVOC is based on carbon content in the VOCs respectively and a calculation into CO_2, NMVOC is therefore not included in Table 4.4.

The projections are based on the average emission of the historical years 2009-2013. Calculated emission projections are shown in Table 4.10.

4.2.6 2E – Electronic Industry

Fibre optics is the only source in CRF category 2E. Fibre optics leads to emissions of both HFC (HFC-23) and PFCs (PFC-14 and PFC-318) and is projected by Poulsen (2015).

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

Substance:	Typical use	GWP CO_2 eqv.
HFC-23	Fibre optics	14 800
PFC-14	Fibre optics	7 390
PFC-318	Fibre optics	10 300

Calculated emission projections are shown in Table 4.10.

4.2.7 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 six HFCs (HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-152a and unspecified HFCs) and one PFC (PFC-218).

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 4.6 Global Warming Potentials (GWPs) for the HFCs.

Substance:	Typical use	GWP CO_2 eqv.
HFC-32	Refrigeration (K2)	675
HFC-125	Refrigerants (K1-4)	3,500
HFC-134a	Refrigerants (K1-4), foam blowing and aerosols	1,430
HFC-143a	Refrigerants (K1-4)	4,470
HFC-152a	Refrigerants (K2) and foam blowing	124
Other HFCs	Refrigerants (K2)	2,088

However, HFCs in Denmark are estimated in accordance with the trade names for HFC mixtures, Table 4.7 provides the "pure" HFC content of the mixtures.

Table 4.7 Relationship (mass %) between HFCs, as calculated for the Climate Convention ("'pure" HFCs) and the HFC mixtures used under trade names in Denmark.

HFC mixtures \ Pure HFCs	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 *2E Electronic Industry*.

PFCs

PFCs comprise a range of substances, of which only PFC-218 (C_3F_8) 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 8,830; 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 *2E Electronic Industry*.

Calculated emission projections from *product uses as substitutes for ODS* are shown in Table 4.10 and Table 4.12.

4.2.8 2G – Other Product Manufacture and Use

There are four sources of GHG emissions within the CRF category *2G Other Product Manufacture and Use*; "use of electrical equipment", "SF_6 from other product uses", "N_2O from product uses" and "other product uses".

Table 4.8 Sources/processes included in *2G Other Product Manufacture and Use*.

		Sources/processes
2G1	Electrical equipment	Use of electrical equipment
2G2	SF_6 and PFCs from other product use	SF_6 from other product uses:
		Double glazed windows
		Laboratories/research
		Running shoes
2G3	N_2O from product uses	N_2O from medical applications
		Propellant for pressure and aerosol products
2G4	Other	Other product uses
		Fireworks
		Tobacco
		Charcoal for barbeques

The different substances reported within category 2G are shown in Table 4.9 along with their typical use and their respective GWPs.

Table 4.9 Global Warming Potentials (GWPs) for substances in category 2G.

Substance:	Typical use	GWP CO_2 eqv.
CO_2	Fireworks	1
CH_4	Fireworks, tobacco, charcoal for BBQs	25
N_2O	Anaesthetics, propellant, fireworks, tobacco, charcoal for BBQs	298 anaesthetics projection for this source is calculated as the constant average of the five latest historical years, 2008-2012.474747
SF_6	High voltage electrical equipment, double glazing, laboratories/research, running shoes	22,800

The annual F-gas report from Poulsen (2015) contains both SF_6 consumption and emission data for both historic years and projected years until 2030. For more details on this report and the model it is based on, see the section on F-gasses under Section 4.2 Methodology.

The emission projections for the sources "use of electrical equipment" and "SF_6 and PFCs from other product use" are available from Poulsen (2015). Emissions from the "use of electrical equipment" cover SF_6 from high voltage equipment. The emissions from "SF_6 and PFCs from other product use" cover SF_6 from double glazed windows, running shoes and use of SF_6 in laboratories/research. 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 product uses", covers N_2O from medical use i.e. anaesthetics and N_2O used as propellant for pressure and aerosol products i.e. canned whipped cream. The emission projections for these sources are calculated as the constant average of the five latest historical years, 2009-2013.

The fourth source, "Other product use", covers CO_2, CH_4 and N_2O emissions from the use of fireworks, tobacco and charcoal for barbeques. The emission projections for these sources are calculated as the constant average of the five latest historical years, 2009-2013.

The calculated emission projections are shown in Table 4.10 and Table 4.13.

4.3 Emissions

The results of the GHG emission projections for the entire industrial sector are presented in Table 4.10.

In 2014 62 % of GHG emissions from *Industrial processes and product use* originate from *Mineral industry*, in 2035 the number will have increased to 82 % 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* and *Other product manufacture and use*).

The second largest source category in respect to GHG emissions is for 2014-2017 *Product uses as ODS substitutes* with 12-16 % of emissions. Due to the strong decrease in emissions from this source category (i.e. *Product uses as ODS substitutes) Non-energy products from fuels and solvent use* becomes the second largest source of emissions in 2018-2035 with 11-12 %.

Table 4.10 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	1078	1417	1628	1564	804	992	994	995	1013	965
2B	Chemical Industry	1003	870	966	1	1	1	1	1	1	1
2C	Metal Industry	60	73	61	16	0.2	0.2	0.1	0.2	0.2	0.2
2D	Non-energy products from fuels and solvent use	165	184	190	214	203	187	182	191	187	187
2E	Electronic industry	0	0	0	0	13	11	5	4	5	5
2F	Product uses as ODS substitutes	0	243	726	951	956	890	806	789	706	652
2G	Other product manufacture and use	35	91	60	42	57	92	131	152	154	140
	Total	2341	2878	3630	2790	2033	2175	2119	2133	2066	1951
		2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
2A	Mineral Industry	1009	1044	1084	1124	1160	1184	1205	1217	1226	1234
2B	Chemical Industry	1	1	1	1	1	1	1	1	1	1
2C	Metal Industry	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2D	Non-energy products from fuels and solvent use	187	187	187	187	187	187	187	187	187	187
2E	Electronic industry	5	5	5	5	5	5	5	5	5	5
2F	Product uses as ODS substitutes	582	528	490	480	440	427	358	307	265	232
2G	Other product manufacture and use	113	99	99	98	79	53	52	52	53	53
	Total	1898	1864	1867	1896	1872	1857	1809	1770	1737	1711
		2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
2A	Mineral Industry	1241	1251	1264	1273	1291	1306	1313	1323	1329	1349
2B	Chemical Industry	1	1	1	1	1	1	1	1	1	1
2C	Metal Industry	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2D	Non-energy products from fuels and solvent use	187	187	187	187	187	187	187	187	187	187
2E	Electronic industry	5	5	5	5	5	5	5	5	5	5
2F	Product uses as ODS substitutes	205	183	165	150	138	116	112	108	105	101
2G	Other product manufacture and use	53	53	53	53	53	53	53	53	53	53
	Total	1692	1680	1675	1669	1675	1668	1671	1677	1681	1697

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

Figure 4.2 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.

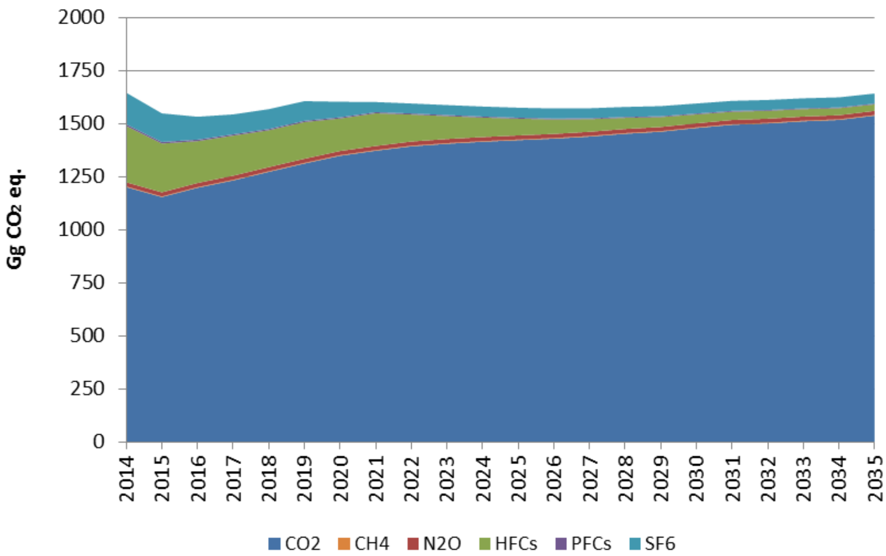

Figure 4.2 Time series for emissions, divided into individual pollutants.

4.3.1 2A – Mineral Industry

Emission projections for mineral industries are shown in Table 4.11.

Table 4.11 Some historical emissions and 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	887	840
2A2	Lime production	105	83	76	61	41	49	57	54	48	48
2A3	Glass production	18	12	14	11	8	8	9	6	8	9
2A3	Glass wool production	2	2	2	2	1	1	1	1	1	1
2A4a	Bricks/tiles production	25	31	36	35	15	20	17	16	18	18
2A4a	Expanded clay production	16	17	16	15	6	7	6	10	7	7
2A4b	Other uses of soda ash	12	11	9	18	11	5	8	9	8	8
2A4d	Flue gas cleaning	10	49	82	51	41	33	18	25	28	27
2A4d	Stone wool production	8	8	8	8	7	7	7	6	7	7
	Total	1078	1417	1628	1564	804	992	994	995	1013	965
		2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
2A1	Cement production	882	925	966	1004	1043	1065	1085	1097	1107	1114
2A2	Lime production	48	48	48	48	48	48	48	48	48	48
2A3	Glass production	9	9	9	10	10	10	11	11	11	11
2A3	Glass wool production	1	1	1	1	1	1	1	1	1	1
2A4a	Bricks/tiles production	19	20	21	21	22	23	23	23	24	24
2A4a	Expanded clay production	8	8	9	9	9	9	10	10	10	10
2A4b	Other uses of soda ash	8	8	8	8	8	8	8	8	8	8
2A4d	Flue gas cleaning	27	16	15	14	9	10	9	9	8	8
2A4d	Stone wool production	8	8	8	9	9	9	9	10	10	10
	Total	1009	1044	1084	1124	1160	1184	1205	1217	1226	1234
		2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
2A1	Cement production	1123	1133	1146	1155	1171	1186	1193	1202	1208	1227
2A2	Lime production	48	48	48	48	48	48	48	48	48	48
2A3	Glass production	11	11	11	11	11	11	11	11	11	11
2A3	Glass wool production	1	1	1	1	1	1	1	2	2	2
2A4a	Bricks/tiles production	24	24	24	25	25	25	25	26	26	26
2A4a	Expanded clay production	10	10	10	10	10	11	11	11	11	11
2A4b	Other uses of soda ash	8	8	8	8	8	8	8	8	8	8
2A4d	Flue gas cleaning	6	5	5	5	5	6	5	6	6	6
2A4d	Stone wool production	10	10	10	10	10	10	10	10	11	11
	Total	1241	1251	1264	1273	1291	1306	1313	1323	1329	1349

The largest source of emissions in *Mineral industry* is cement production; 87-91 %. Cement production has an increasing trend in the projected years due to the extrapolation factors presented in Table 4.3. The second largest emission source for all projected years is lime production; 4-5 %.

In the 2014 emission inventories the contribution from category 2A constituted 2.0 % of the Danish total CO_2 eqv. emission without LULUCF. In 2025 (the last complete year in the projection) this contribution is estimated to have increased to 2.8 %.

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 4.10.

4.3.3 2C – Metal Industry

There is only one source of GHG emissions within this category; *2C5 Lead production*. There is therefore no additional aggregation available to the data presented in Table 4.10.

4.3.4 2D – Non-Energy Products from Fuels and Solvent Use

All sources within this category were projected as the constant average of the historical years 2009-2013. Category 2D makes up 11-12% of CO_2 eqv. emissions in 2014-2035.

The sources within this category have not been projected individually and are therefore not available in this report. The total emission from category 2D is presented in Table 4.10.

4.3.5 2E – Electronic Industry

There is only one source in category 2E, Fibre optics. There is therefore no additional aggregation available to the data presented in Table 4.10. Emissions from this category are projected to be constant for 2014-2035 and 44 % of the CO_2 equivalent emissions stems from HFC emissions; 56 % from PFCs.

4.3.6 2F – Product Uses as Substitutes for Ozone Depleting Substances

Table 4.12 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 4.12 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		43	519	798	842	789	718	710	648	608
2F2	Foam blowing agents		200	184	131	96	85	73	61	40	26
2F4	Aerosols		0	21	23	18	17	17	18	18	18
2F5	Solvents		0	2	0	0	0	0	0	0	0
	Total		243	726	951	956	890	806	789	706	652
		2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
2F1	Refrigeration and air conditioning	551	505	471	462	422	409	340	289	246	214
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	582	528	490	480	440	427	358	307	265	232
		2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
2F1	Refrigeration and air conditioning	187	165	147	132	120	97	94	90	87	83
2F2	Foam blowing agents	1	1	1	1	1	1	1	1	1	1
2F4	Aerosols	18	18	18	18	18	18	18	18	18	18
	Total	205	183	165	150	138	116	112	108	105	101

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 of 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).

The emission of F-gases is divided up in application areas and the time series are presented graphically below.

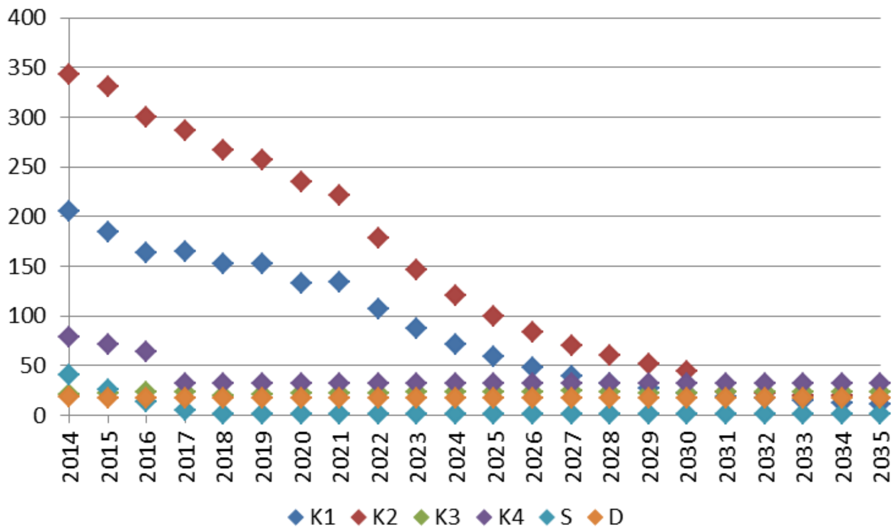

Figure 4.3 Projected F-gas emissions for the years 2014 to 2035 (Gg CO_2 eqv.). S: Foam blowing, K1: Residential refrigerant, K2: Commercial refrigerant, K3: Transport refrigerant, K4: Mobile A/C. D: Aerosols.

In the 2014 emission inventories the total contribution from category 2F, converted into CO_2 equivalents, constituted 1.4 % of the Danish total without CO_2 from LULUCF. In 2025 (the last complete year in the projection) this contribution is estimated to have decreased to 0.5 %.

4.3.7 2G – Other Product Manufacture and Use

Emission projections for *Other Product Manufacture and Use* are shown in Table 4.13.

Table 4.13 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	2.4	3.7	10.7	11.5	13.2	13.1	12.2	13.1	11.9	12.0
2G2	SF_6 and PFCs from other product uses	11.4	64.5	25.1	8.4	22.6	56.3	99.8	117.4	120.4	106.2
2G3	Medical application	11.9	11.9	11.9	11.0	10.1	12.5	8.9	11.0	11.3	11.3
2G3	Propellant	5.6	6.9	5.9	5.6	5.5	5.3	4.5	4.8	5.1	5.1
2G4	Other product uses	3.2	4.3	6.4	5.8	5.6	4.9	5.3	5.9	5.6	5.6
	Total	34.5	91.3	59.9	42.2	57.1	92.1	130.7	152.3	154.3	140.1
		2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
2G1	Electrical equipment	12.1	12.2	12.3	12.3	12.4	12.5	12.6	12.7	12.8	12.8
2G2	SF_6 and PFCs from other product uses	79.5	65.0	65.1	64.0	44.2	18.9	17.9	17.9	17.8	17.8
2G3	Medical application	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3
2G3	Propellant	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
2G4	Other product uses	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
	Total	113.5	99.1	99.3	98.3	78.5	53.4	52.4	52.4	52.5	52.6
		2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
2G1	Electrical equipment	12.9	13.0	13.1	13.2	13.2	13.1	13.1	13.1	13.1	13.1
2G2	SF_6 and PFCs from other product uses	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8
2G3	Medical application	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3
2G3	Propellant	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
2G4	Other product uses	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
	Total	52.6	52.7	52.8	52.8	52.9	52.8	52.8	52.8	52.8	52.8

In 2014 86 % of the CO_2 equivalent emission from category 2G originates from SF_6 emissions. Through the projected time series this number decreases to 58 %. Of the 2014 SF_6 emission, 79 % is emitted from double glazed windows. Since double glazed windows are the primary reason for the drop in SF_6 emissions, the share of SF_6 that originated from windows will also decrease during the projected years and is only 4 % in 2035. 2G2 is still the dominating subcategory of 2G in 2035, but this is due to the use of SF_6 in laboratories/research.

4.4 Recalculations

Table 4.14 shows emissions from this projection report and the last (Nielsen et al., 2014) along with the difference between the two. Descriptions of the recalculations are given for each category in the following sections.

Table 4.14 Recalculations in the industrial processes and product use sector.

	Unit	2014	2015	2016	2020	2025	2030	2035
2A Mineral Industry								
2015 Projection	Gg CO_2	1,013	965	1,009	1,160	1,234	1,291	1,349
2014 Projection	Gg CO_2	967	963	988	1,086	1,167	1,231	1,291
Difference	Gg CO_2	45	2	21	74	67	59	58
Difference	%	5 %	0 %	2 %	7 %	6 %	5 %	4 %
2B Chemical Industry								
2015 Projection	Gg CO_2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
2014 Projection	Gg CO_2	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Difference	Gg CO_2	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Difference	%	-21 %	-21 %	-21 %	-21 %	-21 %	-21 %	-21 %
2C Metal Industry (new category)								
2015 Projection	Gg CO_2 eqv.	0.18	0.18	0.18	0.18	0.18	0.18	0.18
2014 Projection	Gg CO_2 eqv.	0	0	0	0	0	0	0
Difference	Gg CO_2 eqv.	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Difference	%	-	-	-	-	-	-	-
2D Non-Energy Products from Fuels and Solvent Use								
2015 Projection	Gg CO_2 eqv.	187	187	187	187	187	187	187
2014 Projection	Gg CO_2 eqv.	192	193	194	198	203	209	215
Difference	Gg CO_2 eqv.	-5	-6	-7	-11	-16	-22	-28
Difference	%	-3 %	-3 %	-4 %	-6 %	-8 %	-10 %	-13 %
2E Electronic Industry (new category)								
2015 Projection	Gg CO_2 eqv.	4.7	4.7	4.7	4.7	4.7	4.7	4.7
2014 Projection	Gg CO_2 eqv.	0	0	0	0	0	0	0
Difference	Gg CO_2 eqv.	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Difference	%	-	-	-	-	-	-	-
2F Product uses as ODS substitutes								
2015 Projection	Gg CO_2 eqv.	706	652	582	440	232	138	101
2014 Projection	Gg CO_2 eqv.	605	508	401	80	68	65	65
Difference	Gg CO_2 eqv.	100	144	182	360	164	73	36
Difference	%	17 %	28 %	45 %	449 %	243 %	113 %	56 %
2G Other product manufacture and use								
2015 Projection	Gg CO_2 eqv.	154	140	113	79	53	53	53
2014 Projection	Gg CO_2 eqv.	157	143	116	82	38	32	32
Difference	Gg CO_2 eqv.	-2	-3	-3	-4	15	21	21
Difference	%	-2 %	-2 %	-2 %	-4 %	40 %	67 %	67 %
Total								
2015 Projection	Gg CO_2 eqv.	2,066	1,951	1,898	1,872	1,711	1,675	1,697
2014 Projection	Gg CO_2 eqv.	1,925	1,811	1,703	1,450	1,479	1,540	1,606
Difference	Gg CO_2 eqv.	140	140	195	423	232	135	90
Difference	%	7 %	8 %	11 %	29 %	16 %	9 %	6 %

4.4.1 2A – Mineral Industry

There are recalculations in every one of the 9 subcategories in *2A Mineral Industries*, but the vast majority of changes are caused by recalculations of emissions from cement industry. About 90 % of emissions in category 2A come from cement production; it is therefore also natural that the recalculations that show up in Table 4.10 and Table 4.11 are caused by cement production. The performed recalculation of emissions from cement production results in an increase between 2 Gg in 2015 and 74 Gg in 2022 equal to 0.2 to

7.3 % respectively. This increase is a result of the base years 2009-2013 being replaced by 2010-2014 (807 Gg vs 832 Gg average respectively) in this year's projection. The increase is strengthened a little by an increased expectation to this industry (Table 4.3).

In addition to the cement production there are smaller changes for the other eight categories, but none larger than 1 % of the total emission from mineral industries for any given projected year. After cement production, the largest change is the addition of the new source category called "Other uses of soda ash" with 8 Gg per year.

4.4.2 2B – Chemical Industry

Since no production values are available from the Danish Energy Agency, emissions are estimated to keep the constant average value of the 2009-2013 emissions. The update of base years from 2008-2012 to 2009-2013 causes a decrease from 1.5 to 1.2 Gg. Though the change in emissions is miniscule (0.3 Gg) the percentage change is quite high; 21 %.

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

Due to insufficient resources this category was not evaluated and projected for each source category separately but simply kept constant as the average value from 2009-2013, this method is in large contrast with the methodology applied in the latest GHG projection (Nielsen et al., 2014). This method shows a decrease in emissions of 28 Gg (13 %) to 5 Gg (3 %) for 2035 and 2014 respectively.

4.4.4 2E – Electronic Industry

This category is new in this submission and an increased emission from this category is therefore obvious.

4.4.5 2F – Product Uses as Substitutes for Ozone Depleting Substances

The projection of F-gas emissions are prepared by Poulsen (2015). Some changes were made for F-gas emissions from category 2F to increase emissions and to make the expected decreasing slope more evened out. These changes were performed within the larger of the subsectors, i.e. 2F1 refrigeration and air conditioning, only miniscule changes were made to 2F2 and 2F4 (i.e. less than 1 Gg). The previous and present F-gas emission from category 2F is shown in Figure 4.4.

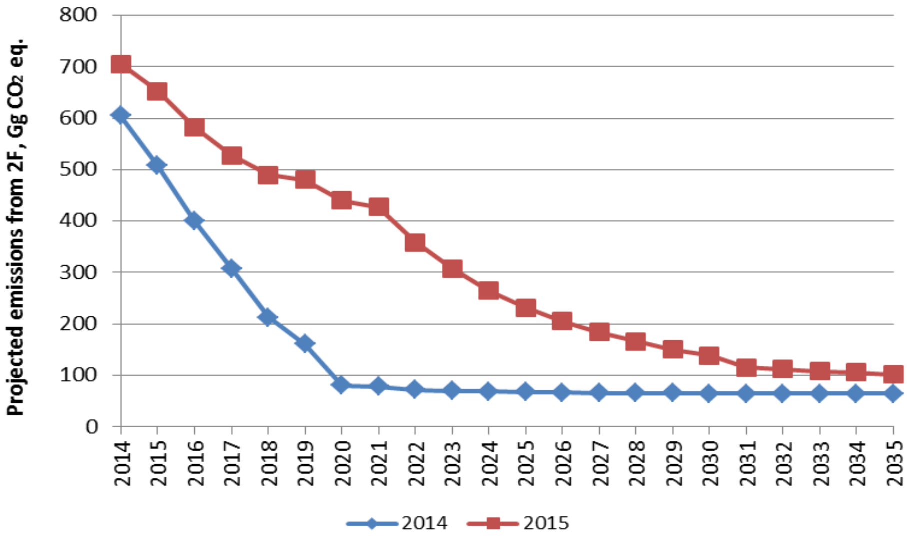

Figure 4.4 Projected F-gas emissions from category 2F from this and the previous projection.

4.4.6 2G – Other Product Manufacture and Use

As previously mentioned, all F-gas projections are performed by Poulsen (2015), for category 2G this means emissions from the subcategories 2G1 and 2G2. The recalculations for the subcategories in 2G are presented in Table 4.15.

Table 4.15 Recalculations in the industrial processes and product use sector.

		Unit	2014	2015	2016	2020	2025	2030	2035
2G1	Electrical equipment								
	2015 Projection	Gg CO_2	12	12	12	12	13	13	13
	2014 Projection	Gg CO_2	27	27	28	29	15	14	14
	Difference	Gg CO_2	-15	-15	-16	-16	-3	-1	-1
	Difference	%	-56 %	-56 %	-56 %	-57 %	-17 %	-7 %	-8 %
2G2	SF_6 and PFCs from other product uses								
	2015 Projection	Gg CO_2	120	106	79	44	18	18	18
	2014 Projection	Gg CO_2	119	104	78	42	11	6	6
	Difference	Gg CO_2	2	2	2	2	7	11	11
	Difference	%	2 %	2 %	2 %	4 %	59 %	178 %	178 %
2G3	N_2O from product uses								
	2015 Projection	Gg CO_2	16	16	16	16	16	16	16
	2014 Projection	Gg CO_2	11	11	11	11	11	11	11
	Difference	Gg CO_2	5	5	5	5	5	5	5
	Difference	%	48 %	48 %	48 %	48 %	48 %	48 %	48 %
2G4	Other product uses								
	2015 Projection	Gg CO_2	5	5	5	5	5	5	5
	2014 Projection	Gg CO_2							
	Difference	Gg CO_2	5	5	5	5	5	5	5
	Difference	%	-	-	-	-	-	-	-

For subcategory 2G3, emissions from medical application have increased and the subcategory 2G4 is new as these sources were previously included in category 2D.

4.5 References

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5 Transport and other mobile sources

In the Danish emission database, all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution), according to the CollectER system. The emission inventories are prepared from a complete emission database based on the SNAP sectors.

For mobile sources, the aggregation of emission results into the formats used by the UNFCCC and UNECE Conventions is made by using the code correspondence information shown in Table 5.1. In the case of mobile sources, the CRF (Common Reporting Format) and NFR (National Format for Reporting) used by the UNFCCC and UNECE Conventions, respectively, are similar.

Table 5.1 SNAP – CRF/NFR correspondence table for mobile sources.

SNAP classification	CRF/NFR classification
0701 Road traffic: Passenger cars	1A3bi Road transport: Passenger cars
0702 Road traffic: Light duty vehicles	1A3bii Road transport: Light duty vehicles
0703 Road traffic: Heavy duty vehicles	1A3biii Road transport: Heavy duty vehicles
0704/0705 Road traffic: Mopeds and motor cycles	1A3biv Road transport: Mopeds & motorcycles
0706 Road traffic: Evaporation	1A3bv Road transport: Evaporation
0707 Road traffic: Brake and tire wear	1A3bvi Road transport: Brake and tire wear
0708 Road traffic: Road abrasion	1A3bvii Road transport: Road abrasion
0801 Military	1A5b Other, Mobile
0802 Railways	1A3c Railways
0803 Inland waterways	1A5b Other, Mobile
080402 National sea traffic	1A3dii National navigation (Shipping)
080403 National fishing	1A4ciii Agriculture/Forestry/Fishing: National fishing
080404 International sea traffic	1A3di (i) International navigation (Shipping)
080501 Dom. airport traffic (LTO < 1000 m)	1A3aii (i) Civil aviation (Domestic, LTO)
080502 Int. airport traffic (LTO < 1000 m)	1A3ai (i) Civil aviation (International, LTO)
080503 Dom. cruise traffic (> 1000 m)	1A3aii (ii) Civil aviation (Domestic,Cruise)
080504 Int. cruise traffic (> 1000 m)	1A3ai (ii) Civil aviation (International, Cruise)
0806 Agriculture	1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry
0807 Forestry	1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry
0808 Industry	1A2gvii Manufacturing industries/Construction (mobile)
0809 Household and gardening	1A4bii Residential: Household and gardening (mobile)
0811 Commercial and institutional	1A4aii Commercial/Institutional: Mobile

Military transport activities (land and air) refer to the CRF/NFR sector Other (1A5), the latter sector in principle also includes recreational craft (SNAP code 0803).

Road traffic evaporation, brake and tire wear, and road abrasion (SNAP codes 0706-0708) is not a part of the CRF list since no greenhouse gases are emitted from these sources.

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

[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.

(0805010) and domestic cruise (080503) and flights between Denmark and Greenland or the Faroe Islands are regarded as domestic flights.

Agricultural and forestry non-road machinery (SNAP codes 0806 and 0807) is accounted for in the Agriculture/forestry/fisheries (1A4c) sector together with fishing activities (SNAP code 080403).

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 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.

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, 2015). The latter source also provides information of the mileage split between urban, rural and highway driving. The respective average speeds come from The Danish Road Directorate (e.g. Winther & Ekman, 1998). Additional data for the moped fleet and motorcycle fleet disaggregation is given by The National Motorcycle Association (Markamp, 2013). For information on the historical vehicle stock and annual mileage, please refer to Winther (2015).

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 projected to 2025.

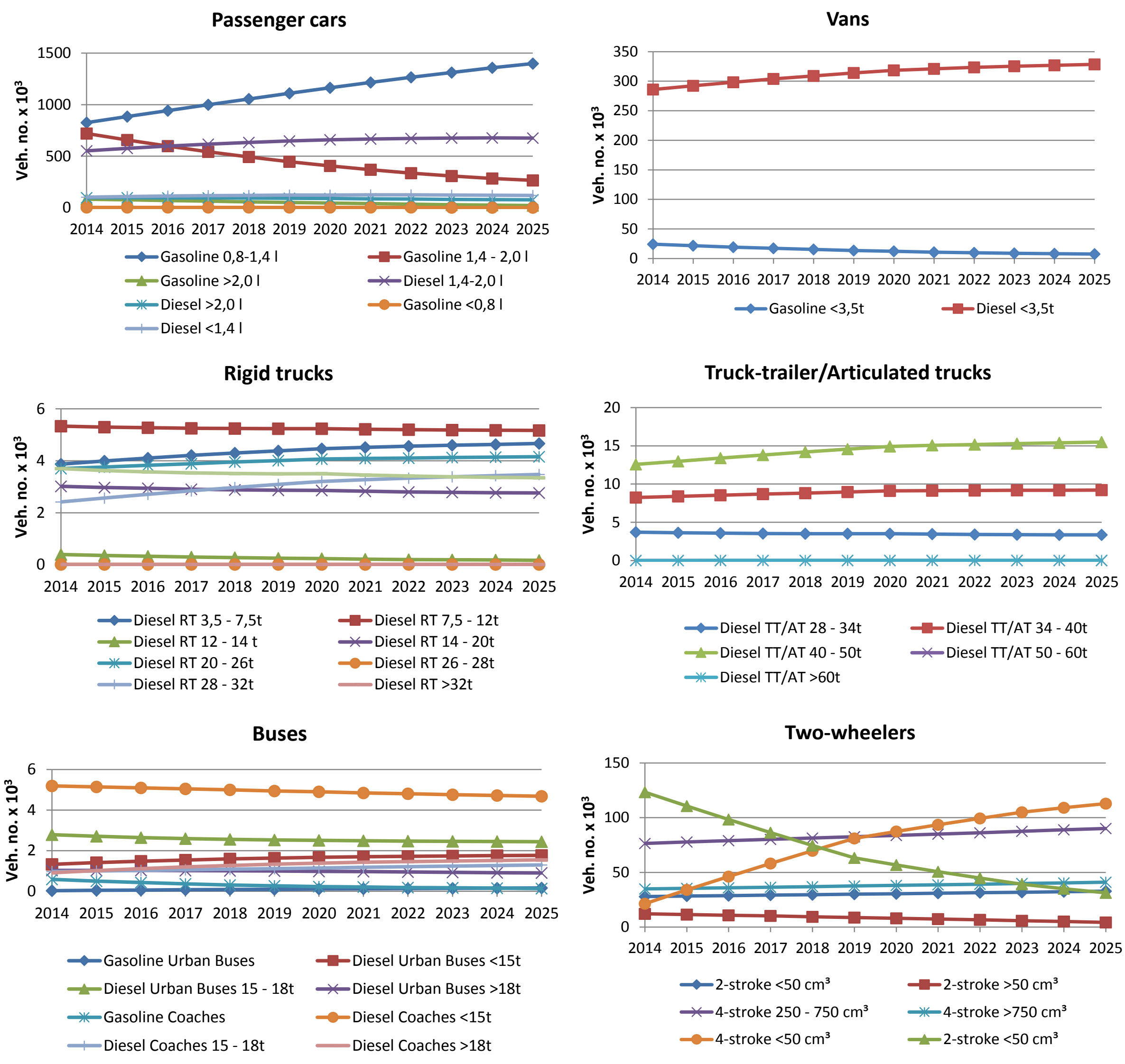

Figure 5.1 Number of vehicles in sub-classes from 2014-2025.

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.

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

The trends in vehicle numbers per EU layer are also shown in Figure 5.2 for the 2014-2025 periods. The latter figure clearly shows how vehicles complying with the gradually stricter EU emission levels (EURO 5/V, Euro 6/VI and Euro 6c) are introduced into the Danish motor fleet in the projection period.

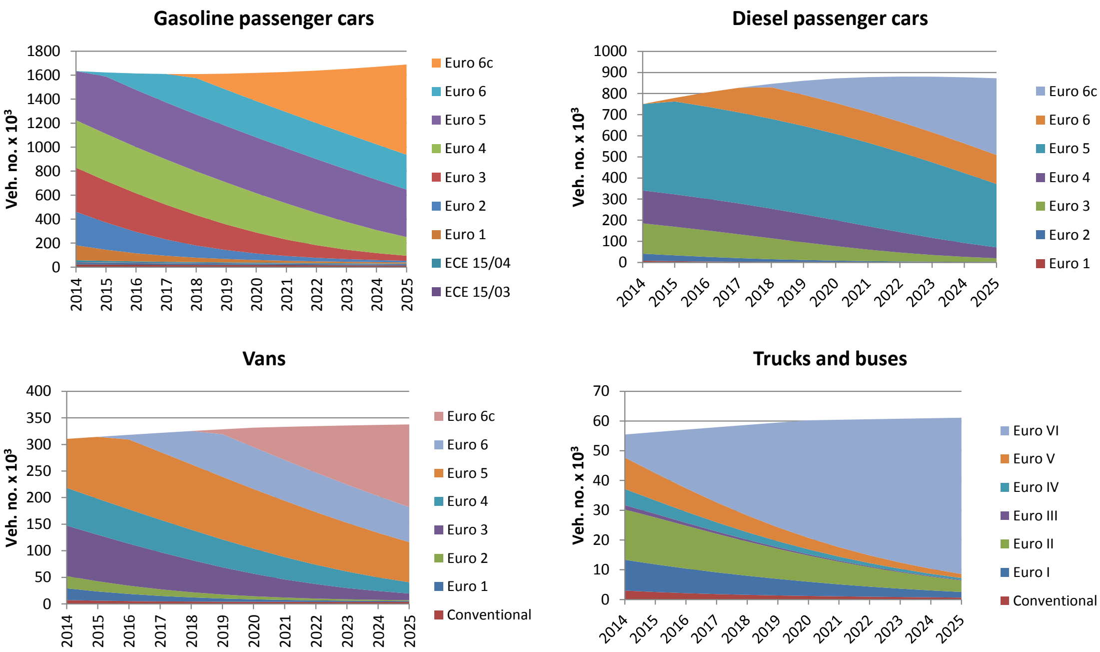

Figure 5.2 Layer distribution of vehicle numbers per vehicle type in 2014-2025.

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.

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.

For Euro 1-6 passenger cars and vans, the chassis dynamometer test cycle used in the EU for emission approval is the NEDC (New European Driving Cycle), see e.g. www.dieselnet.com. The test cycle is also used for fuel consumption measurements. The NEDC cycle consists of two parts, the first part being a 4-time repetition (driving length: 4 km) of the ECE test cycle. The latter test cycle is the so-called urban driving cycle[3] (average speed: 19 km per h). The second part of the test is the run-through of the EUDC (Extra Urban Driving Cycle) test driving segment, simulating the fuel consumption under rural and highway driving conditions. The driving length of EUDC is 7 km at an average speed of 63 km per h. More information regarding the fuel measurement procedure can be found in the EU-directive 80/1268/EØF.

The NEDC test cycle is not adequately describing real world driving behavior, and as an effect, for diesel cars and vans, there is an increasing mismatch between the step wise lowered EU emission limits the vehicles comply with during the NEDC test cycle, and the more or less constant emissions from the same vehicles experienced during real world driving. In order to bridge this emission inconsistency gap a new test procedure for future Euro 6 vehicles, the so-called Euro 6c vehicles, the "World-Harmonized Light-Duty Vehicles Test Procedure" (WLTP), has been developed which simulates much more closely real world driving behavior. The new test procedure still awaits its final adoption in the EU legislation frame and the announcement of new legislative emission limits. This is expected to happen in September 2017.

For the new Euro 6c vehicles it has been decided that emission measurements must also be made with portable emission measurement systems (PEMS) during real traffic driving conditions with random acceleration and deceleration patterns. During the new Real Driving Emission (RDE) test procedure the emissions of NO_x are allowed to exceed the existing emission limits by 110 % by January 2017 for all new car models and by January 2019 for all new cars. From January 2020 the NO_x emission exceedance levels are adjusted downwards to 50 % for all new car models and by January 2021 for all new cars. Implementation dates for vans are one year later.

In the present emission projection, the dates for implementation of the Euro 6c technology are set to 1 September 2018 and 1 September 2019, for diesel cars and vans, respectively.

For NOx, 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. For cars and vans the emission directives distinguish between three vehicle classes according to vehicle reference mass[4]: Passenger cars and light duty trucks (<1305 kg), light duty trucks (1305-1760 kg) and light duty trucks (>1760 kg). The specific emission limits are shown in Winther (2015).

For heavy-duty vehicles (trucks and buses), the emission limits are given in g per kWh and the measurements are carried out for engines in a test bench, using the ECE R-49, EU ESC (European Stationary Cycle) and ETC (European Transient Cycle) test cycles, depending on the Euro norm and exhaust gas

[3] For Euro 3 and on, the emission approval test procedure was slightly changed. The 40 s engine warm up phase before start of the urban driving cycle was removed.
[4] Reference mass: net vehicle weight + mass of fuel and other liquids + 100 kg.

after-treatment system installed. For Euro VI engines the WHSC (World Harmonized Stationary Cycle) and WHTC (World Harmonized Transient Cycle) test cycles are used. For a description of the test cycles see e.g. www.dieselnet.com.

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(692/2	1.1.2011
	Euro VI	715/2007(692/2	1.9.2015
	Euro VIc	459/2012	1.9.2018
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(692/2	1.1.2011
	Euro VI	715/2007(692/2	1.9.2015
	Euro VIc	459/2012	1.9.2018
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
	Euro VIc	459/2012	1.9.2019
Vehicle category	Emission layer	EU directive	First reg. date
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

Table 5.3 *Continued*

Vehicle category	Emission layer	EU directive	First reg. date
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). f: Applies for new types only. Until 2017, mopeds with an existing Euro II type approval can be sold.

5.1.3 Fuel consumption and emission factors

In practice, the emissions from vehicles in traffic are different from the legislation limit values and, therefore, the latter figures are not suited for total emission calculations. Besides difference in test versus real world driving behaviour, as discussed in the previous section, the emission limit values do not reflect the emission impact of cumulated mileage driven, and engine and exhaust after treatment maintenance levels for a vehicle fleet as such.

Therefore, in order to represent the Danish fleet and to support average national emission estimates, the selected emission factors must be derived from numerous emission measurements, using a broad range of real world driving patterns and a sufficient number of test vehicles. It is similarly important to have separate fuel consumption and emission data for cold-start emission calculations and gasoline evaporation (hydrocarbons).

Trip speed dependent base factors for fuel consumption and emissions are taken from the COPERT IV (version 11) model, using trip speeds representative for urban, rural and highway driving. The factors can be seen in Winther (2015). The scientific basis for COPERT IV is fuel consumption figures and emission information from various European measurement programmes, transformed into trip speed dependent fuel consumption and emission factors for all vehicle categories and layers.

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. At 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.

The calculation procedure for hot engines is to combine basis fuel consumption and emission factors, number of vehicles and annual mileage numbers and mileage road type shares. For additional description of the hot and cold start calculations and fuel balance approach, please refer to Winther (2015).

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 aviation, air traffic statistics for the latest historical year is used in combination with flight specific emission data to determine the share of fuel used for LTO and cruise by domestic and international flights and to derive the corresponding emission factors. The LTO and cruise fuel shares are then used to make a LTO/cruise split of the fuel consumption projections for domestic and international aviation from the DEA (2015) due to lack of a projection of air traffic movements.

In more details the historical activity data used in the DCE emission model for aviation consists of records per flight (city-pairs) provided by the Danish Transport Authority. Each flight record consists of e.g. ICAO codes for aircraft type, origin and destination airport, maximum takeoff mass (MTOM), flight call sign and aircraft registration number.

In the DCE model each aircraft type is paired with a representative aircraft type, for which fuel consumption and emission data exist in the EMEP/EEA databank. As a basis the type relation table is taken from the Eurocontrol AEM model, which is the primary source for the present EMEP/EEA fuel consumption and emission data. Supplementary aircraft types are assigned to representative aircraft types based on the type relation table already established in the previous version of the DCE model (e.g. Winther, 2015).

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

Please refer to the reports by Winther et al. (2006) and Winther (2015) for detailed information of the number of different types of machines, their load factors, engine sizes and annual working hours.

National sea transport

For national sea transport the energy projections from DEA (2015) for the sectors “National sea transport” and “Greenland/Faroe Islands maritime” are used as activity data input for the subsequent emission calculations. The projected energy totals for national sea transport are disaggregated into subcategories based on fleet activity estimates for regional ferries, local ferries, sailing activities between Denmark and Greenland/Faroe Islands, and other national sea transport (Winther; 2008, 2015).

Table 5.5 lists the most important domestic ferry routes in Denmark in 2014. For these ferry routes the following detailed traffic and technical data have been gathered: Ferry name, year of service, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size and sailing time (single trip). Please refer to Winther (2015) for more details.

Table 5.5 Ferry routes comprised in the Danish inventory.

Ferry service	Service period
Esbjerg-Torshavn	1990-1995, 2009+
Hanstholm-Torshavn	1991-1992, 1999+
Hou-Sælvig	1990+
Frederikshavn-Læsø	1990+
Kalundborg-Samsø	1990+
Køge-Rønne	2004+
Sjællands Odde-Ebeltoft	1990+
Sjællands Odde-Århus	1999+
Svendborg-Ærøskøbing	1990+
Tårs-Spodsbjerg	1990+

Other sectors

The activity data for military, railways, international sea transport and fishery consists of fuel consumption information from DEA (2015). 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.

5.2.2 Emission legislation

For other modes of transport and non-road machinery, the engines have to comply with the emission legislation limits agreed by the EU and different UN organisations in terms of NO_x, CO, VOC and TSP emissions and fuel sulphur content. In terms of greenhouse gases, the emission legislation requirements for VOC influence the emissions of CH_4, the latter emission component forming a part of total VOC. Only for ships legislative limits for specific fuel consumption have been internationally agreed in order to reduce the emissions of CO_2.

For non-road 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 [g per kWh]	VOC [g per kWh]	NO_X [g per kWh]	VOC+NO_X [g per kWh]	PM [g per kWh]	Diesel machinery EU directive	Diesel machinery Implement. date Transient	Diesel machinery Implement. date Constant	Tractors EU directive	Tractors Implementation 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]	Implementation 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 5.8. 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 5.9 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 5.8 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 5.9 Overview of the EU Emission Directive 2013/53 for recreational craft.

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

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

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

Table 5.10 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 ICAO (International Civil Aviation Organization). The engine emission certification standards are contained in Annex 16 — Environmental Protection, Volume II — Aircraft Engine Emissions to the Convention on International Civil Aviation (ICAO Annex 16, 2008, plus amendments). The emission standards relate to the total emissions (in grams) from the so-called LTO (Landing and Take Off) cycle divided by the rated engine thrust (kN). The ICAO LTO cycle contains the idealised aircraft movements below 3000 ft (915 m) during approach, landing, airport taxiing, take-off and climb out.

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

For NO_x, the increasingly strengthened emission regulations fall in five categories depending on date of manufacture of the first individual production model and production date of the individual engine. The emission limits are further grouped into engine pressure ratio intervals and levels of rated engine thrust.

The regulations published by ICAO are given in the form of the total quantity of pollutants (D_p) emitted in the LTO cycle divided by the maximum sea level thrust (F_{oo}) and plotted against engine pressure ratio at maximum sea level thrust.

A further description of the technical definitions in relation to engine certification, the emission limit values for NO_x, CO, HC and smoke 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.easa.europa.eu" hosted by the European Aviation Safety Agency (EASA).

Marpol 73/78 Annex VI agreed by IMO (International Maritime Organisation) concerns the control of NO_x emissions (Regulation 13 plus amendments) and SO_x and particulate emissions (Regulation 14 plus amendments) from ships (DNV, 2009). The so called Energy Efficiency Design Index (EEDI) fuel efficiency regulations for new built ships was included in Chapter 4 of Annex VI in the Marpol convention for the purpose of controlling the CO_2 emissions from new built ships larger than 400 GT (Lloyd's Register, 2012).

EEDI is a design index value that expresses how much CO_2 is produced per work done (g CO_2/tonnesnm). At present the IMO EEDI scheme comprises the following ship types; bulk carriers, gas carriers, tankers, container ships, general cargo ships, refrigerated and combination cargo carriers.

The EEDI percentage reductions that need to be achieved for new built ships relative to existing ships, are shown in Table 5.11 stratified according to ship type and dead weight tonnes (DWT) in the temporal phases (new built year in brackets); 0 (2013-14), 1 (2015-19), 2 (2020-24) and 3 (2025+).

Table 5.11 EEDI percentage reductions for new built ships relative to existing ships.

Ship type	Size	Phase 0 1-Jan-2013 to 31-Dec-2014	Phase 1 1-Jan-2015 to 31-Dec-2019	Phase 2 1-Jan-2020 to 31-Dec-2024	Phase 3 1-Jan-2025 onwards
Bulk carrier	20,000 DWT and above	0	10	20	30
	10,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
Gas carrier	10,000 DWT and above	0	10	20	30
	2,000 – 10,000 DWT	n/a	0-10*	0-20*	0-30*
Tanker	20,000 DWT and above	0	10	20	30
	4,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
Container ship	15,000 DWT and above	0	10	20	30
	10,000 – 15,000 DWT	n/a	0-10*	0-20*	0-30*
General cargo ship	15,000 DWT and above	0	10	15	30
	3,000 – 15,000 DWT	n/a	0-10*	0-15*	0-30*
Refrigerated cargo carrier	5,000 DWT and above	0	10	15	30
	3,000 – 5,000 DWT	n/a	0-10*	0-15*	0-30*
Combination carrier	20,000 DWT and above	0	10	20	30
	4,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*

It is envisaged that also ro-ro cargo, ro-ro passenger and cruise passenger ships will be included in the EEDI scheme in the near future.

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, 2015) and a NMVOC/CH_4 split based on own judgment.

For agriculture, forestry, industry, household gardening and recreational craft, the NO_x, VOC, CO and TSP emission factors are derived from various European measurement programmes; see IFEU (2004, 2009) and Winther et al. (2006). The NMVOC/CH_4 split is taken from IFEU (2009).

The source for civil and military aviation (jet fuel) emission factors is the EMEP/CORINAIR guidebook (EMEP/EEA, 2013).

For national sea transport and fisheries, the VOC emission factors come from Trafikministeriet (2000). Specifically for the ferries used by Mols Linjen 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.

5.2.4 Calculation method

Air traffic

For aviation the emissions are calculated as the product of the projected fuel consumption and emission factors derived from flight activity statistics (see paragraph 5.2.1). The calculations are made for separately for domestic and international flights and a furthermore split into LTO and cruise. For more details regarding the calculation procedure, please refer to Winther (2015).

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 (2015).

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 (2008). 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 (2015).

5.3 Fuel consumption and emission results

An overview of the emission results is given in Table 5.12 for all mobile sources in Denmark.

Table 5.12 Summary table of emissions for mobile sources in Denmark.

		1990	1995	2000	2005	2010	2013	2014	2015	2020	2025
CO_2, Gg	Industry-Other (1A2f)	844	850	880	954	1053	1025	569	572	499	498
	Civil Aviation (1A3a)	258	250	182	171	172	140	137	133	135	137
	Road (1A3b)	9 284	10 589	11 203	12 214	12 080	11 021	11 470	11 420	11 436	11 360
	Railways (1A3c)	297	303	228	232	242	248	252	245	216	170
	Navigation (1A3d)	748	784	502	482	491	393	552	582	582	582
	Commercial/Institutional (1A4a)	74	78	87	162	173	171	164	164	160	160
	Residential (1A4b)	39	40	43	59	63	62	82	82	80	80
	Agriculture, forestry and fishing (1A4c)	1894	1727	1760	1763	1681	1654	1332	1354	1288	1313
	Military (1A5)	167	318	197	374	206	239	132	130	130	130
	Navigation int. (1A3d)	3012	4987	4032	2359	2071	1886	2377	2377	2377	2377
	Civil Aviation int. (1A3a)	1721	1816	2321	2538	2405	2473	2680	2735	2898	3014
		1990	1995	2000	2005	2010	2013	2014	2015	2020	2025
CH_4, Mg	Industry-Other (1A2f)	66	60	56	48	38	34	29	29	27	26
	Civil Aviation (1A3a)	4	5	3	3	2	2	1	2	2	2
	Road (1A3b)	2233	2230	1788	1274	694	481	451	408	304	286
	Railways (1A3c)	12	13	10	9	7	6	6	5	0	0
	Navigation (1A3d)	16	17	10	10	11	10	16	17	16	16
	Commercial/Institutional (1A4a)	117	123	154	327	228	173	148	147	147	147
	Residential (1A4b)	51	49	47	57	51	42	83	82	81	81
	Agriculture, forestry and fishing (1A4c)	264	183	143	126	140	120	101	101	99	99
	Military (1A5)	82	102	92	74	27	15	3	3	3	3
	Navigation int. (1A3d)	64	108	91	55	50	47	56	60	62	63
	Civil Aviation int. (1A3a)	5	8	6	4	3	4	3	3	3	3
N_2O, Mg		1990	1995	2000	2005	2010	2013	2014	2015	2020	2025
	Industry-Other (1A2f)	34	35	37	40	45	44	24	25	22	22
	Civil Aviation (1A3a)	10	10	8	8	9	7	5	5	5	5
	Road (1A3b)	292	352	360	335	351	379	406	414	434	445
	Railways (1A3c)	8	8	6	6	7	7	7	7	6	5
	Navigation (1A3d)	47	49	32	30	31	25	32	34	34	34
	Commercial/Institutional (1A4a)	1	1	1	2	3	3	3	3	3	3
	Residential (1A4b)	1	1	1	1	1	1	2	2	2	2
	Agriculture, forestry and fishing (1A4c)	87	81	87	88	81	81	63	64	62	64
	Military (1A5)	5	8	6	11	7	9	5	5	5	5
	Navigation int. (1A3d)	249	426	340	195	154	155	150	150	150	150
	Civil Aviation int. (1A3a)	57	60	78	82	78	85	87	89	94	98
GHG eqv., Gg		1990	1990	1995	2000	2005	2010	2013	2014	2015	2020
	Industry-Other (1A2f)	856	862	892	967	1067	1038	577	581	506	506
	Civil Aviation (1A3a)	261	253	185	173	175	142	139	134	137	138
	Road (1A3b)	9 426	10 750	11 355	12 345	12 201	11 146	11 602	11 553	11 573	11 499
	Railways (1A3c)	299	306	230	234	244	250	254	247	217	171
	Navigation (1A3d)	762	799	511	492	501	401	562	592	592	592
	Commercial/Institutional (1A4a)	77	81	91	170	179	177	168	168	164	164
	Residential (1A4b)	41	41	44	61	64	64	85	84	82	82
	Agriculture, forestry and fishing (1A4c)	1927	1755	1789	1792	1708	1682	1353	1376	1310	1335
	Military (1A5)	170	323	201	379	209	242	134	131	131	131
	Navigation int. (1A3d)	3088	5117	4136	2418	2118	1933	2423	2423	2423	2423
	Civil Aviation int. (1A3a)	1738	1834	2345	2562	2428	2499	2706	2762	2926	3043

5.3.1 Road transport

The total CO_2 emissions decrease is expected to be 1 % from 2014-2025. 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.

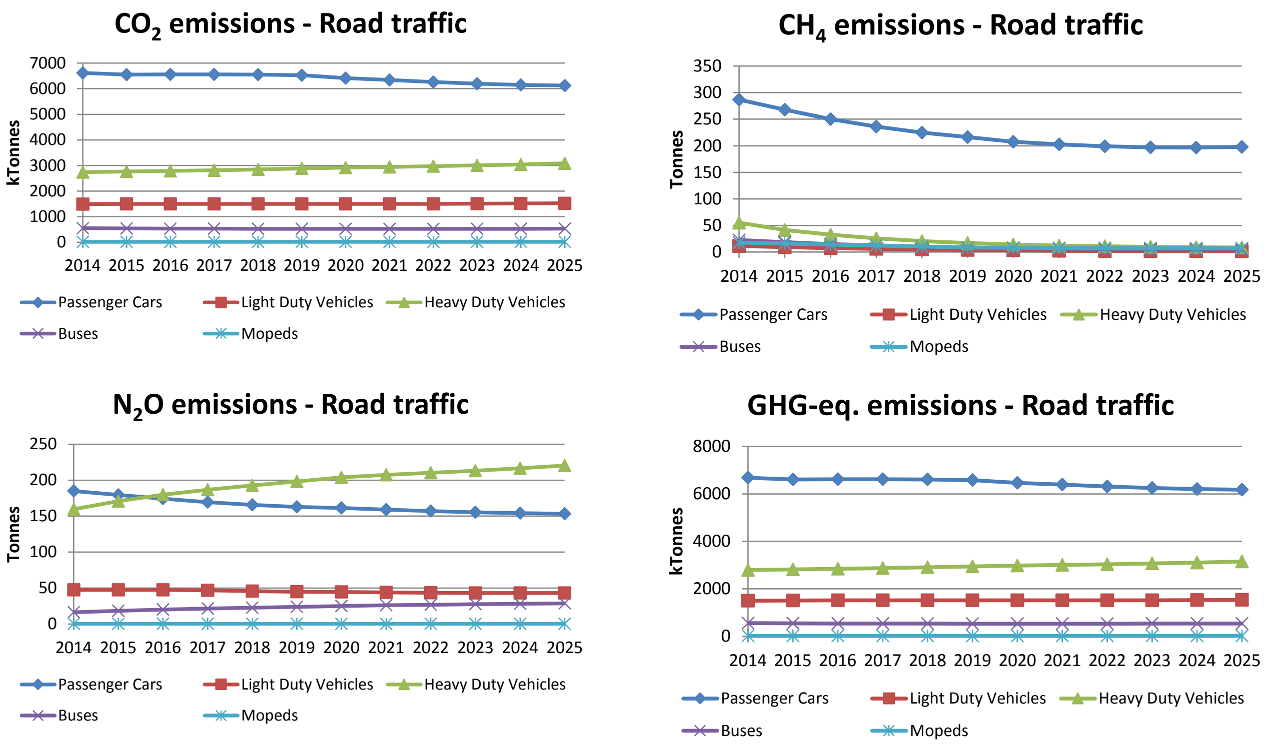

Figure 5.3 Fuel consumption, CO_2, CH_4 and N_2O emissions from 2014-2025 for road traffic.

The total CO_2 emissions decrease is expected to be 1 % from 2014-2025.

The majority of the CH_4 and N_2O emissions from road transport come from gasoline passenger cars (Figure 5.3). The CH_4 emissions decrease by 37 % whereas N_2O emissions increase by 10 %, from 2014 to 2025.

5.3.2 Other mobile sources

The development in CO_2 emissions for other mobile sources, see Figure 5.4, corresponds with the development in fuel consumption. Agriculture/forestry/fisheries (1A4c) is by far the largest source of CO_2 emissions followed by Navigation (1A3d) and Industry (1A2g). Minor CO_2 emission contributing sectors are Commercial/institutional (1A4a), Other (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 (1A2g). The emission contributions from Railways (1A3c), Domestic aviation (1A3a) and Other (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), Agriculture/forestry/fisheries (1A4c) and Residential (1A4b), whereas for Railways (1A3c), Domestic aviation (1A3a) and Other (1A5) categories only small emission contributions are noted.

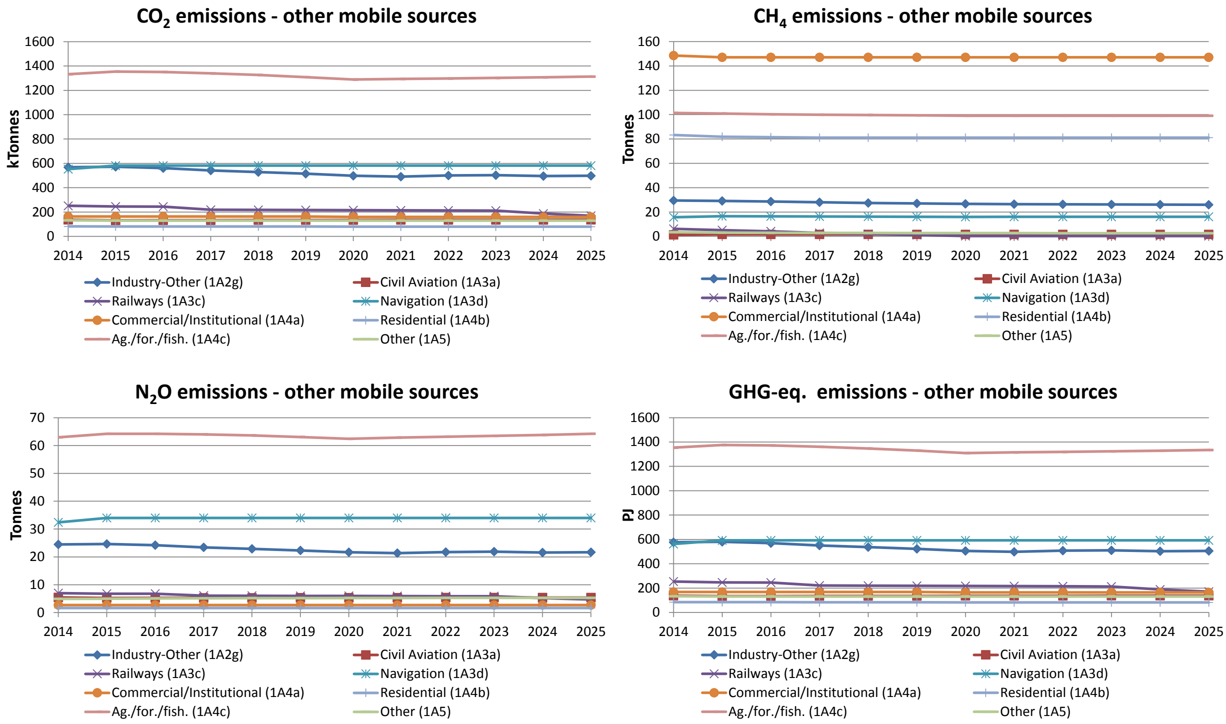

Figure 5.4 Fuel consumption, CO_2, CH_4 and N_2O emissions from 2014-2025 for other mobile sources.

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 flowchart 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 fertiliser.

The latest official reporting of emissions includes time series until 2013 for all emission sources. For some variables such as the number of animals, the official 2014 data have been available and are therefore included.

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 under mobile combustion.

6.1 Introduction

Projection of greenhouse gas emissions is regularly updated based on new scientific knowledge as a consequence of new emission sources, changes of emission factors or changes in agricultural production conditions e.g. changes regarding the export markets or legislation and regulation. Some of the changes may lead to revision also of the historical emission inventory as well and therefore will show some deviations compared to previous published projections. The present projection of greenhouse gases replaces the latest projection published in Scientific Report from DCE – Danish Centre for Environment and Energy No. 129, 2014 (Nielsen et al., 2014).

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 expanding biogas production is agreed. The current government has proposed a "16-point plan" to limit regulatory requirements for the agricultural production e.g. by allowing increased fertilisation. This plan was not yet adopted at the time of the projection and the emission related consequences of this is not taken into account in current projection. Some preliminary reflections on the quantification of the impact on emissions are described in Chapter 6.9. The plan was adopted in December of 2015.

The assumptions on the expected development of livestock production are in general the same as those in the latest greenhouse gas projection (Nielsen et al., 2014), but adjusted according to the real development in production over the past two years. According to Statistics Denmark, the number of dairy cattle and fattening pigs has both decreased during the last two years.

This has influenced the current projection, lowering the number of cattle and pigs for the overall time series compared to the previous projection.

6.2 Projected agricultural emission 2014 - 2030

The development of agricultural greenhouse gases from 1990 to 2013 shows a decrease from 12.5 million tonnes CO_2 equivalents to 10.1 million tonnes CO_2 equivalents, which correspond to a 19 % reduction. The current projection, based on the assumptions provided, estimates almost unchanged emissions in 2030 compared to 2013 (Table 6.1). A slight decrease of the emission from agricultural soils is estimated, but is outweighed by an increase of CH_4 emission from enteric fermentation processes.

Table 6.1 Historic and projected emission from the agricultural sector, given in CO_2 equivalents.

kt CO_2 equivalents	1990	2000	2005	2010	2013	2014	2015	2020	2025	2030
Enteric fermentation	3 799	3 389	3 242	3 392	3 467	3 504	3 633	3 694	3 838	3 937
Manure management	2 707	3 040	3 145	2 794	2 673	2 664	2 600	2 539	2 561	2 598
Agricultural soils	5 362	4 196	3 839	3 736	3 758	3 779	3 695	3 661	3 613	3 566
Field burning of agricultural residue	3	4	5	3	4	4	4	4	4	3
Liming	565	261	220	153	244	238	195	193	191	189
Urea application (CO_2 emission)	15	2	0	1	1	1	1	1	1	1
Other carbon-containing fertilisers	38	5	2	3	2	2	2	2	2	2
Total	12 489	10 897	10 452	10 082	10 148	10 191	10 130	10 094	10 209	10 296

The 7 % decrease in emission from agricultural soils is mainly due to a decrease in the cultivated area, and to removal of soils with high organic content (histosols). The 11 % increase of emission from enteric fermentation is caused by an expected growth in the number of dairy cattle.

6.3 Comparison with previous projection

Given in CO_2 equivalents the emission is decreasing 0 to 5 % through the time-series 2014 – 2030, (Figure 6.1). This is mainly caused by a lower CH4 emission

In general the CH_4 emission is at a lower level compared to the previous projection (4-9 %), and the main reason for this is a lower production of dairy cattle in 2013 and 2014. The same expectations to future production increases are assumed but starting from a lower level. Lower CH_4 emission is also a result of slurry acidification and a decrease in the methane conversion factor, which is taken into account in the current projection.

The N_2O emission is 0-4 % higher (2014-2030) compared to the previous projection. Changes in livestock production has little impact, the N_2O emission sources affects differently - some upwards and other downwards because the N content in manure and inorganic N fertilisers are complementary variables. A change in cultivated area is more important for changes in N_2O emission. The higher N_2O emission trough the time series (2014-2030) is due to mineralization, which was not included in previous projection.

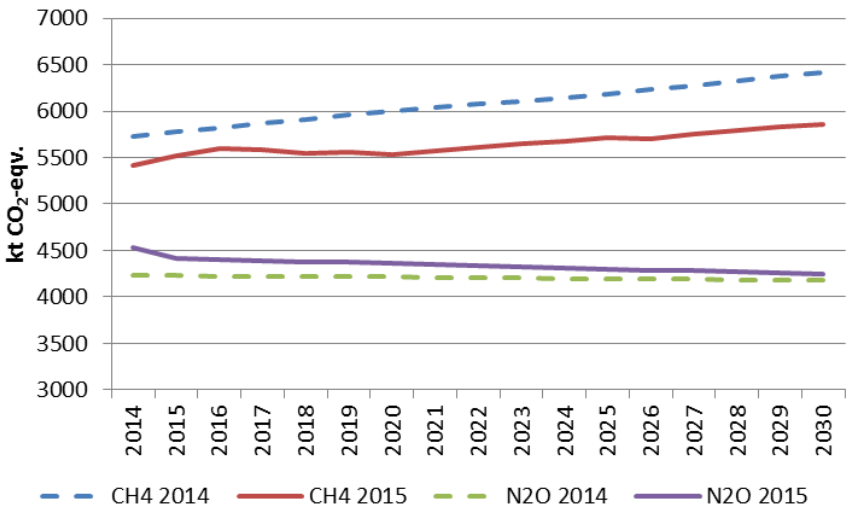

Figure 6.1 Projection 2015 compared to projection 2014.

6.4 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.

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 N_2O emissions, as well as on CH_4 emissions. In the current projection ammonia reducing technology including acidification of slurry in animal housing amongst other, is taken into account. The assumptions on uptake of ammonia reducing technologies are discussed with Danish Environmental Agency (DEPA, 2015a), whose information is based on the environmental approvals register. The expectations to expansion of the biogas production are based on assumptions provided by DEA - the Danish Energy Agency.

The main part of the emissions is related to the livestock production and thus the assumption regarding the expectations to the development is a key element and has a substantial impact on the emission The most important animal categories are dairy cattle and swine, and the development in these productions are less driven by national demand but highly driven by the export market conditions.

6.5 Livestock production

6.5.1 Cattle

Basically the same assumptions as made in the previous projection are used. However, the production of dairy cattle is adjusted downwards due to the real situation in 2013 and 2014 which showed a decrease in production. The same growth rate is used.

The milk yield and the N-excretion are closely related. The estimations used are based on assumptions provided by DCA - Danish Centre for Food and Agriculture (DCA/DCE, 2015). The Danish normative data shows a remarkably increase in milk yield from 2013 to 2014. Until 2020, the milk yield is expected to increase with approximately 75 liter per cow per year and increases from 2020 to 2030 with 125 l/cow/yr. The average milk yield is expected to increase from 9600 l/cow/yr in 2014 to 12000 l/cow/yr in 2030, which correspond to rise of 18 %. This development corresponds to an N-excretion in 2020 for large breed cattle at 148 kg N, increasing to 151 kg N in 2030.

Table 6.2 Number of dairy cattle and milk yield - figures used in the projection to 2030.

	2013	2014	2015	2020	2025	2030
Dairy cattle, 1000 unit	582	563	575	582	594	607
Milk yield, kg milk per cow per year	9 114	9 633	9 708	10 086	10 711	11 336
Large breed, kg N-excretion	142	146	146	148	150	151

The beef cattle production is limited in Denmark and heifers are the main part of the category "non-dairy cattle" and thus mainly driven by the production of dairy cattle. No significant change in the shares of the subcategories of non-dairy cattle; heifers, bulls and suckling cattle, is expected until 2030. The share of each subcategory of non-dairy cattle is based on an average of 2010-2014.

The historic normative data for N-excretion for all cattle sub-categories show few changes. In the projection no significant changes in N-excretion is expected and therefore kept at the same level as in 2014.

6.5.2 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 Danish Environmental Approval Act for Livestock Holdings.

Basically the same assumptions as made in the previous projection are used, but adjusted to a lower level due to a decrease in the production of fattening pigs from 2012 to 2014.

The number of sows is essential for the production of weaners and fattening pigs. In the current projection a production level of 1 million sows is assumed for all years 2015–2030 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, based on an increase in produced weaners per sow.

Assumption on efficiency development in this variable is based on a relatively conservative judgement of an increase of 0.5 piglets per sow per year until 2020 and 0.4 piglets per sow per year for the period 2020-2030. This results in an average production of 37 produced weaners per sow in 2030.

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 11.1 million weaners in 2014 to 13.5 million in 2030, which increase the number of produced weaners from 30.5 million in 2014 to

32.8 in 2020, with a further increase to 36.8 in 2030. This corresponds to a 21 % increase in production of weaners from 2014 to 2030. Because of the rising export of weaners, the production of fattening pigs is expected to increase from 19.8 million in 2014 to 23.3 million in 2030, corresponding to 18 %.

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

Swine, million produced	2013	2014	2015	2020	2025	2030
Sows	1.0	1.0	1.0	1.0	1.0	1.0
Weaners	29.7	30.5	30.3	32.8	34.8	36.8
Fattening pigs	20.1	19.8	19.0	20.8	21.8	23.3

6.5.3 Housing system

In 2014, around 80 % of the dairy cattle and 40 % of the heifers are placed in housing systems with cubicles. In 2020, it is assumed that 99 % 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 16 % expects to be housed in deep litter systems and the remaining part is assumed to be placed in housing systems with cubicles.

In 2014 44 % of the fattening pigs are housed in systems with fully slatted floor. These systems and systems with solid floor and with a 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 2030. 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 2030.

6.5.4 Other livestock categories

All other livestock categories than cattle and swine have a minor effect of the total GHG emission. Except from fur bearing animals, the population is therefore kept at a level equivalent to average production conditions in 2010-2014.

Production of mink has increased particularly from 2.9 million in 2012 to 3.3 in 2014. The mink fur can be considered as a luxury product and the production is very sensitive to conditions on the export market, which can vary considerably. Therefore, production will be maintained at 2014 level until 2030.

6.6 Implementation of emission reducing technology

Emission reducing technology which is included in the projection is biogas treatment of animal manure, sulphuric acid treatment of the slurry in housing, in tank, and during application, housing with air cleaning system (pig housing), heat exchanger in broiler housing and more frequent removal of slurry in mink housing systems.

The reduction in emission factors refers for most of the technologies to the Technology list (DEPAb, 2015) or to VERA verification. DCA has quantified the reduction of methane emission as a consequence of acid treatment of slurry in a GHG scenario project conducted in 2015, and this is used.

Table 6.4 Reducing technology included.

Technology	Location	Category	Compound	Reduction, %	Reference
Acid treatment	Housing	Cattle	NH_3	50	Technology list
	Housing	Swine	NH_3	65	Technology list
	Tank	Cattle	NH_3	49	Technology list
	Tank	Swine	NH_3	40	Technology list
	Housing/tank	Cattle/swine	CH_4	60	DCA, pers.comm. Søren Pedersen
	Application	Cattle/swine	NH_3	49	Technology list
Air cleaning	Housing	Swine	NH_3	70	Technology list
Biogas treatment	Large-scale or farm-scale biogas plants	Cattle/swine	CH_4	30	Preliminary results from ongoing research (DCE/DCA)
Heat exchanger	Housing	Broilers	NH_3	40	VERA test
Removal of slurry – 2 x weekly	Housing	Mink	NH_3	27	Technology list

6.6.1 Biogas treatment of animal manure

Biogas treatment leads to a lower CH_4 emission from animal manure. In 2014, approximately 2.9 million tonnes slurry was treated in biogas plants which are equivalent to approximately 8 % of all slurry. Prognoses provided by DEA assume an increase of biogas production to 12.4 PJ in 2020 and 17.1 PJ in 2030.

Data reported by biogas plants gives an overview of the actual amount and different types of biomass used in biogas production in crop season 2014/2015 (register of Biomass Input to Biogas production). The register does not fully cover all biogas plants but includes the most important biogas producers. DEA estimates that the register 2014/2015 covers 78 % of the total biogas production. However, data given in this register can be used to estimate the relation between the biogas production and the amount of slurry delivered to biogas plants. Based on the preliminary calculations, this relation between biogas production and slurry input will be used to estimate the amount of biomass input for the years 2015-2030.

In 2015, 3.9 Mtonnes of slurry is expected to be delivered to biogas treatment increasing to 12.9 Mtonnes in 2030. It is assumed that cattle slurry account for 58 % and swine slurry for 42 % based on data from the register.

Table 6.5 Biogas production on manure based biogas plants.

Year	Total biogas production [PJ]	Biogas production on manure based biogas plants [PJ]	Slurry delivered to biogas plants [M tonnes]
2015	6.6	5.1	3.85
2020	14.0	12.4	9.36
2025	17.0	15.3	11.55
2030	18.8	17.1	12.92

A biogas task force set up by the DEA has initiated a number of projects in order to improve the Danish emission inventory regarding the reduction of GHG emissions as a consequence of biogas treated slurry. These projects are still in process. However, the preliminary results indicate that biogas treatment of slurry can reduce the CH_4 emission by 30 %. This reduction estimate is used for both the cattle- and swine slurry.

6.6.2 Other emission reducing technologies

Emission reducing technologies are assumed to be implemented in cattle-, swine-, broilers- and mink production.

The environmental technologies are closely related to the growth in livestock production. An expansion of existing or new farms will be met by environmental requirements and the introduction of emission reducing technology maybe the solution chosen. On the other hand, the current economic conditions makes it is difficult for farmers to expand the livestock production. However, barns will be outdated over time, and thus need to be replaced.

Different assumptions and different methods have been used to include the emission reducing technology in the projections. In current projection the emission reducing technology regarding the cattle- and swine production has been in consulting process at DEPA, which are responsible for the environmental approvals register. Based on data in this register combined with information from SEGES and IFRO, DEPA has provided an estimate of implementation rate in 2020 and 2030 (DEPA, 2015a). The DEPA estimate is used, but adjusted to a form which can be implemented in the DCE calculation set-up, which implies that it is converted from percentage of slurry to percentage of production with emission reducing technologies (Table 6.6).

Assessment of ammonia reducing technologies in broiler- and mink housing is provided based on information from a.o. Danish Poultry Meat Association and Kopenhagen Fur (Nielsen et al., 2013).

It is estimated that around 13 % of the cattle slurry is acid treated during application of manure and for swine slurry it is only 1 %. In 2030, it is assumed that 30 % of the cattle slurry and 50 % of the swine slurry is acid treated (Annette Westergaard, Knowledge Centre for Agriculture, Department for Cattle, pers. Comm. 2013).

Table 6.6 Emission reducing technology included.

Technology	Percentage of total production with technology	
Acid treatment in housing	2020	2030
Dairy cattle	5	6
Heifer	4	4
Sows	4	5
Piglets	4	5
Fattening pigs	4	5
Acid treatment in tank	2020	2030
Dairy cattle	6	8
Heifer	4	6
Sows	6	7
Piglets	6	7
Fattening pigs	6	7
Acid treatment during application	2020	2030
Cattle manure	20	30
Swine manure	20	50
Air cleaning	2020	2030
Sows	0,5	0,5
Piglets	0,5	0,5
Fattening pigs	0,5	0,5
Heat exchanger		
Broilers	50	100
Removal of slurry -2 x weekly	2020	2030
Mink	55	100

6.7 Other agricultural emission sources

Besides the livestock production, the most important variable regarding the emission of the greenhouse gases is the use of inorganic N fertiliser on agricultural soils.

6.7.1 Agricultural area

Historical data indicate a decrease in the agricultural area, which is expected to continue. The current projection assumes a decrease by 126 000 ha from 2014-2035, which correspond to 0.23 % per year. This reflects the same trend as seen for the development in agricultural land for 2000-2014. The decrease in agricultural area is a result of urban development and infrastructure, but also due to afforestation and removal of marginal land, such as soils with high organic content (histosols). It is assumed that 1 000 ha of histosols per year is removed from the cultivated area, 1 900 ha per year to afforestation and 3 100 ha per year to urban purposes.

Table 6.7 Agricultural land area in the projection.

	2013	2014	2015	2020	2025	2030
Agricultural land area, 1 000 ha	2 628	2 621	2 615	2 585	2 555	2 525

6.7.2 Use of inorganic N fertilisers

The nitrogen requirement of crops is covered by nitrogen in animal manure and inorganic N fertilisers. The total agricultural area is estimated to be 2 585 kha in 2020 and 2 525 kha in 2030 and it is assumed that 1.4 % is not fertilised. The historical data (2011-2014) shows an average nitrogen requirement of 130 kg N per ha for the total cultivated area. Based on knowledge of nitrogen content in manure (N ex storage) and the nitrogen from other sources, which is included in the farmers fertilisers account, the requirement for nitrogen in inorganic N fertiliser can be calculated (see Table 6.8).

Table 6.8 Consumption of inorganic N fertilisers, kt N.

	2013	2014	2015	2020	2025	2030
N in animal manure (N ex storage), which is included in the farmers' fertiliser accounts	140	141	140	145	149	154
N from sewage storage	7	7	7	6	6	6
N in inorganic N fertilisers	194	187	190	181	173	164

The use of nitrogen in inorganic N fertilisers is estimated to decrease from 194 Gg in 2013 to 164 Gg in 2030, which is a 15 % 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).

6.8 Results

In Table 6.9-6.11 the historical greenhouse gas emission 1990-2013 is listed, followed by the projected emissions 2014-2030. The greenhouse gas emission is expected to decrease from 10.15 million tonnes CO_2 equivalents in 2013 to 10.09 million tonnes CO_2 equivalents in 2020. Until 2030 an increase to 10.30 million tonnes CO_2 equivalents is estimated. Thus, the projection indicates an increased emission by 1 % from 2013 to 2030. The increased emission is mainly a result of an increase in the CH_4 emission due to increase of the dairy cattle production. The CO_2 emission comes from liming, urea application and application of other carbon containing fertilisers.

Table 6.9 Total historical (1990-2013) and projected (2014-2030) emission, given in CO_2 eqv.

CO_2 equivalents, million tonnes	1990	2000	2013	2014	2015	2020	2025	2030	Average 2011/15
CH_4	5.53	5.48	5.39	5.42	5.52	5.54	5.72	5.86	5.42
N_2O	6.34	5.15	4.51	4.53	4.41	4.36	4.30	4.24	4.49
CO_2	0.62	0.27	0.25	0.24	0.20	0.20	0.19	0.19	0.21
Agriculture, total	12.49	10.90	10.15	10.19	10.13	10.09	10.21	10.30	10.12

6.8.1 CH_4 emission

The overall CH_4 emission has decreased from 221 kt CH_4 in 1990 to 216 kt CH_4 in 2013 but is projected to increase to 235 kt CH_4 in 2030 corresponding to an increase of 9 % (Table 6.10).

The decrease in emission from enteric fermentation from 1990 to 2013 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 to 2030. 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 to 2013, which is a result of change in housing systems towards more slurry based systems. In future the emission is estimated first to decrease due to implementation of acidification of the manure in the housings but to increase again due to increase in number of animals.

Table 6.10 Historical (1990-2013) and projected (2014-2030) CH_4 emission.

CH_4 emission, kt	1990	2000	2013	2014	2015	2020	2025	2030	Average 2011/15
Enteric fermentation	152.0	135.5	138.7	140.1	145.3	147.7	153.5	157.5	139.3
Manure management	69.2	83.6	76.7	76.5	75.4	73.7	75.1	77.0	77.4
Field burning	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total CH_4, kt	221.2	219.2	215.5	216.7	220.8	221.5	228.7	234.5	216.8

The numbers in this table should be multiplied with a GWP value of 25, to calculate the CO_2e presented in Table 6.9.

6.8.2 N_2O emission

The N_2O emission is reduced from 1990 to 2013, in the projected period 2014-2030 the emission is also estimated to decrease, corresponding to an emission in 2030 of 14.23 kt N_2O. This is a reduction of 6 % (Table 6.11).

Due to an increased number of animals the amount of manure applied to soil increases. The emission from the use of inorganic N fertiliser 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 for inorganic N fertiliser.

Table 6.11 Historical (1990-2013) and projected (2014-2030) N_2O emission.

N_2O emission, kt	1990	2000	2013	2014	2015	2020	2025	2030	Average 2010/14
Manure management	2.62	2.58	2.07	2.05	1.95	1.89	1.84	1.81	2.05
Indirect N_2O emission	0.66	0.61	0.47	0.47	0.45	0.45	0.45	0.45	0.48
Inorganic N fertiliser	6.29	3.95	3.04	2.94	2.98	2.84	2.72	2.58	3.00
Animal manure applied to soils	3.37	3.08	3.26	3.27	3.27	3.49	3.60	3.74	3.26
Sludge applied to soils	0.07	0.14	0.11	0.11	0.10	0.10	0.10	0.10	0.10
Urine and dung deposited by grazing animals	1.00	1.01	0.62	0.62	0.56	0.53	0.54	0.54	0.60
Crop residues	1.91	1.83	2.15	2.33	2.19	2.16	2.13	2.11	2.21
Mineralization	0.64	0.42	0.57	0.57	0.50	0.50	0.49	0.49	0.47
Histosols	1.82	1.57	1.23	1.17	1.14	1.03	0.93	0.83	1.22
Atmospheric deposition	1.05	0.67	0.51	0.51	0.51	0.49	0.47	0.45	0.51
Nitrogen leaching and run-off	1.84	1.39	1.11	1.17	1.14	1.15	1.14	1.14	1.15
Field burning	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Total N_2O, kt	21.28	17.26	15.14	15.21	14.80	14.63	14.42	14.23	15.06

Note: The numbers in this table should be multiplied with a GWP value of 298, to calculate the CO_2e presented in Table 6.9.

6.9 16-point plan – emission consequences

The current government has proposed a "16-point plan" to limit regulatory requirements for the agricultural production and to allow increased fertilization. This plan was not yet adopted when the current project was conducted and the emission consequences of it are not taken into account. However, some of the points can include actions which potentially may lead to change in emission. This chapter covers some considerations of points in the programme which may have a relation to changes in greenhouse gas emission.

1) Phasing out the fertilization norms. The N_2O emission is closely related to the use of nitrogen. An increase of N input in the agricultural production will cause an increase of N_2O corresponding to 1 kg N_2O-N per kg N input. Assuming that the fertilizer situation in 2014 is 15 % below the economic optimum a cancellation of the fertilizer norm may lead to a 15 % increase of fertilization. This can increase the N_2O emission (incl. emission from N-leaching) with 1.86 kt N_2O emission corresponding to 0.55 CO_2 eqv. per year. However, it is not necessarily all farmers which will use the opportunity to increase the fertilization level by 15 %.

2) No requirements to buffer zones and 60 000 ha catch crops. The emission inventory includes ammonia emission from growing crops and N_2O emission from crop residues. The emission is depending on crop type as wheat, barley etc. In the Agreement of Green Growth a removal of 50 000 hectare buffer zones was planned. If this area continues to be a part of the cultivated area with an average fertilization 130 kg N per hectare (based on average 2011 – 2014), the increase in emission can be quantified to 0.18 kt N_2O per year or 0.05 CO_2 eqv.

3) Separate regulation of housing and land area. Regulation of livestock facilities are planned to be separated from regulation of agricultural soils, so emissions requirements will be related to emission output rather than to the number of animal units. The consequences of this regulation are not quantified. The change in the regulation could for some farmers create the possibilities for expansion, but will also depend on livestock holding approval and good economic conditions.

4) Organic agriculture - enhancing competitiveness and export. No emission calculation separately for organic livestock production is provided in the inventory. The Danish normative standard does not distinguish between organic- and conventional livestock production. A number of different studies exist on comparison between organic and conventional production, but there is no clear conclusion on emission differences between the two farming systems.

5) Change of harmony requirements. Change in area requirements for swine production from the current 1.4 to 1.7 animal units per hectare can result in increases of the pig production. Danish Agriculture & Food Council has estimated that this could lead to increased production of fattening pigs with 1-1½ million in 2030. By using the average CH_4 emission per produced swine (2014), the increase in emission of CH_4 and N_2O from 1-1½ million extra produced swine is estimated to 0.24 – 0.36 Mtonnes CO_2 eqv. in 2030. It is important to emphasize that this expansion of the pig production not only depends on the harmony requirements, but also is highly depending on the farmers' possibilities to get an environmental permit and on the economic situation.

Table 6.13 Quantification of changes in GHG emission as a consequence of the 16 points programme (worst case situation).

Emission consequences		N_2O, kt per yr	CO_2 eqv., million tonnes per yr
Out phasing of N norm		1.86	0.55
No buffer zones		0.18	0.05
Separately environmental regulation for housing			Not quantified
Increase of organic agricultural production			Not quantified
	CH_4, kt in 2030	N_2O, kt in 2030	CO_2 eqv., million tonnes in 2030
Harmony requirements - swine	2.1 – 3.1	0.6 -1.0	0.24 – 0.36

6.10 References

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7 Waste

7.1 Solid waste disposal on land

The CRF source category *5.A Solid waste disposal*, gives rise to CH_4 emissions.

CH_4 emissions are calculated by means of a first order decay (FOD) emissions model, where activity data are annual data for the amount of waste deposited and where emission 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., 2015.

7.1.1 Emissions model

The model has been developed and used in connection with the historic emission 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-called 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 2015 NIR report (Nielsen et al., 2015). In short, the degradation and release of methane is modelled according to 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., 2015.

7.1.2 Activity data

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.

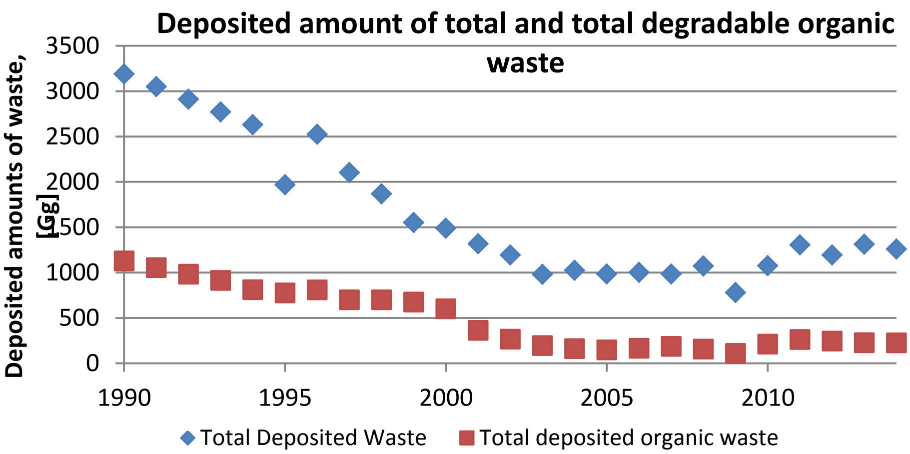

Figure 7.1 Historical data on the total amount of waste, i.e. organic/degradable and inert/non-degradable waste, and total organic waste disposed of at solid waste disposal sites.

According to DEPA (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, 2013, 2014, 2015a). According to the national projection of the generation and treatment of waste, a minor increase in percentage of the total waste being deposited at landfills will occur which is however lower than the estimated reduction in total amount of primary waste estimated to be deposited at landfills taking into account the impacts of implementation of the National Resource Action Plan for waste management (DEPA, 2015b). In the present projection of methane emissions from SWDSs, the characteristics and total amounts of waste have been set constant throughout the projection period 2015-2035, and equal to the average of the data reported in the period 2011-2014. It should be mentioned, that some landfills receiving mainly soil and stones are excluded from the dataset received from the Danish EPA in relation to the present projection of methane emissions from the Danish waste disposal sites; the latter does however not influence the modelled methane emissions as soil and stone are characterised as a climate inert waste fraction in the FOD model (Nielsen et al., 2014 and 2015).

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 2015 onwards.

7.1.3 Historical and projected activity data and emissions

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 organic matter	Annual amount of degraded organic matter	Annual deposited CH_4 potential	Annual Gross CH_4 emission	Recovered methane	Annual net emission after oxidation	Implied Emission Factor Gg/Gg
1990	3190	1128	2813	135	98	79	1	71	0.022
1995	1969	776	2768	132	62	77	8	62	0.032
2000	1489	601	2664	124	65	68	11	51	0.034
2005	983	147	2227	105	10	59	10	44	0.045
2010	1075	212	1844	85	6	47	6	37	0.035
2011	1305	261	1783	81	10	45	4	37	0.028
2012	1193	244	1717	78	12	43	4	36	0.030
2013	1311	227	1652	75	7	42	4	34	0.026
2014	1258	226	1589	72	6	40	3	33	0.026
2015	1267	240	1533	69	5	38	3	31	0.025
2020	3190	1128	1294	57	8	31	3	25	0.020
2025	1969	776	1108	47	8	26	3	20	0.016
2030	1489	601	962	40	8	22	3	17	0.013
2035	983	147	846	35	8	19	3	14	0.011

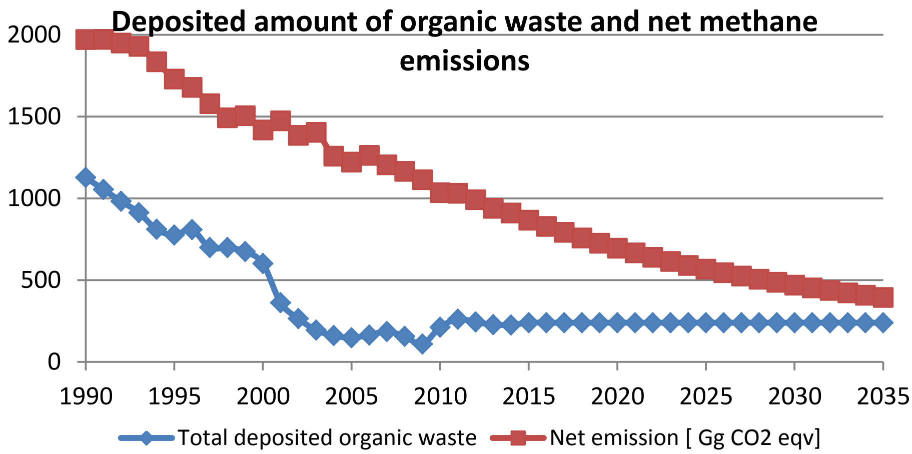

Figure 7.2 Historical and projected amounts of waste deposited at landfill and net CH_4 emissions. Historic data: 1993-2009. Projections: 2010-2035. All in Gg.

The reason for the sharp decrease in historical data on deposited amounts of organic waste in the period 1990-2009, is to be found in a combination of the Danish waste strategies and action plans including goals for a continued minimising the amount of deposited waste in favour of an increased reuse and combustion for energy production. It is assumed that the sum of primary and secondary organic waste has reached a constant low level (see above), which may decrease upon the implementation of the upcoming European action plan for the circular economy (COM(2015) 614/2).

Lastly, it should be mentioned that the impact of implementing the Biocover instrument have not been included in the projected methane emissions (Tværministeriel arbejdsgruppe, 2013). Work is ongoing to document the effect with the aim of including this in future projections.

7.2 Biological Treatment

The CRF source category *5.B Biological Treatment of Solid Waste,* gives rise to CH_4 and N_2O emissions. In Denmark, biological treatment of solid biological waste includes composting of:

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

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. (2015) are used for this projection.

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

	Garden and Park waste (GWP)	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

7.2.2 Activity data

Garden and park waste for 1995-2009 is 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 are not used for the projection as 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* from a linear regression of the 1995-2009 data.

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 1990-2014 data are used in a linear regression to project home composting for 2013-2035.

Table 7.3 Projected activity data for compost production, Gg.

Gg	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Garden and park waste	1005	1031	1056	1082	1108	1133	1159	1184	1210	1235	1261
Organic waste	56	56	56	56	56	56	56	56	56	56	56
Sludge	138	143	148	153	158	163	168	173	178	183	188
Home composting	23	23	24	24	24	24	24	24	24	25	25

Continued

	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Garden and park waste	1286	1312	1338	1363	1389	1414	1440	1465	1491	1516
Organic waste	56	56	56	56	56	56	56	56	56	56
Sludge	193	198	203	208	213	218	223	228	233	238
Home composting	25	25	25	25	25	25	26	26	26	26

7.2.3 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	1,4	1,9	3,1	3,4	3,0	3,8	3,5	5,0	5,0	4,6
N_2O	0,04	0,1	0,5	0,2	0,3	0,3	0,3	0,4	0,4	0,4
CO_2 equivalents	47,0	68,1	232,4	144,6	151,1	190,3	175,3	247,5	247,5	236,6
Continued										
	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
CH_4	4,7	4,9	5,0	5,1	5,2	5,3	5,4	5,5	5,6	5,7
N_2O	0,4	0,4	0,4	0,5	0,5	0,5	0,5	0,5	0,5	0,5
CO_2 equivalents	243,1	249,7	256,2	262,7	269,3	275,8	282,3	288,8	295,4	301,9
Continued										
	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
CH_4	5,8	6,0	6,1	6,2	6,3	6,4	6,5	6,6	6,7	6,8
N_2O	0,5	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,7
CO_2 equivalents	308,4	315,0	321,5	328,0	334,6	341,1	347,6	354,1	360,7	367,2

7.3 Waste Incineration

The CRF source category *5.C Waste Incineration,* includes cremation of human bodies and cremation of animal carcasses that gives rise to CH_4 emissions.

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 1990-2014.

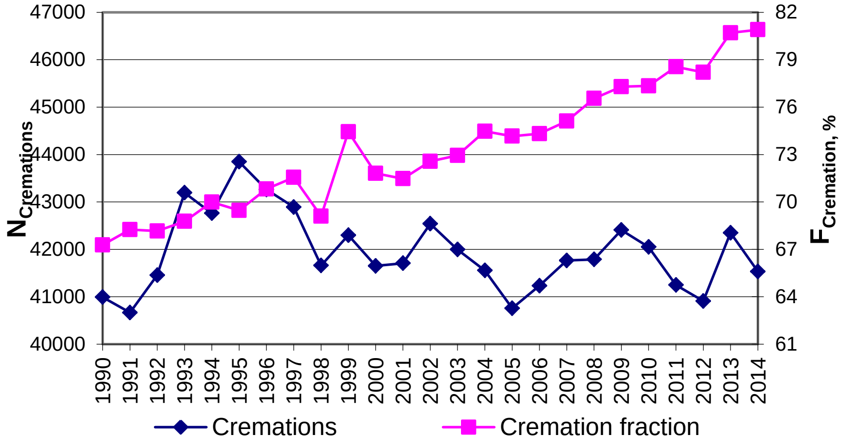

Figure 7.3 The development in the number of annual cremations.

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 1990-2014 data.

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
Population	5 602 628	5 627 235	5 648 580	5 668 253	5 687 089	5 705 758	5 725 204	5 746 161	5 768 823
Deaths	52 471	56 272	56 486	56 683	56 871	57 058	57 252	57 462	57 688
Cremation fraction	80.70%	78.8%	79.3%	79.8%	80.3%	80.7%	81.2%	81.7%	82.2%
Cremations	42 349	44 361	44 797	45 222	45 643	46 064	46 492	46 936	47 395

Continued

	2022	2023	2024	2025	2026	2027	2028	2029	2030
Population	5 792 613	5 816 931	5 841 292	5 865 324	5 888 879	5 911 715	5 933 696	5 954 748	5 974 766
Deaths	57 926	58 169	58 413	58 653	58 889	59 117	59 337	59 547	59 748
Cremation fraction	82.6%	83.1%	83.6%	84.1%	84.5%	85.0%	85.5%	86.0%	86.4%
Cremations	47 865	48 342	48 822	49 302	49 779	50 253	50 722	51 184	51 640

Continued

	2031	2032	2033	2034	2035
Population	5 993 782	6 011 772	6 028 756	6 044 770	6 059 816
Deaths	59 938	60 118	60 288	60 448	60 598
Cremation fraction	86.9%	87.4%	87.9%	88.3%	88.8%
Cremations	52 089	52 531	52 966	53 394	53 814

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. (2015).

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 1998-2014.

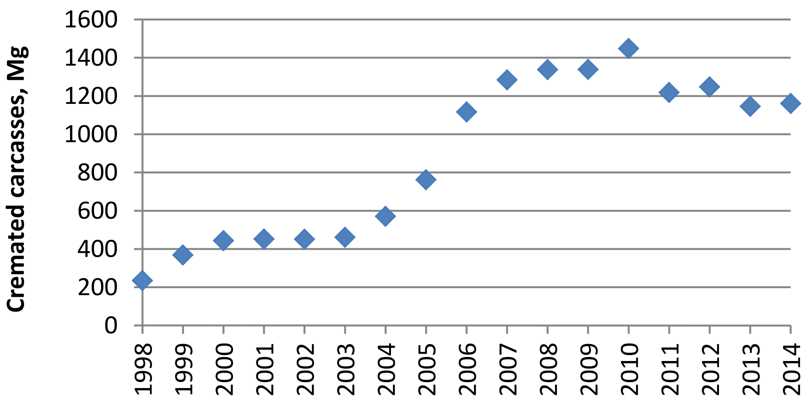

Figure 7.4 Cremated amount of carcasses, 1998-2014.

It is assumed that the 2013-2035 projection of activity data for animal cremation can be described by the constant average of the years 2009-2014.

Table 7.6 Amount of incinerated carcasses.

	2009	2010	2011	2012	2013	2014	Average
Cremated carcasses, Mg	1339	1449	1219	1248	1146	1161	1280

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. (2015).

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	0.49	0.53
Animal cremation	Mg	0.03	0.04	0.08	0.14	0.26	0.22	0.22	0.24	0.21	0.24
Total	Mg	0.51	0.55	0.57	0.62	0.76	0.71	0.70	0.74	0.70	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	0.61	0.66
Animal cremation	Mg	0.03	0.05	0.10	0.17	0.33	0.28	0.28	0.30	0.26	0.30
Total	Mg	0.64	0.69	0.71	0.77	0.95	0.88	0.88	0.92	0.87	0.96
5C. Waste incineration											
CO_2 equivalents	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	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Total	Mg	0.76	0.77	0.77	0.78	0.78	0.79	0.79	0.80	0.81	0.81
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	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Total	Mg	0.95	0.96	0.97	0.97	0.98	0.99	0.99	1.00	1.01	1.01
5C. Waste incineration											
CO_2 equivalents	Gg	0.30	0.31	0.31	0.31	0.31	0.31	0.32	0.32	0.32	0.32
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	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Total	Mg	0.82	0.82	0.83	0.83	0.84	0.84	0.85	0.85	0.86	0.86
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	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Total	Mg	1.02	1.03	1.04	1.04	1.05	1.06	1.06	1.07	1.07	1.08
5C. Waste incineration											
CO_2 equivalents	Gg	0.32	0.33	0.33	0.33	0.33	0.34	0.34	0.34	0.34	0.34

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., (2015) and Thomsen (2016).

Emission from the sewer system, primary settling tank and biological N and P removal processes

The fugitive emissions from the sewer system, primary (and secondary) settler tanks (clarifiers) and aerobic biological treatment processes, $CH_{4,sewer+MB}$, are estimated as:

$$CH_{4,sewer+MB} = EF_{sewer+MB} \cdot TOW_{inlet}$$

$$\Downarrow$$

$$CH_{4,sewer+MB} = B_o \cdot MCF_{sewer+MB} \cdot TOW_{inlet}$$

where TOW_{inlet} equals the influent organic degradable matter measured as the chemical oxygen demand (COD) in the influent wastewater flow, B_o is the default maximum CH_4 producing capacity, i.e. 0.25 kg CH_4 per kg COD (IPCC, 2006).

The fraction of *TOW* that is unintentionally converted to CH_4 in sewers, primary clarifiers and aerobic biological treatment processes, $MCF_{sewer+MB}$, is set equal to 0.003 based on an expert judgement . The emission factor, $EF_{sewer+MB}$, for these processes equals 0.00075 kg CH_4 per kg COD in the inlet wastewater (Nielsen et al., 2015; Thomsen, 2016). An overview of the historical and projected amount of COD in the influent wastewater is provided in Table 7.8.

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

Year	1990	1995	2000	2005	2010	2011	2012
TOW	295	327	365	364	372	378	364
Year	2013	2014	2015	2020	2025	2030	2035
TOW	383	332	333	338	344	350	354

"TOW, National Unit PE BOD value" are the national BOD value of 21.9 kg BOD per year multiplied by a national COD/BOD conversion factor of 2.7 and multiplied by the population number of Denmark (Thomsen, 2016).

Methane emissions from anaerobic treatment processes

The net methane emission from anaerobic digestion in biogas tanks are at present estimated according to the below equation for the whole time series:

$$CH_{4,AD} = EF_{AD} \cdot CH_{4,AD,recovered}$$

where the emission factor, EF_{AD}, has been set equal to 1.3 %, i.e. 0.013, of the methane content in the gross energy production at national level reported by the Danish Energy Agency. Table 7.9 shows the historical and projected gross energy production reported by the Danish Energy Agency.

Table 7.9 Gross Energy production [TJ] and the corresponding methane content [Gg CH_4].

Year	1990	1995	2000	2005	2010	2011	2012
Energy production	58	598	857	913	840	822	922
CH_4 content	8,8	11,5	16,4	17,5	16,1	15,7	17,7
Year	2013	2014	2015	2020	2025	2030	2035
Energy production	939	1019	1084	1200	1300	1300	1300
CH_4 content	18,0	19,5	20,8	23,0	24,9	24,9	24,9

The methane content in the biogas is calculated from the calorific value 23 GJ/1000 m^3 biogas provided by the Danish Energy Agency, a percent volume content of methane of 65 % and a density of 0.68 kg CH_4/Nm^3

Methane emissions from septic tanks

Methane emission from septic tanks is calculated as:

$$CH_{4,st} = EF_{st} \cdot f_{nc} \cdot P \cdot DOC_{st}$$

where the emission factor is calculated from the default IPCC value quantifying the maximum methane producing capacity B_o of 0.25 kg CH_4 per kg COD multiplied by the methane conversion factor for septic tanks, corresponding to the amount of suspended organic material that settles in the septic tank, equal to 0.5 (IPCC, 2006). Hence, an EF_{st} value of 0.125 kg CH_4 per kg COD is obtained.

The fraction of the population, P, not connected to the collective sewer system, f_{nc}, is set equal to 10 % for the entire time series estimated from National statistics of scattered houses in percent of the total number of households in Denmark (DME, 2014; Statistics Denmark).

Lastly, the default IPCC value of the per capita produced degradable organic matter, DOC_{st}, i.e. 22.63 kg BOD per person corresponding to 56.6 kg COD per person (IPCC, 2006), were used.

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., 2015). The population numbers used for deriving historical and projected emissions from septic tanks is provided in table 7.10.

Table 7.10 Population numbers and projections for Denmark.

1990	1995	2000	2005	2010	2011	2012
5135	5216	5330	5411	5535	5561	5581
2013	2014	2015	2020	2025	2030	2035
5603	5615	5633	5723	5821	5911	5984

Historical data: 1990-2014, Projected data: 2015-2035.

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. (2015) and Thomsen (2016).

Nitrous oxide

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., 2015) 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 2005-2013 and projected according to population statistics (Table 7.10). A person equivalent (PE) value for the N content in the influent wastewater of 5.5 kg total N per year was obtained, which is higher compared to the value of 4.4 for normal household wastewater defined in the Executive Order No. 1448, 2007. This 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 collective sewer system as substances from industrial, road, rain, infiltration, etc. is also fed to the WWTP via the sewer system. Total N in the influent and effluent wastewater is presented in Table 7.11 and total N_2O emissions from wastewater treatment and discharge in Table 7.12.

Table 7.11 Total N in the influent and effluent waste waters [Mg].

Year	1990	1995	2000	2005	2010	2011	2012
Influent N	14 679	22 340	26 952	32 288	27 357	30 049	26 316
Effluent N	16 884	15 152	10 005	7038	6960	6809	6597
Year	2013	2014	2020	2025	2030	2035	
Influent N	29 557	30 638	31 228	31 759	32 254	32 648	
Effluent N	6399	6698	6711	6774	6843	6907	

Historical data: 1990-2013, Projected data: 2014-2035.

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 is observed and the 2013 emission data are 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 2005-2013; 0.7 Mg N/person/yr for the years 2005-2013.

The emission projection for the total N_2O emission is provided in Table 7.12.

Remarks to the presented projection of nitrous oxide from wastewater handling

Direct emissions from wastewater treatment within industries are missing in the historical as well as projected N_2O emissions from wastewater treatment plants in Denmark (Thomsen, 2015).

The default IPCC emission factor for N_2O emissions from domestic wastewater nitrogen effluent is 0.0056 (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 implemented in the present emissions projections.

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., 2015) 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 Methane and nitrous oxide emission from wastewater treatment and discharges, Gg

Year	1990	1995	2000	2005	2010	2011	2012
$CH_{4,\text{ sewer system and MB}}$	0.21	0.24	0.26	0.26	0.27	0.27	0.26
$CH_{4,\text{ septic tanks}}$	3.35	3.40	3.47	3.53	3.61	3.62	3.64
$CH_{4,\text{ AD}}$	0.11	0.15	0.21	0.23	0.21	0.20	0.23
$CH_{4,\text{ net emission}}$	3.67	3.78	3.95	4.02	4.08	4.10	4.13
$N_2O_{,\text{ total}}$	0.34	0.35	0.29	0.27	0.25	0.26	0.23
$CO_{2\text{eqv.,total}}$	193	199	186	181	175	179	173
Continued							
Year	2013	2014	2015	2020	2025	2030	2035
$CH_{4,\text{ sewer system and MB}}$	0.28	0.24	0.24	0.24	0.25	0.25	0.25
$CH_{4,\text{ septic tanks}}$	3.65	3.66	3.67	3.73	3.79	3.85	3.90
$CH_{4,\text{ AD}}$	0.23	0.25	0.27	0.30	0.32	0.32	0.32
$CH_{4,\text{ net emission}}$	4.16	4.15	4.18	4.27	4.37	4.43	4.48
$N_2O_{,\text{ total}}$	0.25	0.24	0.25	0.25	0.25	0.25	0.26
$CO_{2\text{eqv.,total}}$	178	177	178	181	184	187	189

Historical data: 1990-2013, Projected data: 2014-2035.

The total N_2O and net CH_4 emission figures converted to CO_2 equivalents and the sum up result for emissions from wastewater treatment and discharge are provided in the last row of Table 7.12.

Further measures

WWTPs

An ongoing development project for the restructuring and optimisation of wastewater treatment technologies for optimised conversion of COD into CH_4 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 allocated to the digester tank with increased biogas production, improved aeration technologies at the secondary treatment step etc http://www.udviklingssamarbejdet.dk/prioriterede-omr%C3%A5der).

Scattered settlements

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 settlements obtained from the Danish Nature Agency.

Indirect emissions from mariculture and fish farming

As part of the water plan of the 23 water districts in Denmark cultivation of mussels and algae species on lines are mentioned as instruments for nutrient extraction (NA, 2013). Furthermore, initiatives 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 policy on growth (Green Growth, 2009) will have on the indirect emission from mariculture and fish farming. Furthermore, research is ongoing to verify the extent to which nutrient harvest through green engineered offshore blue biomass production can counterbalance an expected increased N effluent from fish farms (e.g. Skermo et al., 2014). These aspects will be included in future emission projections when new knowledge is available.

7.5 Other

The sub-sector category 5.E Other is a catch up for the waste sector. Emissions presently included in this category are accidental building and vehicle fires.

7.5.1 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 2010-2014 data.

Table 7.13 Number of accidental building fires 2010-2014.

	2010	2011	2012	2013	2014	Average
Container FSE fires	594	729	584	584	584	615
Detached house FSE fires	833	818	742	761	660	763
Undetached house FSE fires	194	206	181	162	318	212
Apartment building FSE fires	348	362	327	316	299	330
Industrial building FSE fires	281	334	298	275	751	388
Additional building FSE fires	429	740	610	619	577	595
All building FSE fires	2678	3189	2741	2717	3189	2903

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.

7.5.2 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 7.14.

Table 7.14 Population of vehicles.

	Passenger cars	Buses	Light duty vehicles	Heavy duty vehicles	Motorcycles /Mopeds	Caravans	Trains	Ships	Airplanes	Tractors	Combine harvesters
2013	2 296 253	13 176	335 764	43 500	296 094	146 184	2763	1757	1112	98 872	17 564
2014	2 255 398	13 174	347 453	44 074	296 359	148 967	2763	1757	1114	94 666	16 429
2015	2 210 396	13 173	363 353	44 706	296 628	151 749	2763	1757	1117	89 087	14 857
2020	2 188 820	13 169	426 724	48 111	300 906	165 662	2763	1757	1128	75 879	13 996
2025	2 301 824	13 166	462 698	51 626	307 915	179 574	2763	1757	1140	73 075	11 923
2030	2 415 081	13 163	496 761	55 448	315 257	193 487	2763	1757	1151	67 106	11 234
2035	2 534 453	13 161	533 221	59 685	322 631	207 399	2763	1757	1163	65 021	10 636

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 7.15 Average number of full scale vehicle fires relative to the total number of nationally registered vehicles for 2010-2014.

Category	Fraction, %
Passenger cars	0.03
Buses	0.13
Light duty vehicles	0.01
Heavy duty vehicles	0.13
Motorcycles/Mopeds	0.03
Caravans	0.03
Trains	0.11
Ships	1.05
Airplanes	0.06
Tractors	0.06
Combine harvesters	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 2010-2014 is used in the projection 2015-2035. By assuming that the average number of FSE fires from 2010-2014 (shown in Table 7.15), is applicable for describing the risk of accidental fires in the future vehicle population, activity data for the projection 2015-2035 can be calculated.

Table 7.16 Projection of number of full scale equivalent accidental vehicle fires.

	2015	2016	2017	2018	2019	2020	2021	2025	2030	2035
Passenger cars	619	608	600	603	608	613	619	645	676	710
Buses	17	17	17	17	17	17	17	17	17	17
Light duty vehicles	41	43	45	47	48	49	49	53	56	61
Heavy duty vehicles	60	61	61	63	63	64	65	69	74	80
Motorcycles/mopeds	99	99	99	100	100	101	101	103	105	108
Other transport	70	70	70	70	70	70	70	70	70	70
Caravans	39	40	41	41	42	43	44	46	50	54
Trains	3	3	3	3	3	3	3	3	3	3
Ships	18	18	18	18	18	18	18	18	18	18
Airplanes	1	1	1	1	1	1	1	1	1	1
Bicycles	3	3	3	3	3	3	3	3	3	3
Tractors	57	54	53	51	50	49	48	47	43	42
Combine harvesters	23	22	22	22	22	22	21	19	17	17
Machines	113	113	113	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 7.17 Average vehicle weight in 2012, kg.

Passenger cars	1160
Buses	11 625
Light duty vehicles	4150
Heavy duty vehicles	10 844
Motorcycles/Mopeds	136
Combine harvesters	12 800

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 7.18.

Table 7.18 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. (2015) are used for this projection.

7.5.3 Historical emission data and projections

Table 7.19 gives an overview of the Danish non-biogenic greenhouse gas emission from the CRF source category *5.E Waste Other*.

Table 7.19 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 equivalents	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 equivalents	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 equivalents	Gg	20.88	20.91	20.96	21.00	21.06	21.11	21.15	21.20	21.26	21.33

7.6 Emission overview

The total emissions from the waste sector are presented in Table 7.20 below.

Table 7.20 Emissions from the waste sector in kt CO_2 equivalents.

		1990	2000	2010	2014	2015	2020	2025	2030
5A	Solid waste disposal	1774	1276	931	819	780	626	510	422
5B	Biological treatment of solid waste	47	235	152	248	237	269	302	335
5C	Incineration and open burning of waste	0	0	0	0	0	0	0	0
5D	Waste water treatment and discharge	200	194	184	177	178	181	184	187
5E	Other	19	20	20	21	21	21	21	21
	Total	2041	1725	1288	1265	1215	1097	1017	965

7.7 Source specific recalculations

For the solid waste disposal minor changes, i.e. less than ±10%, have occurred, which is due to a change in the reference year of the national model from 1960 to 1940 according to the IPCC (2006) guidelines.

For category 5B Biological treatment of solid waste, activity data received from the Danish EPA has resulted in a reduction in the total amount of bio-waste composted in 2010-2014. The new data system on composting is associated with high uncertainties due to difficulties in the implementation of the new reporting system. The reduction in the projected emissions is less than 5%.

For category 5C, a minor decrease of less than 1% is observed, which is due to a change in the activity; i.e. the basis for the projection has shifted to the last five years.

For category 5D Wastewater treatment and discharge, there is a general increase in the CO_2 eqv. emissions of 9 %, which is explained by a change in activity data and methodology as described in Nielsen et al., 2015.

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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, the 2006 IPCC Guidelines (IPCC 2006) and the 2013 Wetlands Supplement (IPCC 2014) has been taken into account.

Approximately two thirds of the total Danish land area is cultivated and 14.3 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 distribution shown will therefore differ from other national statistics.

Land use conversions impacts whether a category is a sink or a source. In the following, emissions by sources are provided as positive values (+) and removals by sinks as negative values (-).

Under the Kyoto Protocol, Denmark has elected 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 and Forest Management under article 3.4. 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 8.10.

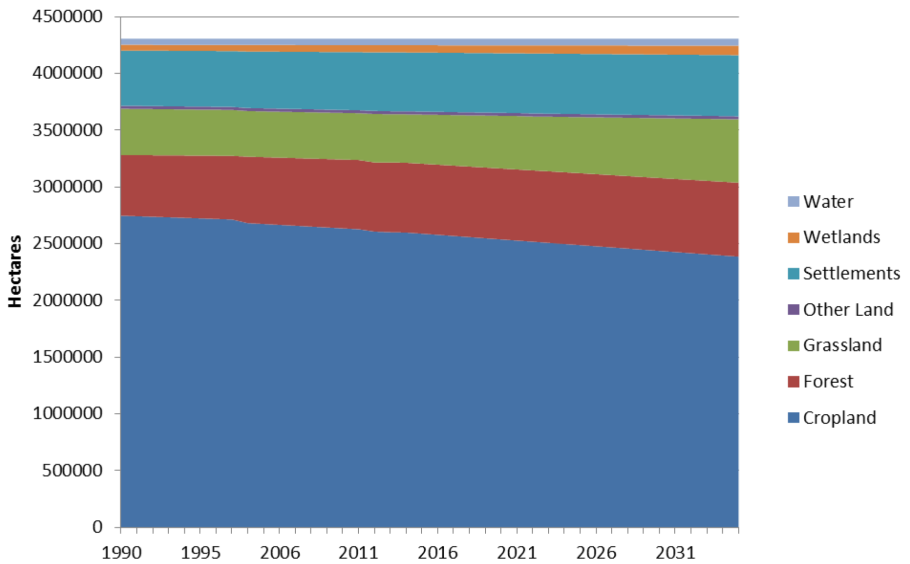

Figure 8.1 Land area use 1990-2035.

Table 8.1.a and b shows the projected average land use changes between the different land use categories. Two distinct periods has been chosen, from 2015 to 2020 where it is expected that an average of 1911 ha is converted to wetlands due to the current economic funding for restoration of wetlands (Ministry of Environment and Food, 2015). From 2021 and onwards a wetland restoration of only 969 ha per year is expected. This approximately corresponds to the current annual decrease in the agricultural area on organic soils (>12 per cent organic carbon).

Table 8.1.a The general annual land use change in hectares per year from 2015-2020.

	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	16	8		78	0	26	21	149
Grassland	576	23	899		0	792	0	2290
Other land	0	0	0	0		0	0	0
Wetland, partly water covered	0	0	0	0	0		0	0
Cropland	748	141	1000	7702	0	1093		10 684
Total, ha per year	1340	172	1899	7779	0	1911	21	13 123

Table 8.1.b The general annual land use change in hectares per year from 2021-2035.

	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	16	8		78	0	26	21	149
Grassland	576	23	899		0	396	0	1894
Other land	0	0	0	0		0	0	0
Wetland, partly water covered	0	0	0	0	0		0	0
Cropland	748	141	1000	7702	0	546		10 137
Total, ha per year	1340	172	1899	7779	0	969	21	12 181

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 dry matter (dm)/ha
	Grassland	8.360 tonnes dm/ha
	Wetlands	13.680 tonnes dm/ha
	Settlement	4.400 tonnes dm/ha
Default amount of C in soils	Forest	158 tonnesC/ha
	Cropland	151 tonnesC/ha
	Grassland	150 tonnesC/ha
	Wetlands	No changes assumed when converted from other land uses
	Settlements	120 tonnesC/ha
		Emissions
Soil	Crop in rotation: Organic soils >12% OC	11.5 tonnesC/ha/yr 13 kg N_2O-N/ha/yr
	Crop in rotation: Organic soils 6-12 % OC	5.75 tonnesC/ha/yr 6.25 kg N_2O-N /ha/yr
	Permanent Grassland: Organic soils >12% OC	8.4 tonnesC/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 tonnesC/ha/yr 4.1 kg N_2O-N /ha/yr
	Forest land, drained: Organic soils >12% OC	2.6 tonnesC/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 tonnesC/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 independently provided a projection to the Danish Energy Agency. The parameters in IGNs projection are almost identically with those used here, but a minor deviation is foreseen. The raw data from IGN has not been available for this part of the projection and therefore some of the tables are deliberately not filled in (changes in living, dead biomass and emission from organic soils in the forest in this projection. It is assumed that a continuous afforestation rate of 1899 ha per year is taking place and a deforestation of 149 ha per year. Changes in soil mineral carbon stocks in the forest due to land use conversion are included.

Since 1990 the forested area has increased. This is expected to continue in the future as a Danish policy aim is to double the forest area from 1980 to 2080. Afforestation is expected to take place on 1899 hectares per year in the future. No estimates are provided for the accumulative carbon storage in the afforested area, but emission from the related conversion of other land uses to forest is included in this projection.

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 149 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 for settlements is assumed. No estimates are given for the carbon stock in the deforested areas.

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 covers the far majority.

Cropland is subdivided into four types: Agricultural cropland which is the area defined by Statistics Denmark, Wooden agricultural crops which are fruit trees, willow, Christmas trees on Cropland 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 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 around 7 000 hectares of agricultural land every year. This loss is split on Cropland and Grassland. Not all of this land is leaving the Cropland and Grassland to other LULUCF categories. In the land use matrix, it is assumed that approximately 4 300 ha per year is leaving to land use categories and the remaining is reported in Cropland and Grassland.

The Danish government decided that 25 000 hectares along water courses should be converted to unmanaged grassland by the end of 2014 (Ministry of the Environment, 2014). This is implemented by 1 September 2014 as 9 meter buffer strips along all water courses and ponds. The buffer zones will consist of grassland and should 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 25000 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. 140 kt CO_2 eqv. 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. C-TOOL has been used for this projection. 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 Danish Meteorological Institute (DMI, 2012) scenario A1B.

Hence, an annual loss of approximately 960 kt 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 are based on high organic soils with an organic carbon content >12 % organic carbon (OC) and soils having a medium soil OC, 6-12 %. 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. Very few measured values can be found for these soils, but as they are drained they will experience a continuous degradation of the OC until they reach the equilibrium state between input and degradation, which is around 2-3 % OC in most cultivated 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 assumed to be very precise. The new soil map has shown a 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 can be identified. In 2010 only 41 817 hectares with organic soils could be found within this area. The area of soils having 6-12 % organic C in 1975 were > 40 000 hectares, and in 2010 it has decreased to 30 174 hectares. The 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 wetland 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 1333 ha per year until 2017 due to a special targeted political initiative for taking organic soils out of rotation and convert them to wetlands (Ministry of Environment and Food, 2015). From 2018 to 2035 an annual reduction of 1000 ha per year is expected. Because of the high uncertainty related to the organic soils and their actual emission no area has been assumed to be change to below 6 % OC. As a consequence the area with light organic soils is increasing from 2010 and onwards.

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.

8.2.3 Perennial wooden crops

Perennial wooden crops in Cropland covers fruit trees, fruit plantations and energy crops and Christmas trees grown on Cropland. 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 be stable on 5 700 hectares as in 2014 as there are currently no incentives to increase the area. An possible 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.

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 kt C per year (not shown).

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

The overall expected emission trend is shown in Table 8.3.

Emission from Cropland is expected to decrease from 4 104 kt CO_2-eq. in 2013 to 2 611 kt CO_2-eq. in 2035. Generally a decreasing trend in the emission from Cropland is expected. This is both due to developments related 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 of organic matter. 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 8.3 Overall emission trend for Cropland and other LULUCF sectors from 1990 to 2035.

Greenhouse gas source and sink categories	1990	2000	2010	2013	2015	2018	2020	2025	2030	2035
4. Land Use, Land-Use Change and Forestry, kt CO_2 eqv.	6772.0	4765.2	3045.8	2390.4	NE	NE	NE	NE	NE	NE
A. Forest Land	367.8	-496.1	-1841.9	-2310.1	NE	NE	NE	NE	NE	NE
B. Cropland	5460.7	4522.6	4126.7	4103.6	3858.4	3499.1	3398.7	3158.6	2865.4	2611.2
C. Grassland	830.1	686.5	686.6	586.3	221.6	257.1	229.5	141.8	61.0	-22.4
D. Wetlands	102.5	73.2	97.0	20.7	223.8	250.2	264.6	300.6	288.1	324.1
E. Settlements	13.0	24.1	52.8	78.7	67.7	67.9	73.2	78.4	82.3	86.2
F. Other Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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 372 194 hectares is reported in the Grassland sector in 2014. The area is expected to increase to 558 949 hectares in 2035 primarily due to regulation for more environmental friendly farming and conversions between Cropland and Grassland. The Danish reporting is based on information from the EU subsidiary system for each land parcel. In this system the actual crop grown on each field is known. As the farmers reporting for a given field often changes from annual crops to perennial crops, this information adds a lot of noise to the reporting system because a high share of the agricultural land, either cropland or grassland is reported in the category "Land converted". It should be mentioned here that the Grassland definition differs from the one used by Statistics Denmark for permanent Grassland and includes heath land and other marginal areas, which are not reported in the other land use categories. Therefore areas reported here for grassland are not comparable to data from Statistics Denmark.

The amount of living biomass in Grassland is limited and only minor changes are foreseen.

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 is resulting from the new 2013 Wetlands Supplement, which assume an emission of 16 kg CH_4 per ha per year, due to burning of heath land.

Because of the expected conversion of cropland to Grassland and Wetlands on organic soils and because of the conversion of Cropland to Grassland on mineral soil, it is expected that the Grassland sector will be converted from a source to a situation almost in balance, although this balance is due to an emission from the organic soils and a carbon sequestering from the mineral soils. Overall it is therefore expected that the emission from Grassland will decrease over time.

8.4 Wetlands

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

8.4.1 Peat land

Peat excavation 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 current 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 excavation is expected in Denmark.

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

In 2014 192 000 m^3 of peat were excavated. The total emission from this is estimated at 13.15 kt C and 0.000377 kt N_2O per year.

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 located on unmanaged grassland and the impact on the emission estimates from establishing wetlands is therefore sometimes limited. This is also 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. Subsidies are made available for turning 2500 hectares of Cropland or Grassland into Wetlands in the period 2015 to 2017. In the projection, it is assumed that 1093 hectares of Cropland, 792 hectare of Grassland and 26 hectares of Forest land are converted to wetland per year until 2020 and from 2021 and onwards 546 ha of Cropland, 396 ha of Grassland and 26 ha of Forest per year.

When establishing wetlands on agricultural soils the most important factor is to halt the degradation of soil carbon in the agricultural land by re-wetting the soils.

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 occur. 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 trend for Wetlands is shown in Table 8.3. From 1990 to 2022 the emission is dominated by emissions from the excavated peat of around 80-90 kt CO_2 eqv. per year. From 2022 and onwards the dominating emission is CH_4 emission from the water saturated areas. Due to the assumed closure of the peat extraction areas and a high conversion rate of drained organic soils into wetlands a high CH_4 emission from land converted to partly water covered Wetlands is expected, at the level of around 10-15 kt CH_4 per year equivalent to 250-325 kt CO_2 eqv. per year in the future.

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 the need for settlement areas in the vicinity of Copenhagen to 1 250 hectares per year for the period 2013 to 2025 (Danish Nature Agency, 2011). To this should be added the settlements in 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 8.3. As the carbon stock in land use categories other than settlements, is higher than in settlement areas, land converted to settlement is a source of CO_2. 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 reached. It is assumed that it will take 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 settlement areas will increase in the future.

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 very seldom in Denmark and only as wild fires. In general Forest fires are very seldom in Denmark and only as wild fires. In general this is between 0 and 2 hectares burned per year. Controlled burning of heathland to maintain the heath is carried out by the Danish Nature Agency. Previously around 300 hectares were burned every year. In recent years more areas have burnt, 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 takes place very fast. The emissions from these fires are included in table 8.3.

Table 8.4 Emission from forest fires and burning of heath land.

	1990	2000	2005	2010	2014	2015	2018	2020	2025	2030	2035
Forest area burned, ha	150.0	0.0	0.0	0.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Heathland area burned, ha	47.0	121.6	638.4	359.0	705.0	705.0	705.0	705.0	705.0	705.0	705.0
Total burned area, ha	197.0	121.6	638.4	359.0	707.0	707.0	707.0	707.0	707.0	707.0	707.0
Emission, CH_4, kt	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emission, N_2O, kt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total, kt CO_2 eqv.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

8.8 Total emission

The total emission is shown in Table 8.3. Including all land categories except Forest land, an overall emission from Cropland and Grassland of around 4800 kt CO_2 eqv. per year is assumed in 2013, decreasing to 3 000 kt CO_2 eqv. per year in 2035. This is combined with an increase from rewetted organic soils (reported under Wetlands) of 325 kt CO_2 eqv. and 78 kt CO_2 eqv. from land converted to Settlements. In total, around 3400 kt CO_2 eqv. are emitted per year in 2035. The main drivers for this decrease is a reduction in the area with organic soil under agricultural crop production and an expected decrease in the emission from agricultural mineral soils as they approach an equilibrium state for the annual organic matter input and the annual degradation of the organic matter in the soil.

It has not been possible to get forest data and therefore the projection does 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 on mineral soils and loss of living biomass in the converted area. Comparing this with the historical data, the change has this little influence on the overall carbon stock changes in all forest.

Conversion of organic soils from annual crops into permanent grassland will reduce this 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.

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.

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 1540 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. 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.

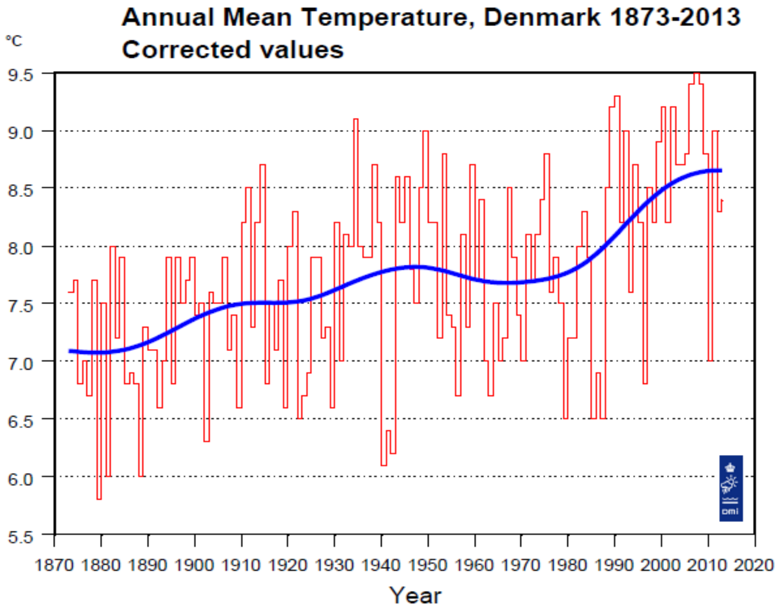

Figure 8.2 Average temperature in Denmark 1873 to 2013 (Source: DMI 2013).

8.10 The Danish Kyoto commitment

In addition to the obligatory inclusion of Afforestation/Reforestation and Deforestation (article 3.3) and in second commitment period Forest Management (FM), Denmark has elected Cropland Management (CM) and Grazing Land Management (GM) under article 3.4 to meet its reduction commitment. 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 area which belongs to any of the elected land use activities 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 relation to the reduction commitment in the first and all subsequent commitment periods.

In Table 8.5 the projected emissions from Cropland Management and Grassland Management until 2035 are shown. As land cannot leave an elected activity, these figures area slightly different from those given in Table 8.3 for Cropland and Grassland. The main driver for the decrease in the emissions is the expected conversion of organic Cropland and Grassland to Wetlands. In table 8.6 the projected effect of the election of Cropland and Grassland management on the Danish reduction commitment is illustrated. The estimates are based on the current net-net accounting. In this the current submitted GHG inventory to UNFCCC for 2013 shows that CM would add a net benefit to the Danish reduction of 1126 kt CO_2-eq. from CM and 204 kt CO_2 from GM. From year 2013 to 2014 the data on agricultural land use has shown an unexpected large decrease in organic areas used for agricultural purposes. The reason for this is currently unknown. Year 2015 is expected to add substantially more to the Danish reduction commitment as a larger decrease in the area with cultivated organic soils is expected. Hence, a further decrease in emission from these soils is expected. It is expected that 2015 will add 2158 kt CO2-eq to the Danish reduction commitment and increasing to 3835 kt CO2-eq in 2035. The large increase is solely dependent on the organic soils taken out of rotation and converted back to Wetlands.

Table 8.5 Projected emission estimates for article 3.3 and 3.4 activities 1990 to 2035, kt CO_2 eqv.

	2013	2014	2015	2016	2017	2018	2019	2020	2025	2030	2035
CM	4203	3637	3678	3460	3387	3312	3264	3190	2880	2560	2241
GM	440	938	419	564	488	452	433	429	342	261	178
Total CM and GM	4643	4574	4097	4024	3875	3765	3697	3619	3222	2822	2419

Table 8.6 Projected accounting estimates for Cropland Management and Grazing land Management until 2035, kt CO_2 eqv.

	2013	2014	2015	2016	2017	2018	2019	2020	2025	2030	2035
CM	1126	1810	1768	1986	2059	2134	2182	2256	2566	2886	3205
GM	204	-129	389	244	320	356	375	380	466	547	630
Total CM and GM	1612	1680	2158	2230	2379	2490	2557	2636	3032	3433	3835

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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/

Due to the open Nordic electricity market, there is electricity import and export that impacts the trend in emissions. The greenhouse gas (GHG) emissions both actual and corrected are shown in Figure 9.1.

The historic and projected GHG emissions are shown in Figure 9.2. Projected GHG emissions include the estimated effects of policies and measures implemented until November 2015 and the projection of total GHG emissions is therefore a so-called 'with existing measures' projection.

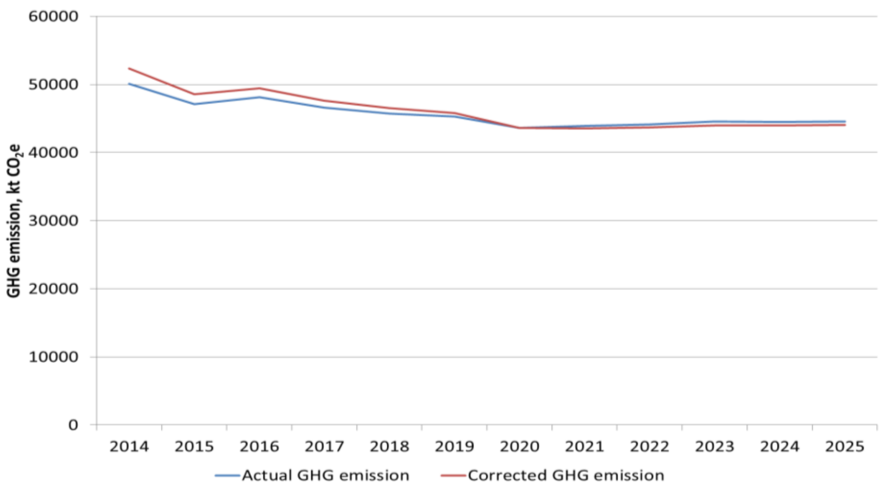

Figure 9.1 Actual GHG emissions in CO_2 equivalents compared with the GHG emission corrected for electricity trade.

The emission corrected for electricity trade, follows the general trend in emissions. For the first years of the time series the actual emission is lower than the corrected emission, i.e. there is an import of electricity. Around 2020 the import/export is close to zero, where after there is an electricity export and hence the actual emissions become larger than the corrected.

The main emitting sectors in 2015 are Energy Industries (27 %), Transport (27 %), Agriculture (21 %) and Other Sectors (10 %). For the latter sector the most important sources are fuel combustion in the residential sector. GHG emissions show a slight decrease in the projection period from 2015 to 2025. The total emissions in 2015 are estimated to be 47.1 million tonnes CO_2 equivalents and 44.6 million tonnes in 2025, corresponding to a decrease of 5 %. From 1990 to 2013 the emissions decrease by 21 %.

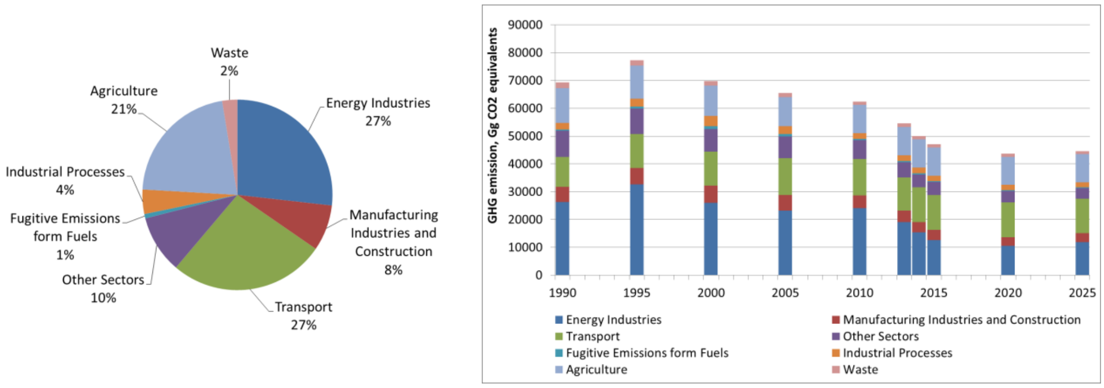

Figure 9.2 Total GHG emissions in CO_2 equivalents. Distribution according to main sectors (2015) and time series for 1990 to 2025.

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 2015 from the main source, which is public power and heat production (56 %), are estimated to decrease in the period from 2015 to 2025 (9 %) due to a partial shift in fuel type from coal to wood and municipal waste as well as a decrease in fuel use following from the increase in wind power and photovoltaics in electricity production. Also, for residential combustion plants and combustion in manufacturing plants a significant decrease in emissions is projected; the emissions decrease by 28 % and 18 % from 2015 to 2025, 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 increased by 145 % from 1990 to 2013 and projected to increase further by 14 % from 2015 to 2025.

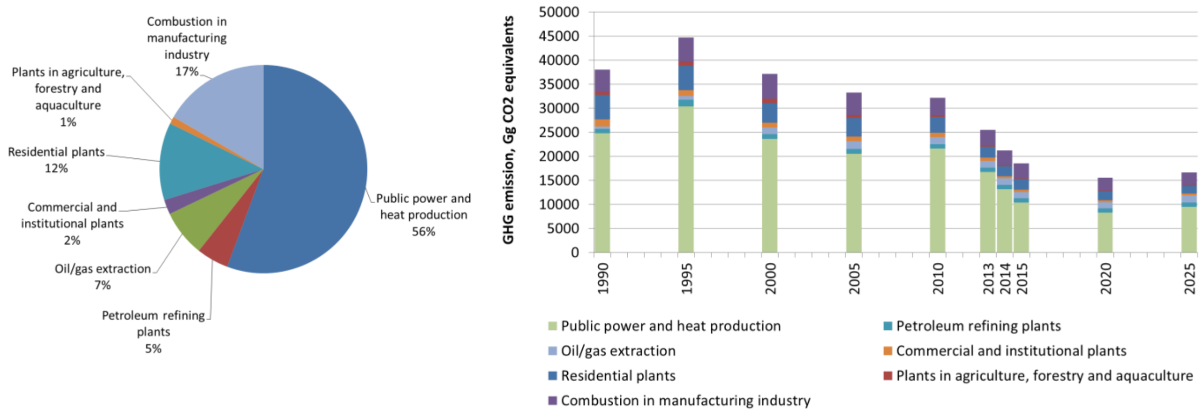

Figure 9.3 GHG emissions in CO_2 equivalents for stationary combustion. Distribution according to sources (2015) and time series for 1990 to 2025.

9.2 Fugitive emissions from fuels

The greenhouse gas emissions from the sector "Fugitive emissions from fuels" show large fluctuations in the historical years 1990-2013, 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 2015-2030 by 12 %. 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 projection period 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.

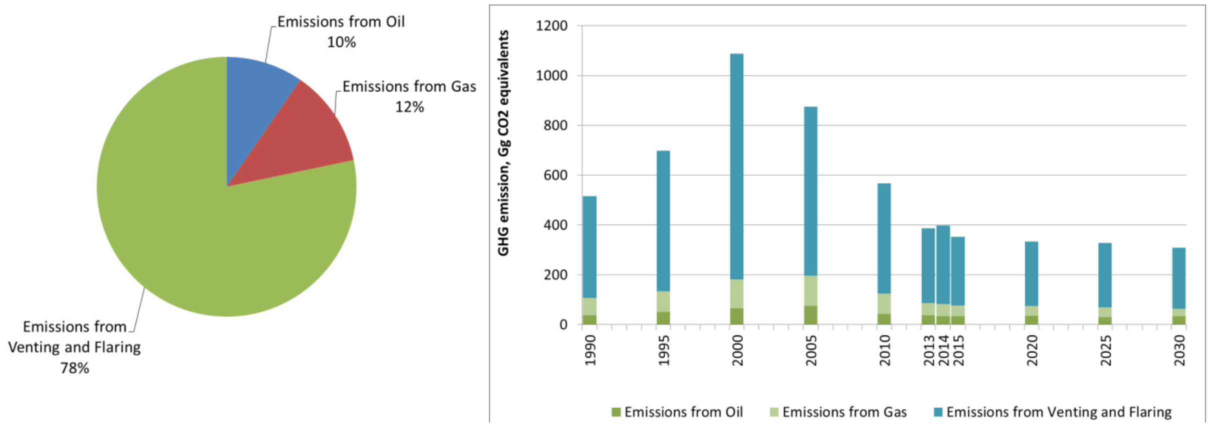

Figure 9.4 GHG emissions in CO_2 equivalents for fugitive emissions. Distribution according to sources for 2015 and time series for 1990 to 2030.

9.3 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 2015 is cement production (49 %) and use of substitutes (f-gases) for ozone depleting substances (ODS) (33 %). The corresponding shares in 2030 are expected to be 77 % and 8 %, 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.

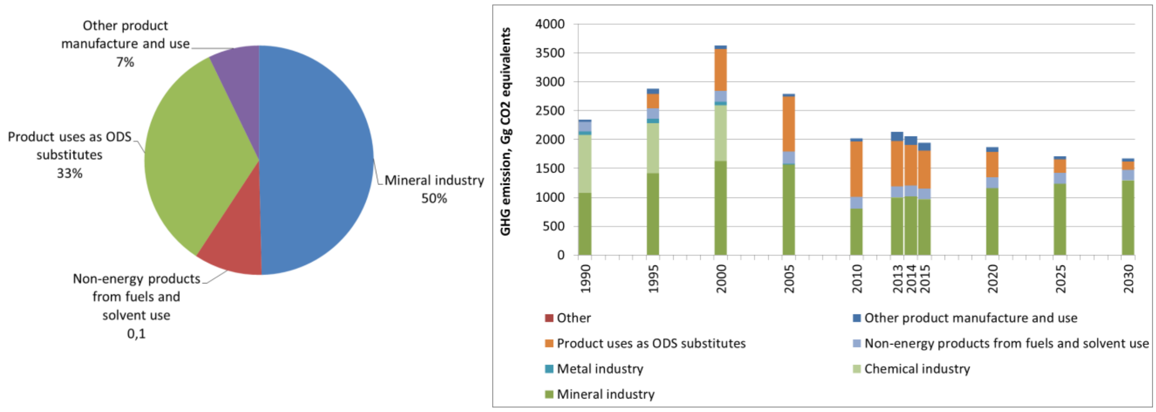

Figure 9.5 Total GHG emissions in CO_2 equivalents for industrial processes. Distribution according to main sectors (2015) and time series for 1990 to 2030.

9.4 Transport and other mobile sources

Road transport is the main source of GHG emissions from transport and other mobile sources in 2015 (86 %) and emissions from this source are expected to be almost constant in the projection period 2015 to 2025. 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 agriculture, forestry and fishing contributes 9 % of the sectoral GHG emission in 2015 and this share is expected to stay at 9 % in 2025.

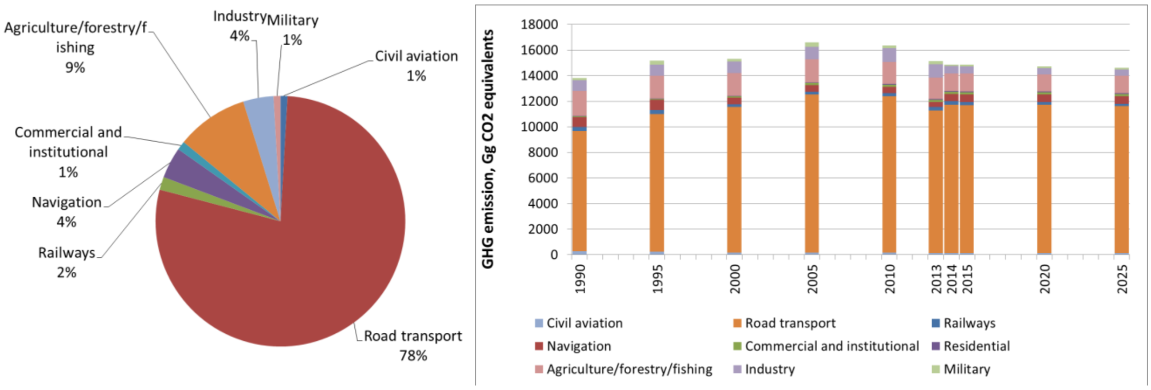

Figure 9.6 GHG emissions in CO_2 equivalents for mobile sources. Distribution according to main sources (2015) and time series for 1990 to 2025.

9.5 Agriculture

The main sources in 2015 are enteric fermentation (36 %), agricultural soils (36 %) and manure management (26 %). The corresponding shares in 2030 are expected to be 38 %, 35 % and 25 %, respectively. From 1990 to 2013, the emission of GHGs in the agricultural sector decreased by 19 %. In the projection years 2015 to 2030 the emissions are expected to increase by 2 %. The reduction in the historical years can mainly be explained by improved utilisation of nitrogen in manure, a significant reduction in the use of synthetic fertiliser and a reduced emission from N-leaching. 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.

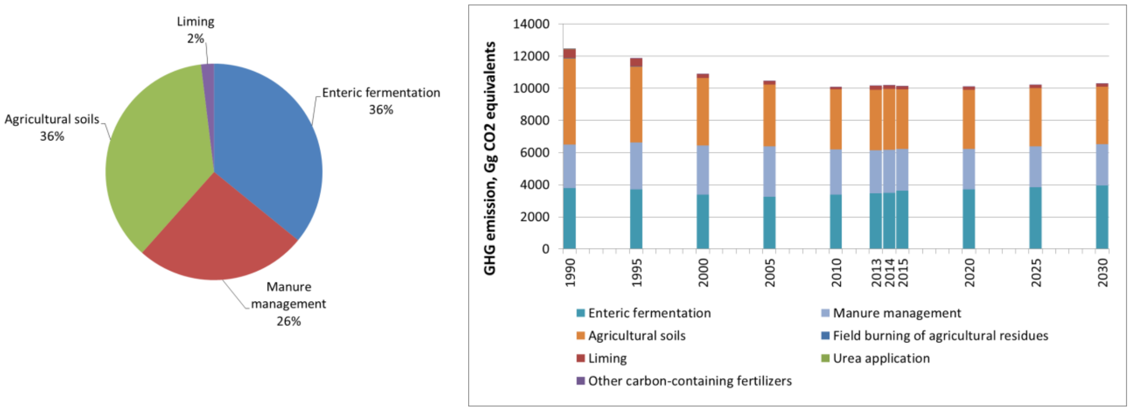

Figure 9.7 GHG emissions in CO_2 equivalents for agricultural sources. Distribution according to main sources (2015) and time series for 1990 to 2030.

9.6 Waste

The total GHG emission from the waste sector has been decreasing in the years 1990 to 2013 by 36 %. The decreasing trend is expected to continue with a decrease of 21 % from 2015 to 2030. In 2015, GHG emission from solid waste disposal is predicted to contribute 64 % of the emission from the sector as a whole. A decrease of 46 % is expected for this source in the years 2015 to 2030, due to less waste deposition on landfills. An almost constant level for emissions from wastewater is expected for the projection period. GHG emissions from wastewater handling in 2015 contribute with 15 %. Emissions from biological treatment of solid waste contribute 19 % in 2015 and 35 % in 2030.

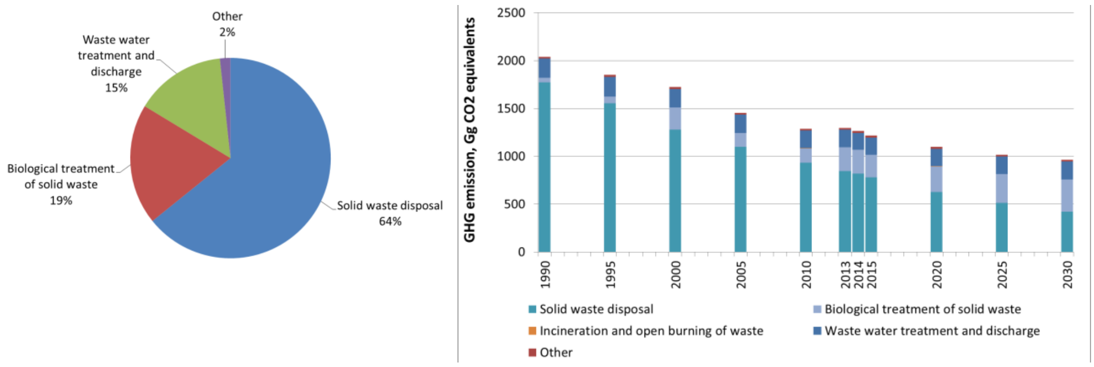

Figure 9.8 GHG emissions in CO_2 equivalents for Waste. Distribution according to main sources (2015) and the time series for 1990 to 2030.

9.7 LULUCF

The overall picture of the LULUCF sector exclusive Forest is a net source of 6406 kt CO_2 eqv. in 1990. In 2013 the estimated emission has been reduced to a net source of 4789 kt CO_2, a net source of 3966 kt CO_2 eqv in 2020, 3679 kt CO_2 eqv in 2025 and 2999 kt CO_2 eqv in 2035. Until 2035 the emission trend is expected to be relatively stable. The major reason for this decrease is an expected continuous decrease in the area with organic soils in rotation and that the agricultural mineral soils are approaching an equilibrium state. Cultivation of organic soils is a major 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.

Projections of emissions/removals from forestry are carried out by the Department of Geosciences and Natural Resource Management, Copenhagen University. They are not included in this report.

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
Public electricity and heat production	8197	7042	8388
Petroleum refining	926	926	926
Other energy industries (oil/gas extraction)	1338	1290	1526
Combustion in manufacturing industry	2346	1989	1977
Civil aviation	133	135	137
Commercial and institutional	6	5	5
Agriculture, forestry and aquaculture	90	80	79
Fugitive emissions from flaring	221	208	208
Mineral industry	957	1152	1226
Total	14 214	12 827	14 471
Civil Aviation, international	2735	2898	3014

PROJECTION OF GREENHOUSE GASES 2014-2025

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.

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