PROJECTION OF SO_2, NO_X, NMVOC, NH_3 AND PARTICLE EMISSIONS – 2012-2035

Scientific Report from DCE – Danish Centre for Environment and Energy No. 81 2013

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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Data sheet

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Abstract: This report contains a description of models and background data for projection of SO_2, NO_X, NH_3, NMVOC, TSP, PM_{10} and $PM_{2.5}$ for Denmark. The emissions are projected to 2035 using basic scenarios together with the expected results of a few individual policy measures. Official Danish projections of activity rates are used in the models for those sectors, for which the projections are available, i.e. the latest official projection from the Danish Energy Agency. The emission factors refer either 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 plants. The emission projection models are based on the same structure and method as the Danish emission inventories in order to ensure consistency.

Keywords: Acidifying gases, projections, emissions, SO_2, NO_X, NH_3, NMVOC, TSP, PM_{10} and $PM_{2.5}$

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List of abbreviations

BAT	Best Available Techniques
BREF	BAT Reference Document
CHP	Combined Heat and Power
CHR	Central Husbandry Register
CLRTAP	Convention on Long-Range Transboundary Air Pollution
COPERT	COmputer Programme to calculate Emissions from Road Transport
CORINAIR	CORe INventory on AIR emissions
DAAS	Danish Agricultural Advisory Service
DAFA	Danish AgriFish Agency
DCA	Danish Centre for food and Agriculture
DCE	Danish Centre for Environment and energy
DEA	Danish Energy Agency
DEPA	Danish Environmental Protection Agency
DSt	Statistics Denmark
EEA	European Environment Agency
EF	Emission Factor
EIONET	European Environment Information and Observation Network
EMEP	European Monitoring and Evaluation Programme
ENVS	Department of ENVironmental Science, Aarhus University
FSE	Full Scale Equivalent
GE	Gross Energy
IDA	Integrated Database model for Agricultural emissions
IEF	Implied Emission Factor
IIR	Informative Inventory Report
LPG	Liquefied Petroleum Gas
LRTAP	Long-Range Transboundary Air Pollution
LTO	Landing and Take Off
MCF	Methane Conversion Factor
MSW	Municipal Solid Waste
NECD	National Emissions Ceiling Directive
NFR	Nomenclature For Reporting
NH_3	Ammonia
NMVOC	Non-Methane Volatile Organic Compounds
NO_x	Nitrogen Oxides
PM	Particulate matter
PM_{10}	Particulate matter with an aerodynamic diameter below 10 µm
$PM_{2.5}$	Particulate matter with an aerodynamic diameter below 2.5 µm
SCR	Selective Catalytic Reduction
SNAP	Selected Nomenclature for Air Pollution
SO_2	Sulphur dioxide
TSP	Total Suspended Particulates
UNECE	United Nations Economic Commission for Europe
VS	Volatile Solids

Preface

This report contains a description of models and background data for projection of sulphur dioxide (SO_2), nitrogen oxides (NO_X), non-methane volatile organic compounds (NMVOC), ammonia (NH_3), total suspended particulates (TSP) and particulate matter with an aerodynamic diameter below 10 µm and 2,5 µm (PM_{10} and $PM_{2.5}$) for Denmark. The emissions are projected to 2035 using basic scenarios, which include the estimated effects on Denmark's emissions of policies and measures agreed upon or implemented until April 2013 ('with measures' projections).

The Department of Environmental Science and DCE - Danish Centre for Environment and Energy at Aarhus University has carried out the work. The project has been financed by the Danish Environmental Protection Agency (DEPA).

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Summary

Introduction

This report contains a description of the models and background data used for the emission projection of the pollutants sulphur dioxide (SO_2), nitrogen oxides (NO_X), non-methane volatile organic compounds (NMVOC), ammonia (NH_3), total suspended particulates (TSP), particulate matter with diameter less than 10 µm (PM_{10}) and particulate matter with diameter less than 2.5 µm ($PM_{2.5}$) for Denmark. The emissions are projected to 2035 using basic scenarios which include the estimated effects on emissions of policies and measures implemented until August 2012 ('with measures' projections). Official Danish projections, e.g. the official energy projection from the Danish Energy Agency, are used to provide activity rates in the models for those sectors for which these projections are available. The emission factors refer to international guidelines or are country-specific, referring to Danish legislation, Danish research reports or calculations based on emission data from a considerable number of plants in Denmark. The projection models are based on the same structure and methodology as the Danish emission inventories in order to ensure consistency.

In Europe, regional air pollution is regulated by a number of protocols under the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP). The objectives of the Gothenburg Protocol are to control and reduce the emissions of SO_2, NO_X, NMVOC and NH_3. In addition to the UN regulation there is also EU legislation addressing the emissions of air pollution (National Emission Ceiling Directive – NECD).

In 2012 the Gothenburg Protocol was amended to establish emission reduction commitments for 2020 and beyond. Furthermore, reduction commitments for particulate matter ($PM_{2.5}$) were introduced for the first time. In the amended Gothenburg Protocol, the reduction commitments are given as a percentage reduction compared to the emission level in 2005. The emission ceilings for Denmark in 2010 according to the Gothenburg Protocol are shown in Table S.1 together with the reduction percentages for 2020 recalculated to a "ceiling" value.

Table S.1 Emission ceilings and reduction commitments for Denmark.

	Unit	SO_2	NO_x	NMVOC	NH_3	$PM_{2.5}$
Emission ceiling – 2010*	Tonnes	55 000	127 000	85 000	69 000	
Emission reduction commitment**	%	35	56	35	24	33
Emission level – 2005	Tonnes	23 000	181 000	110 000	83 000	25 000
"Emission ceiling – 2020"	Tonnes	14 950	79 640	71 500	63 080	16 750
Emission – 2011	Tonnes	13 901	125 532	81 432	74 164	23 196
Projected emission – 2020	Tonnes	12 270	82 999	68 386	70 236	16 734
Projected reduction - 2020	%	47	54	38	15	33

* The NH_3 emission ceiling excludes the emission from straw treatment and growing crops, the NMVOC emission ceiling excludes the emission from growing crops.
** Compared to the emission level in 2005.

Pollutant summary

The historical emissions in the latest historical year, 2011, are shown in Table S.2 together with the projected emissions for 2020, 2025, 2030 and 2035. The results of the projection indicate, that emissions of SO_2, NO_x, NMVOC, NH_3

and particulate matter decrease from the latest historical inventory year (2011) to the projection year 2020. From 2020 to 2035 the projection indicates a further decrease of emissions of the same pollutants, except SO_2, which is expected to show a slight increase.

Table S.2 Historical emissions for 2011 and projected emissions for 2020, 2025, 2030 and 2035.

Tonnes	SO_2	NO_x	NMVOC	NH_3	TSP	PM_{10}	$PM_{2.5}$
2011	13 901	125 532	81 432	74 164	37 648	29 280	23 196
2020	12 270	82 999	68 386	70 236	31 526	23 029	16 734
2025	12 207	73 265	65 817	67 294	30 658	21 912	15 411
2030	12 435	69 248	65 283	64 696	30 296	21 173	14 371
2035	14 061	67 095	64 894	63 617	29 264	20 171	13 342

Nitrogen oxides, NO_X

The largest sources are road transport, other mobile sources, and energy industries, accounting for 37 %, 34 % and 19 % of the NO_x emission in 2011, respectively.

The NO_x emission is expected to decrease 34 % (45 %) from 2011 to 2020 (2030). The decrease is mainly related to road transport and other mobile sources due to the introduction of stricter demands at EU level (new EURO norms).

The projected emission in 2020 is higher than the emission target based on the reduction commitment referenced in Table S.1. Part of the explanation is that the EU regulation of emissions from road transport has not delivered the expected reductions in emission levels.

Sulphur dioxide, SO_2

The largest sources of SO_2 emissions are manufacturing industries and energy industries, accounting for 24 % and 23 %, respectively, of the national SO_2 emission in 2011.

The SO_2 emission is expected to decrease 12 % (11 %) from 2011 to 2020 (2030). The emissions from other mobile sources and manufacturing industries are expected to show a marked decrease, while emissions from combustion in public power and district heating plants are expected to increase.

Non methane volatile organic compounds, NMVOC

The largest sources to emissions of NMVOC are solvents and other product use followed by residential plants, road transport, extraction, storage and refining of oil and gas, and industrial processes in food and drinks production. These sources account for 33 %, 16 %, 15 %, 11 % and 6 %, respectively, of the total NMVOC emission in 2011.

The NMVOC emission is expected to decrease 16 % (20 %) from 2011 to 2020 (2030). The largest decrease is expected for residential plants and solvent and other product use, but pronounced decreases are also expected for road transport, fugitive emissions from fuels and other mobile sources. The emissions from industrial processes are on the other hand expected to increase.

Ammonia, NH_3

The predominant source of NH_3 emissions is agricultural activities (96 %) and the main source is livestock manure.

The NH_3 emission is expected to decrease 5 % (13 %) from 2011 to 2020 (2030). The major decrease is expected from manure management (5 % and 15 %, respectively). The decreased emission is mainly a result of a reduction in emission from the animal housing and in particular from the pig housing, which is due to implementation of NH_3 reducing technology.

The projected emission in 2020 is higher than the emission target based on the reduction commitment referenced in Table S.1. The emission estimate included in both Table S.1 and Table S.2 includes NH_3 emissions from crops (approx. 5 000 tonnes) that are not considered under the NECD.

Total suspended particulate matter, TSP

The main sources of particle emission are non-industrial combustion, mainly wood combustion in residential plants and agriculture, accounting for 44 % and 31 %, respectively, of the total TSP emission in 2011.

The emission is projected to decrease by 16 % (20 %) from 2011 to 2020 (2030). The largest decrease is expected for emissions from residential plants of 34 % and 49 % from 2011 to respectively 2020 and 2030.

Particulate matter with diameter less than 10 µm - PM_{10}

The main sources of the PM_{10} emission are non-industrial combustion, mainly wood combustion in residential plants, and agriculture. In 2011 these sources accounted for 54 % and 20 %, respectively.

The emission projection estimates the PM_{10} emission to decrease by 21 % (28 %) from 2011 to 2020 (2030). The main decrease is expected for residential plants, but the PM_{10} emissions from road transport and other mobile sources are expected to decrease in the projection period as well.

Particulate matter with diameter less than 2.5 µm - $PM_{2.5}$

The single major source of the $PM_{2.5}$ emission is non-industrial combustion, mainly wood combustion in residential plants, which accounted for 67 % of the national $PM_{2.5}$ emission in 2011. Other important sources are road transport, other mobile sources and agriculture with 10 %, 9 % and 6 %, respectively

The $PM_{2.5}$ emission is expected to decrease by 28 % (38 %) from 2011 to 2020 (2030) mainly due to a decreasing emission from residential plants caused by the introduction of new technologies with lower emissions and other mobile sources. The emission from agriculture is expected to increase.

Sammenfatning

Introduktion

Denne rapport indeholder en beskrivelse af de modeller og baggrundsdata, der er benyttet til fremskrivning af svovldioxid (SO_2), kvælstofoxider (NO_X), andre flygtige organiske forbindelser end metan (NMVOC), ammoniak (NH_3), total mængde svævestøv (TSP), svævestøv med diameter mindre end 10 µm (PM_{10}) og svævestøv med diameter mindre end 2,5µm ($PM_{2.5}$), Emissionerne er fremskrevet til 2035 som basisscenarie, som inkluderer de estimerede effekter på emissionerne af vedtaget lovgivning inden august 2012. For aktivitetsdata benyttes, hvor det er muligt, officielle danske fremskrivninger, f.eks. den officielle energifremskrivning fra Energistyrelsen. De anvendte emissionsfaktorer henviser enten til internationale guidelines eller nationale emissionsfaktorer, som refererer til dansk lovgivning, danske forskningsrapporter eller emissionsdata fra et betydeligt antal anlæg i Danmark. Fremskrivningsmodellerne er opbygget efter den samme struktur og benytter samme metodevalg, som anvendes ved udarbejdelsen af de årlige emissionsopgørelser. Dette sikrer konsistens imellem de årlige opgørelser og fremskrivningen.

I Europa reguleres den regionale luftforurening af en række protokoller under FN's konvention om langtransporteret, grænseoverskridende luftforurening (United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP)). Formålet med Gøteborgprotokollen er at kontrollere og reducere emissionerne af SO_2, NO_X, NMVOC og NH_3. I tillæg til FN-reguleringen er der også indenfor EU regulering af emissioner af luftforurening gennem direktivet om emissionslofter (National Emission Ceiling Directive – NECD)

I 2012 blev Gøteborgprotokollen revideret, så den indeholder emissionsreduktionsforpligtigelser for 2020 og fremefter. Derudover blev der for første gang fastsat reduktionsmål for partikler ($PM_{2.5}$). I den reviderede Gøteborgprotokol er reduktionsforpligtigelserne givet som en procentreduktion i forhold til emissionsniveauet i 2005. Emissionslofterne for Danmark i 2010 er vist i Tabel S.1 sammen med reduktionsprocenterne for 2020, som er blevet omsat til et "emissionsloft".

Tabel S.1 Emissionslofter og reduktionsforpligtigelser for Danmark.

	Unit	SO_2	NO_x	NMVOC	NH_3	$PM_{2.5}$
Emissionsloft – 2010*	Ton	55 000	127 000	85 000	69 000	
Emissionsreduktionsforpligtigelse**	%	35	56	35	24	33
Emissionsniveau – 2005	Ton	23 000	181 000	110 000	83 000	25 000
"Emissionsloft – 2020"	Ton	14 950	79 640	71 500	63 080	16 750
Emission – 2011	Ton	13 901	125 532	81 432	74 164	23 196
Fremskrevet emission – 2020	Ton	12 270	82 999	68 386	70 236	16 734
Fremskrevet reduktion - 2020	%	47	54	38	15	33

* NH_3 emissionsloftet er eksklusiv emissioner fra afgrøder og ammoniakbehandlet halm; NMVOC-emissionsloftet er eksklusiv emissioner fra afgrøder.
** Reduktionsforpligtelsen er i forhold til emissionsniveauet i 2005.

Emissionsfremskrivninger

De historiske emissioner for det seneste historiske år, 2011, er vist i Tabel S.2 sammen med de fremskrevne emissioner for 2020, 2025, 2030 og 2035. Resultatet af fremskrivningen indikerer, at emissionerne af SO_2, NO_x, NMVOC, NH_3 og partikler falder fra det seneste historiske år (2011) til fremskrivningsåret 2020. Fra 2020 til 2035 indikerer fremskrivningen et yderligere fald i emissionerne for de samme stoffer, undtagen for SO_2, der forventes at udvise en lille stigning fra 2020 til 2035.

Tabel S.2 Historiske emissioner for 2011 og fremskrevne emissioner for 2020, 2025, 2030 og 2035.

Ton	SO_2	NO_x	NMVOC	NH_3	TSP	PM_{10}	$PM_{2.5}$
2011	13 901	125 532	81 432	74 164	37 648	29 280	23 196
2020	12 270	82 999	68 386	70 236	31 526	23 029	16 734
2025	12 207	73 265	65 817	67 294	30 658	21 912	15 411
2030	12 435	69 248	65 283	64 696	30 296	21 173	14 371
2035	14 061	67 095	64 894	63 617	29 264	20 171	13 342

Kvælstofoxider, NO_X

De største kilder er vejtransport, andre mobile kilder og energiproduktion, der udgør hhv. 37 %, 34 % og 19 % af den samlede NO_x-emission i 2011.

NO_x-emissionen forventes at falde 34 % (45 %) fra 2011 til 2020 (2030). Faldet sker hovedsageligt for vejtransport og andre mobile kilder og skyldes de stigende lovgivningsmæssige krav.

Den fremskrevne emission for 2020 er dermed højere end det beregnede emissionsmål for 2020 baseret på reduktionsforpligtigelsen i Tabel S.1. En del af forklaringen er, at EU reguleringen af emissionerne fra transportsektoren ikke fuldt ud har leveret de forventede sænkninger i emissionsniveauet.

Svovldioxid, SO_2

De største kilder til SO_2-emission er fremstillingsvirksomhed og energiproduktion, der udgør henholdsvis 24 % og 23 % af den nationale SO_2-emission i 2011.

SO_2-emissionen forventes at falde 12 % (11 %) fra 2011 til 2020 (2030). Emissionerne fra andre mobile kilder og fremstillingsvirksomhed forventes at falde væsentligt, mens emissionerne fra forbrænding i offentlig el- og varmeproduktion forventes at stige.

Andre flygtige organiske forbindelser end metan, NMVOC

De største kilder til emissioner af NMVOC er brug af opløsningsmidler, efterfulgt af forbrænding i husholdninger, vejtransport samt udvinding, lagring og raffinering af olie og gas og industrielle processer i føde- og drikkevareindustrien. Disse kilder udgør hhv. 33 %, 16 %, 15 %, 11 %, og 6 % af den totale NMVOC-emission i 2011.

NMVOC-emissionen forventes at falde 16 % (20 %) fra 2011 til 2002 (2030). De største fald forventes for forbrænding i husholdninger og anvendelse af opløsningsmidler, men væsentlige fald forventes også for vejtransport, flygtige emissioner samt for andre mobile kilder. Emissionen fra industrielle processer forventes til gengæld at stige.

Ammoniak, NH_3

Den altdominerende kilde til NH_3-emissioner er landbrugssektoren (96 %) og den største andel herfra kommer fra husdyrgødning.

NH_3-emissionen forventes at falde 5 % (13 %) fra 2011 til 2020 (2030). De største fald forventes for kilder relateret til håndtering af husdyrgødning (hhv. 5 % og 15 % frem til 2020 og 2030).

Den fremskrevne emission for 2020 er højere end det beregnede emissionsmål for 2020 baseret på reduktionsforpligtigelsen i Tabel S.1. Emissionsestimaterne i både Tabel S.1 og Tabel S.2 inkluderer emissioner fra afgrøder (ca. 5000 tons), der ikke er inkluderet under NECD.

Total mængde svævestøv, TSP

De største kilder til emissioner af partikler er ikke-industriel forbrænding, hovedsageligt afbrænding af træ i husholdninger og landbrug, der udgør hhv. 44 % og 31 % af den samlede TSP-emission i 2011.

I fremskrivningen forventes et fald på 16 % (20 %) fra 2011 til 2020 (2030). Det største fald forventes for emissioner fra husholdninger på 34 % og 49 % fra 2011 til hhv. 2020 og 2030.

Svævestøv med diameter mindre end 10 µm - PM_{10}

De største kilder til PM_{10}-emissioner er ikke-industriel forbrænding, hovedsageligt afbrænding af træ i husholdninger, og landbrug. I 2011 udgjorde disse kilder hhv. 54 % og 20 %.

Fremskrivningen estimerer et fald i PM_{10}-emissionen på 21 % (28 %) fra 2011 til 2020 (2030). Det største fald forventes for husholdninger, men PM_{10}-emissionerne fra vejtransport og andre mobile kilder forventes ligeledes at falde i fremskrivningsperioden.

Svævestøv med diameter mindre end 2.5 µm - $PM_{2.5}$

Den altovervejende kilde til emissioner af $PM_{2,5}$ er ikke-industriel forbrænding, hovedsageligt afbrænding af træ i husholdninger, der udgør 67 % af den nationale $PM_{2,5}$-emission i 2011. Andre væsentlige kilder er vejtransport, andre mobile kilder og landbrug med hhv. 10 %, 9 % og 6 %.

$PM_{2,5}$-emissionen forventes at falde med 28 % (38 %) fra 2011 til 2020 (2030) hovedsageligt på grund af faldende emissioner fra husholdninger og andre mobile kilder. For emissionen fra landbrugssektoren forventes en mindre stigning.

1 Introduction

In the project 'Projection models 2010' (Illerup et al., 2002), a number of sector-specific models were developed in order to project emissions of SO_2, NO_x, NMVOC and NH_3 to 2010. These models were further developed in a project published in 2008 (Illerup et al., 2008) in order to include TSP, PM_{10} and $PM_{2.5}$ and to project the emissions to 2030. Furthermore, a project was carried out in 2011 (Nielsen et al., 2012) that incorporated new emission sources that had been included in the Danish emission inventory.

This project has updated the projection models taking into account changes in projected activity data and emission factors since the latest projection project. Additionally, the projection period has been extended to cover the years until 2035.

Projections have been made for all anthropogenic (directly human induced) sources of emissions included in the Danish emission inventory. The calculation methods and activity data for the individual sectors are presented in Chapter 3-9 and the results are discussed. A brief discussion on the most important general assumptions, i.e. the official projections for fuel consumption, transport and waste is included in Chapter 2.

1.1 Obligations

Regional air pollution is regulated by a number of protocols under the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP). The objectives of the most recent of these protocols – the Gothenburg Protocol – is to control and reduce emissions of SO_2, NO_x, NMCOV and NH_3 in order to reduce exceedances of critical loads with regard to acidification, eutrophication and the effect of photochemical air pollution (ozone). In the first Gothenburg Protocol, in contrast to the earlier protocols, the individual countries are not obligated to achieve a certain reduction target, but emission ceilings have been set in order to reduce exceedance of the critical loads, based on the knowledge of critical loads and effects on the ecosystems within the geographic area of Europe.

In 2012 the Gothenburg Protocol was amended to establish emission reduction commitments for 2020 and beyond. Furthermore, reduction commitments for particulate matter ($PM_{2.5}$) were introduced for the first time. In the amended Gothenburg Protocol, the reduction commitments are given as a percentage reduction compared to the emission level in 2005. The emission ceilings for Denmark in 2010 according to the Gothenburg Protocol are shown in Table 1.1 together with the reduction percentages for 2020 and a an emission target value for 2020. Based on the target emission value in 2020 and the projection for 2020 the emission reduction percentage for 2020 is calculated.

Table 1.1 Emission ceilings and reduction commitments for Denmark.

	Unit	SO_2	NO_x	NMVOC	NH_3	$PM_{2.5}$
Emission ceiling – 2010*	Tonnes	55 000	127 000	85 000	69 000	
Emission reduction commitment**	%	35	56	35	24	33
Emission level – 2005	Tonnes	23 000	181 000	110 000	83 000	25 000
“Emission ceiling – 2020”	Tonnes	14 950	79 640	71 500	63 080	16 750
Emission – 2011	Tonnes	13 901	125 532	81 432	74 164	23 196
Projected emission – 2020	Tonnes	12 270	82 999	66 539	65 064	16 734
Projected reduction – 2020	%	47	54	38	15	33

* The NH_3 emission ceiling excludes the emission from straw treatment and growing crops, the NMVOC emission ceiling excludes the emission from growing crops.

** Compared to the 2005 emission level.

The emission ceilings for 2010 are also included in the EU directive: Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants. A revision of the National Emission Ceilings Directive is expected to be initiated during 2013.

According to the amended protocol, Denmark is obligated to report annual emissions of SO_2, NO_x, NMVOC and NH_3, as well as data on projected emissions and current reduction plans. The expected development in the emissions to 2035 can be illustrated using the projection models developed in the present project. Based on the projected emissions, it will be possible to decide, whether it is necessary to implement further measures to reduce the emissions in the individual sectors.

The main development in the projection of activity data towards 2035 is an expected large increase in the use of biomass. The emission factors for biomass fired plants are based on a very limited number of measurements and are therefore highly uncertain. The most uncertain pollutant is particulate matter. There are still several sources of PM (and a few of NMVOC) that is not included in the emission inventory and therefore also is not part of the projection. For the other pollutants the largest uncertainty is for NMVOC, due to the wide variety of sources and the large uncertainties associated with e.g. solvent use.

In the revised Gothenburg protocol it has been agreed to implement an adjustment mechanism for the situation where new emission sources or fundamental changes in the methodologies or emission factors result in emission levels that are larger than assumed in the reduction emission target.

Annual emissions are available for the years until 2011, while the emissions for 2012 presented in this report are projections.

1.2 Environmental problems

Emissions of SO_2, NO_x, NMVOC, NH_3 and PM especially relate to regional environmental problems and may cause acidification, eutrophication or photochemical smog.

1.2.1 Acidification

Acid deposition of sulphur and nitrogen compounds stems mainly from SO_2, NO_x and NH_3 emissions. The effects of acidification are expressed in a number of ways, including defoliation and reduced vitality of trees, and declining fish stocks in acid-sensitive lakes and rivers (European Environmental Agency, 1998).

SO_2 and NO_x can be oxidised into sulphate (SO_4^{--}) and nitrate (NO_3^-), either in the atmosphere or after deposition, respectively resulting in the formation of two H^+-ions and one H^+-ion. NH_3 may react with H^+ to form ammonium (NH_4^+) and by nitrification in soil NH_4^+ is oxidised to NO_3^-, resulting in the formation of two H^+-ions (Wark and Warner, 1981).

The total emissions in terms of acid equivalents can be calculated by means of equation 1.1. Figure 1.1 shows the distribution of emissions of SO_2, NO_x and NH_3 for selected years in terms of acid equivalents.

eq 1.1 $$Total\ acid\ equivalents = \frac{m_{SO_2}}{M_{SO_2}} \cdot 2 + \frac{m_{NO_x}}{M_{NO_x}} + \frac{m_{NH_3}}{M_{NH_3}}$$

where m_i is the emission of pollutant i [tonnes], and M_i is the molecular weight [tonne per Mmole] of pollutant i.

The actual effect of the acidifying substances depends on a combination of two factors: the amount of acid deposition and the natural capacity of the terrestrial or aquatic ecosystem. In areas where the soil minerals easily weather or have a high chalk content, acid deposition will be relatively easily neutralised (Holten-Andersen, 1998).

1.2.2 Photochemical smog

Photochemical smog is caused primarily by NMVOC and NO_x and the main so-called secondary pollutant is ozone (O_3).

Nitrogen dioxide is highly active photochemically, and for solar radiation below 400 nm occurring in the lower atmosphere (troposphere), the gas dissociates to NO and the highly active-monoatomic oxygen O, which combines with O_2 to form O_3 (Wark and Warner, 1981).

Presence of hydrocarbons increases the complexity of the atmospheric reactions. A small part of the atomic oxygen formed by the dissociation of NO_2 is capable of reacting with various organic compounds (NMVOC), forming very reactive products (free radicals), enhancing the formation of NO_2 and thereby the formation of O_3.

The photochemical reactions in the atmosphere are very complex, but overall it can be concluded that in a European context, nitrogen oxide emissions are responsible for much of the ozone formation in thinly populated areas of the countryside. In the more densely populated areas, especially close to towns, ozone formation is enhanced by NMVOC emissions (Holten-Andersen et al., 1998).

Photochemical smog constitutes so-called transboundary air pollution. This means that ozone is spread across national borders in Europe. In pure air ozone has a lifespan of several weeks and can therefore mix into the air and disperse over virtually the whole of the northern hemisphere before it is chemically degraded or physically removed.

Harmful effects are seen both on vegetation and humans. For Europe as a whole it was estimated that the critical concentration of ozone was exceeded in an area corresponding to 83 % of the total cultivated area of Europe. A large number of Danish crops have proven to be sensitive to ozone; among others, beans, clover, potatoes, spinach, tomatoes and wheat. In humans, ozone is an eye and respiratory tract irritant. The critical concentration at street level suggested by the World Health Organisation is rarely exceeded in Danish towns (Holten-Andersen et al., 1998).

1.2.3 Eutrophication

Eutrophication expresses itself in enhanced nutrient loading on ecosystems such as forest, grasslands, fjords, lakes and open marine areas. The two main pollutants contributing to atmospheric deposition of nutrients are NH_3 and NO_X (Bach et al., 2001).

Eutrophication in marine waters may be caused both by leaching of nutrients from agriculture land and by atmospheric deposition of nitrogen compounds. The effects of enhanced nutrient loading are blooms of toxic plankton and oxygen deficit resulting in increasing fish mortality.

The greatest effect of atmospheric deposition of nitrogen compounds is seen on ecosystems vulnerable to nitrogen loading. Examples of such systems are heath bogs and dry grasslands.

Exceedence of critical loads with regard to eutrophication has resulted in altered composition of animal and plant species in these areas and in decreasing species numbers.

1.2.4 Particulate Matter

Air pollution containing particles results from atmospheric emission, dispersal and chemical and physical conversion. Generally we use the terms PM_{10}, i.e. particles up to a diameter of 10 µm (1/1000 mm), and $PM_{2.5}$, i.e. particles up to a diameter of 2.5 µm. Small particles (below 0.25 µm) are formed at high temperatures, for instance in combustion engines, boilers or industrial processes. Some of the particles are soot particles (also referred to as black carbon – BC), which originate primarily from diesel-powered cars and fireplaces/stoves. A number of studies show that – with their content of many different chemical compounds – soot particles are particularly harmful. In addition, soot particles are also contributing to the greenhouse effect as part of the group of short lived climate forcers (SLCFs). Coarse, airborne particles are typically formed by a number of mechanical processes; for instance in dust from the soil and from roads, which is whirled up by the wind, during gravelling and salting of slippery roads, in salty particles from the sea (drying into salt particles), as well as from volcanoes, vegetation (pollen), wear on tyres and road surfaces, traffic-related turbulence in streets, construction and industrial processes. Due to their weight, these particles only remain suspended for a short time, and thus have a short lifetime. Particle pollution is harmful to health, especially via respiratory and cardiovascular diseases. Much indicates that it is the small particles that present the most serious problem to health in relation to air pollution (Palmgren et al., 2005).

1.3 Historical emission data

The Danish historical emissions are estimated according to the EMEP/EEA Emission Inventory Guidebook (EEA, 2009) and the SNAP (Selected Nomenclature for Air Pollution) sector categorization and nomenclature are used. The detailed level makes it possible to aggregate to the UNECE/EMEP nomenclature for reporting (NFR). The historical data are reported to the LRTAP Convention under the UNECE and the latest historic data are provided in Nielsen et al. (2013).

1.3.1 Acidifying gases

Figure 1.1 shows the emission of Danish acidifying gases in terms of acid equivalents. In 1990, the relative contributions in acid equivalents were almost equal for the three gases. In 2011, the most important acidification factor in Denmark was ammonia nitrogen and the relative contributions for SO_2, NO_x and NH_3 were 6 %, 38 % and 56 %, respectively. However, with regard to long-range transport of air pollution, SO_2 and NO_x are still the most important pollutants.

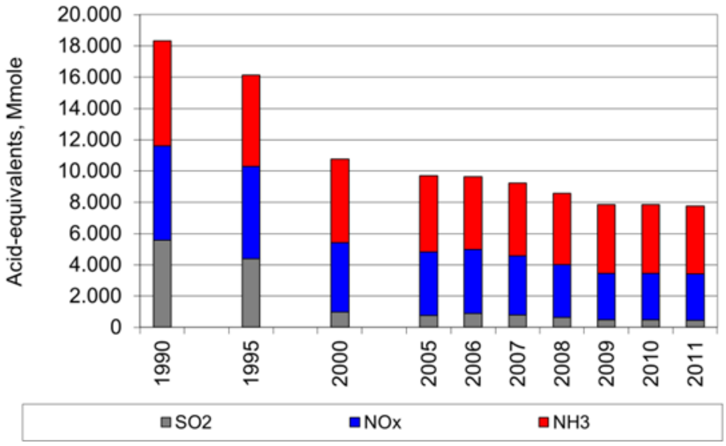


Figure 1.1 Emissions of NH_3, NO_X and SO_2 in acid equivalents.

SO_2

The main part of the SO_2 emission originates from combustion of fossil fuels, i.e. mainly coal and oil. From 1990 to 2011, the total emission decreased by 92.2 %. The large reduction is mainly due to installation of desulphurisation units in public power and district heating plants and use of fuels with lower content of sulphur. Despite the large reduction, energy industries still contribute 23 % of the total emission of SO_2. Also emissions from industrial combustion plants, non-industrial combustion plants and transport are important. National sea traffic (navigation and fishing) contributes with about 13 % of the total SO_2 emission. This is due to the use of residual oil with high sulphur content. Since the year 2000, the emissions of SO_2 have remained at a significantly lower level than in the previous ten years. The SO_2 emissions are still showing a decreasing trend with a 55 % decrease in the years 2000 to 2011.

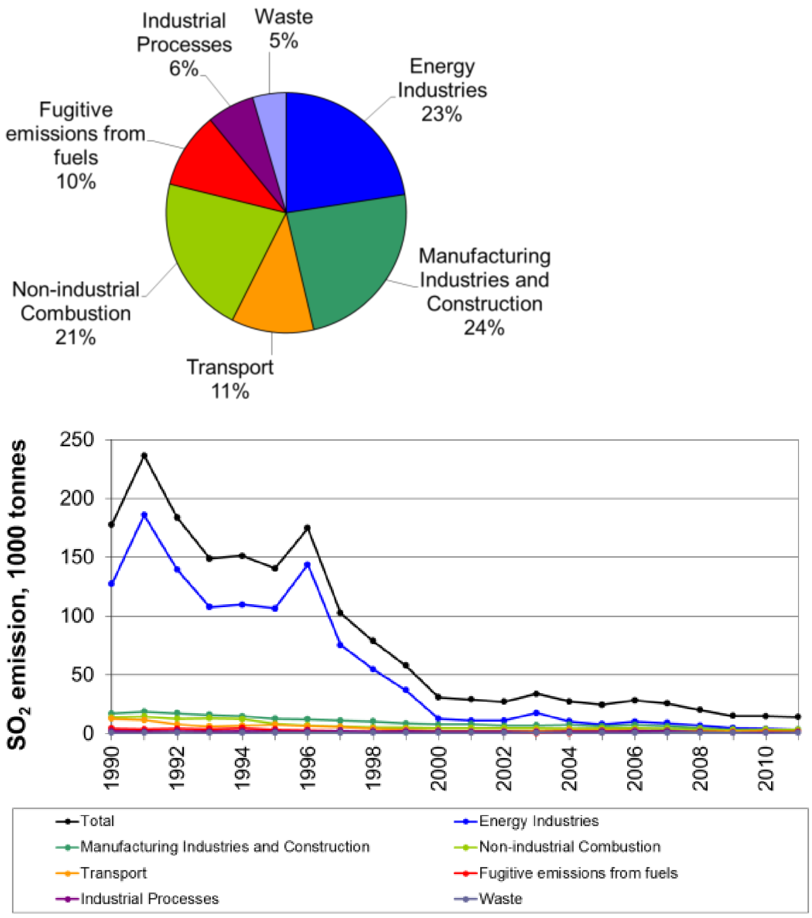


Figure 1.2 SO_2 emissions. Distribution by the main sectors (2011) and time series for 1990 to 2011.

NO_X

The largest sources of emissions of NO_X are the transport sector (mainly road transport), non-industrial combustion (stationary and mobile sources in households and agriculture and fishing) and combustion in energy industries (mainly public power and district heating plants). The transport sector is the sector contributing the most to the emission of NO_X and, in 2011, 46 % of the Danish emissions of NO_X stems from road transport, national navigation, railways and civil aviation. Also, emissions from national fishing and off-road vehicles contribute significantly to the NO_X emission. For non-industrial combustion plants, the main sources are combustion of gas oil, natural gas and wood in residential plants. The emissions from public power plants and district heating plants have decreased by 82 % from 1990 to 2011. In the same period, the total emission decreased by 55 %. The reduction is due to the increasing use of catalyst cars and stricter emission limit values for newer cars and installation of low-NO_X burners and denitrifying units in power and district heating plants.

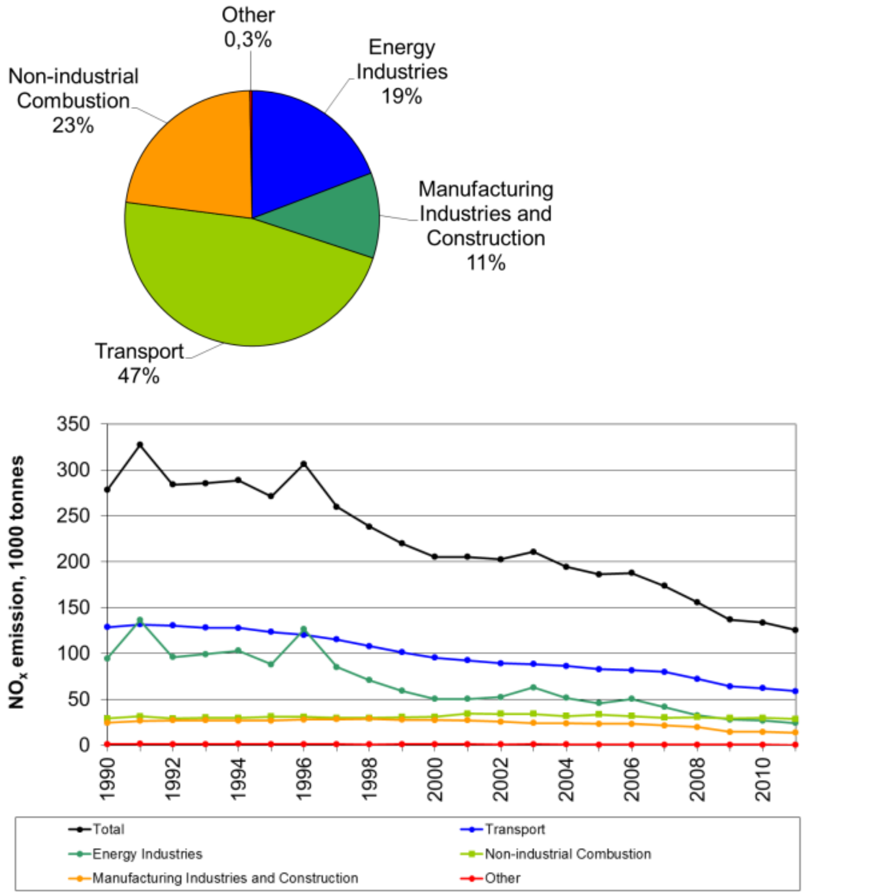
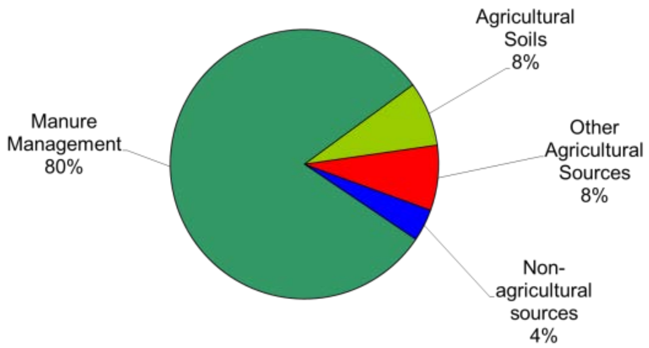


Figure 1.3 NO_X emissions. Distribution by main sectors (2011) and time series for 1990 to 2011.

NH_3

The vast majority of atmospheric emissions of NH_3 result from agricultural activities. Only small emissions originate from stationary combustion, mobile combustion and waste. Due to increasing use of catalyst cars the contribution from road transport was increasing during the 1990s but due to better catalysts the emission has been decreasing since 2002. The major part of the emission from agriculture stems from livestock manure (84 %), and the largest losses of ammonia occur during the handling of the manure in stables and in field application. Other contributions come from use of mineral fertilisers (6 %) and N-excretion on pasture, range and paddock (3 %). The remaining agricultural NH_3 emissions come from crops, sewage sludge used as fertiliser, field burning and ammonia used for straw treatment (8 %).

The total ammonia emission decreased by 35 % from 1990 to 2011. This is due to the action plans for the aquatic environment and the Ammonia Action Plan, introducing a series of measures to prevent loss of nitrogen in agricultural production. The measures have included requirements for improved utilisation of nitrogen in livestock manure, a ban against application of livestock manure in winter, prohibition of broad-spreading of manure, requirements for establishment of catch crops, regulation of the number of livestock per hectare, and a ceiling for the supply of nitrogen to crops. As a result, despite an increase in the production of pigs and poultry, the ammonia emission has been considerably reduced.



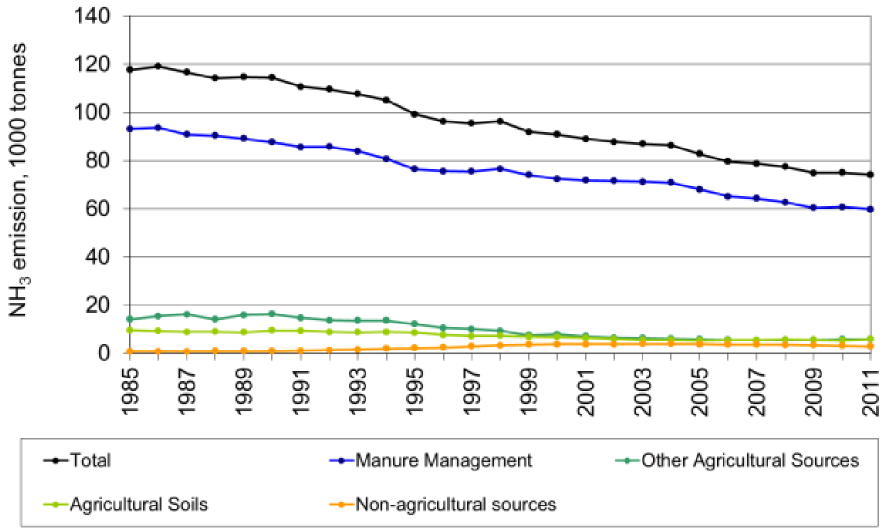


Figure1.4 NH_3 emissions. Distribution by the main sectors (2011) and time series for 1990 to 2011.

1.3.2 Other air pollutants

NMVOC

Emissions of NMVOC originate from many different sources and can be divided into two main groups: incomplete combustion and evaporation. Road vehicles and other mobile sources such as national navigation vessels and off-road machinery are the main sources of NMVOC emissions from incomplete combustion processes. Road transportation vehicles are still the main contributors, even though the emissions have declined since the introduction of catalyst cars in 1990. Another large contributor is wood stoves and boilers in the residential sector. The evaporative emissions mainly originate from the use of solvents and in connection with extraction, transport and storage of oil and gas. The emissions from the energy industries have increased during the 1990s due to the increasing use of stationary gas engines, which have much higher emissions of NMVOC than conventional boilers. However, in later years the use of gas engines has declined due to structural changes in the Danish electricity market. The total anthropogenic emission has decreased by 50 % from 1990 to 2011, largely due to the increased use of catalyst cars and reduced emissions from use of solvents.

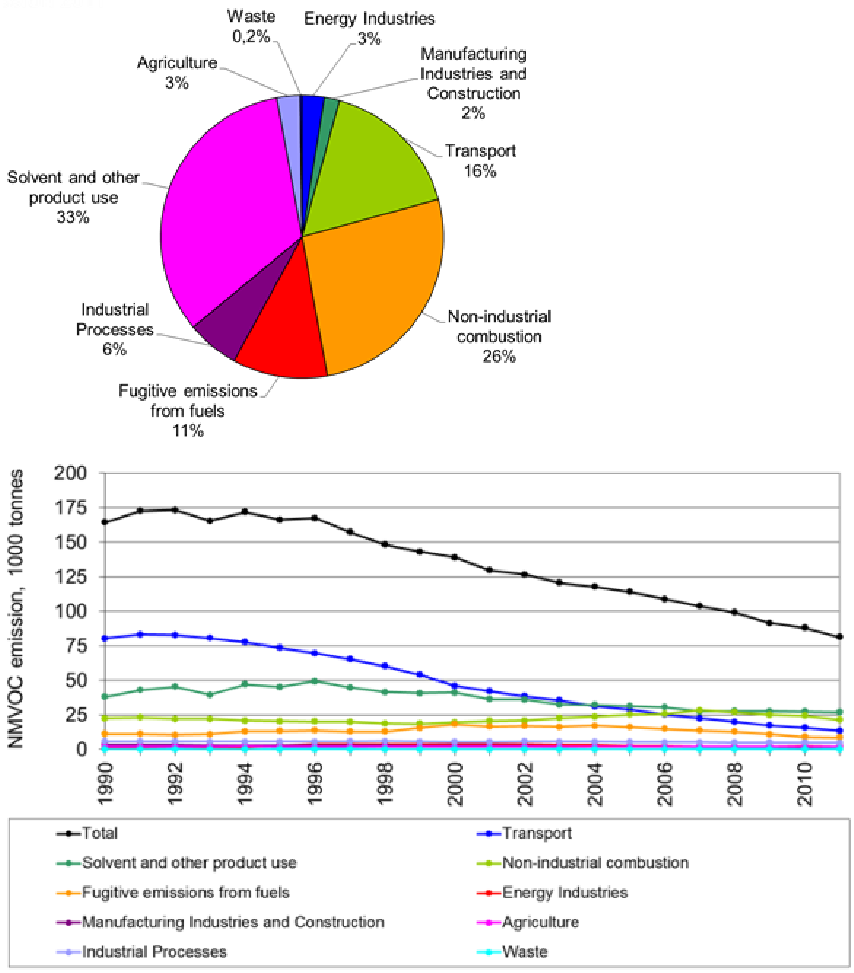


Figure 1.5 NMVOC emissions. Distribution by main sectors (2011) and time series for 1990 to 2011.

Particulate Matter

The particulate matter (PM) emission inventory has been reported for the years 2000-2011. The inventory includes the total emission of particles TSP (Total Suspended Particles), emission of particles smaller than 10 µm (PM_{10}) and emission of particles smaller than 2.5 µm ($PM_{2.5}$).

The largest TSP emission sources are the agricultural sector and the residential sector. TSP emissions from transport are also important and include both exhaust emissions and non-exhaust emissions from brake and tyre wear as well as road abrasion. The non-exhaust emissions account for 63 % of the TSP emission from road transport.

The largest $PM_{2.5}$ emission sources are the residential sector (67 %), road traffic (10 %) and other mobile sources (9 %). For the latter, the most important source is off-road vehicles and machinery in the agricultural-/forestry sector (37 %). For the road transport sector, exhaust emissions account for the major part (63 %) of the emissions.

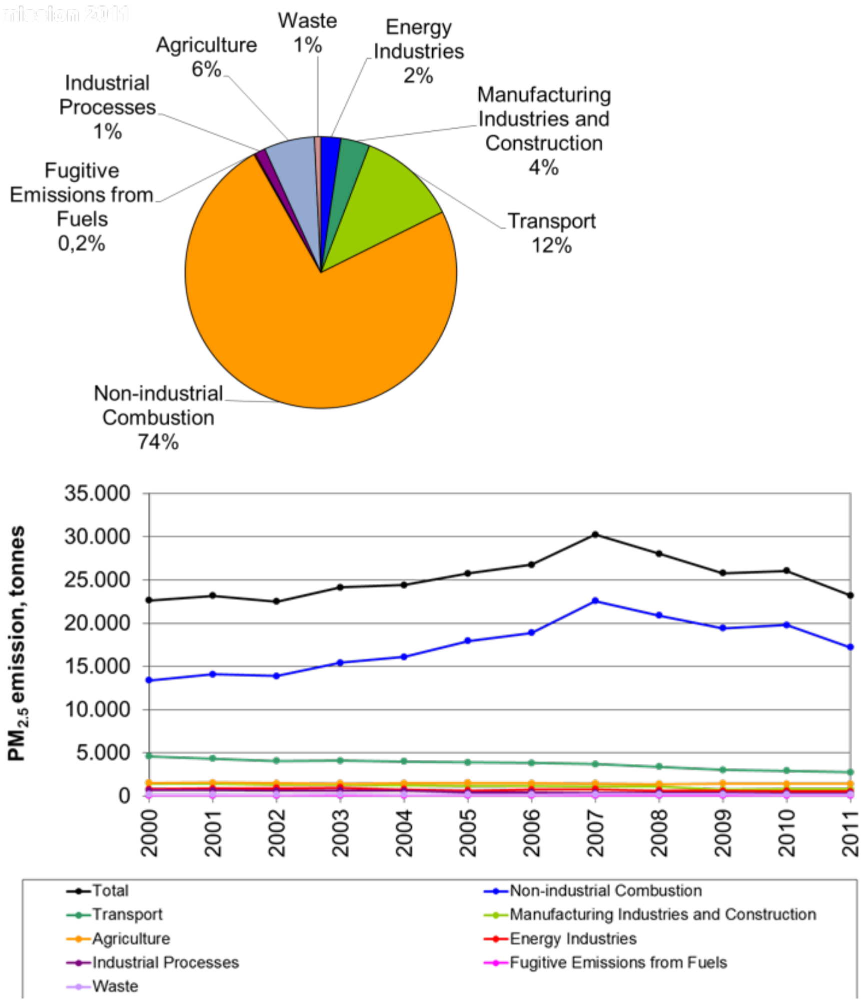


Figure 1.6 $PM_{2.5}$ emissions. Distribution by main sectors (2011) and time series for 2000 to 2011.

1.4 Projection models

Projection of emissions can be considered as emission inventories for the future, in which the historical data are 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:

Eq. 1.2: $$E=\sum_{s} A_s(t)\cdot \overline{EF}_s(t)$$

where As is the activity for sector 's' for the year 't' and EFs(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 1.3:

Eq. 1.3: $$\overline{EF_s}(t) = \sum_k P_{s,k}(t)\cdot EF_{s,k}(t)$$

where P is the activity share of a given technology within a given sector, EFs,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 these 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 primarily country-specific, based on default emission factors from the EMEP/EEA Emission Inventory Guidebook (EEA, 2009), as well as data from measurements carried out at Danish plants. The influence on the emission factors of legislation has been estimated and included in the models.

The projection models are based on the same structure and methodology as the Danish emission inventories in order to ensure consistency. In Denmark the emissions are estimated according to the EMEP/EEA Emission Inventory Guidebook (EEA, 2009) 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 for reporting (NFR) and the IPCC nomenclature for reporting (CRF).

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2 General assumptions

2.1 Energy projection

One of the cornerstones of this projection is the official Danish energy projection as elaborated by the Danish Energy Agency. The energy projection used in this emission projection is from October 2012 (DEA, 2012).

The official energy projection is made to estimate the future situation if no further measures are implemented; this is what is usually called a "with measures" scenario or a "frozen policy" scenario. This means that the projection includes the effects of all the decided, but not necessarily implemented, measures. For this projection, it means that all elements in the energy agreement from March 2012, as well as earlier decided measures in the energy agreement from 2008, the tax reform from 2009 and the review of the tax reform in 2010 have been included.

The projection is based on a number of general economic assumptions, e.g. industrial production, private consumption, fuel prices, etc. Also, a number of specific assumptions on technology are made, e.g. what are the costs of different plant types, what is the efficiency, etc. Finally, there are assumptions on how the energy market players will act under pure market conditions.

The general economic assumptions are described in detail in DEA (2012) and will not be repeated here. In general, the fuel prices and CO_2 price in the Danish energy projection are based on the World Energy Outlook 2011 published by the International Energy Agency. The assumptions related to economic growth are based on information from the Danish Ministry of Finance, published in May 2012.

The models used to make the energy scenario encompass a range of submodels, e.g. separate supply and demand models, household heating model, transport model, etc. Model descriptions are available at the website of the Danish Energy Agency[1].

2.1.1 Key points in the October 2012 projection

The final energy consumption is projected to decrease from 640 PJ in 2011 to 632 PJ in 2020. This covers a decrease in final energy consumption in industry, services and households, while the energy consumption in the transport sector is projected to increase. The energy consumption for the transport sector is projected to increase from 211 PJ in 2011 to 229 PJ in 2020 and a further increase to 245 PJ in 2030. The increased energy efficiency of the vehicle fleet contributes to lessen the increase in energy consumption.

Gross energy consumption is projected to decrease with approximately 6 % in 2020. This is mainly a result of a decrease in the energy consumption for production of electricity and district heating, due to the establishment of

[1] In Danish: http://www.ens.dk/sites/ens.dk/files/info/tal-kort/fremskrivninger-analyser-modeller/fremskrivninger/A%20-%20Modeller%20og%20fremskrivningsprincip.pdf
In English (limited): http://www.ens.dk/en/info/facts-figures/scenarios-analyses-models/models

several large off-shore wind farms (Anholt, Horn Rev 3 & Kriegers Flak). The consumption of fossil fuels is projected to decrease significantly (125 PJ until 2020). However, the fossil fuels are partially replaced by increased use of biogenic fuels, i.e. biomass (9 PJ), biofuels in the transport sector (13 PJ) and biogas (13 PJ). From 2020 onwards the consumption of fossil fuels is projected to remain relatively constant with a decrease in the coal consumption and an increase in the consumption of oil, mostly for transport purposes. The historic and projected development for the share of fossil and renewable energy in the gross energy consumption is illustrated in Figure 2.1 and 2.2.

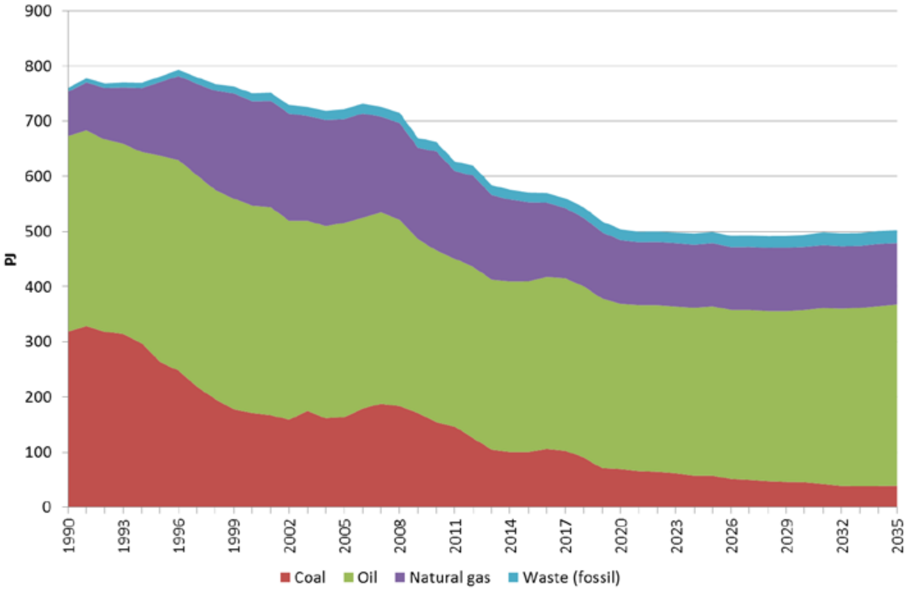

Figure 2.1 Development of fossil fuels in the gross energy consumption.

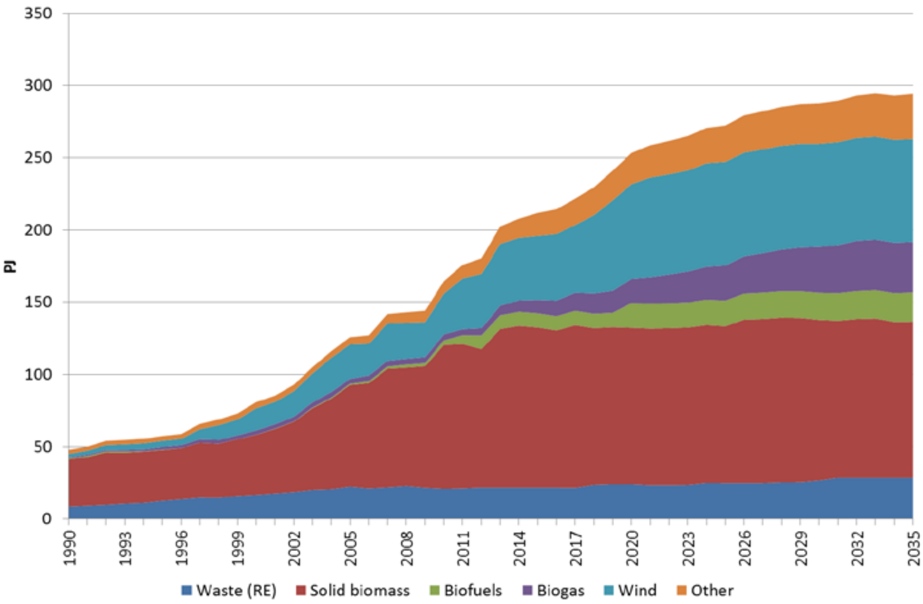

Figure 2.2 Development of renewable energy in the gross energy consumption.

2.1.2 Overall comparison between 2011 and 2012 projection

The 2011 projection only covered years until 2030 while the 2012 projection covered the years until 2035. Hence, the comparison is only made for years until 2030.

Table 2.1 shows the gross energy consumption (Observed energy consumption) for 2012, 2015, 2020, 2025 and 2030 as projected in the 2011 projection and 2012 projection. It can be seen that the total gross energy consumption projected in the 2012 projection is somewhat lower than the 2011 projection for 2015 onwards. All fossil fuel are projected at a lower level in the 2012 projection compared to the 2011 projection. However, the consumption of biogenic fuels and wind energy is higher in the 2012 projection.

Table 2.1 Comparison of gross energy consumption in the 2011 energy projection (DEA, 2011) and the 2012 energy projection (DEA, 2012).

		2012	2015	2020	2025	2030
2011 projection	**Total**	**803**	**805**	**818**	**834**	**859**
2011 projection	Coal	145	127	119	110	104
2011 projection	Oil	311	319	328	339	352
2011 projection	Natural gas	166	150	141	137	140
2011 projection	Fossil waste	13	14	14	15	16
2011 projection	Biogenic Waste	27	29	29	32	33
2011 projection	Biomass	80	96	103	114	126
2011 projection	Biofuels	10	10	10	11	11
2011 projection	Biogas	5	8	18	18	18
2011 projection	Wind	36	42	42	44	45
2011 projection	Other renewables	10	12	14	15	16
2012 projection	**Total**	**799**	**782**	**757**	**772**	**782**
2012 projection	Coal	125	101	69	58	45
2012 projection	Oil	310	309	300	307	312
2012 projection	Natural gas	165	143	115	115	115
2012 projection	Fossil waste	18	18	20	20	22
2012 projection	Biogenic Waste	22	22	24	25	27
2012 projection	Biomass	96	111	108	109	111
2012 projection	Biofuels	9	10	17	18	19
2012 projection	Biogas	5	9	17	24	32
2012 projection	Wind	37	44	65	72	71
2012 projection	Other renewables	11	16	22	25	28

Table 2.2 shows the final energy consumption (Sum of the consumption by the final users, i.e. private and public enterprises and households. Energy consumption in connection with extraction of energy, refining and transformation is not included in final energy consumption) for 2012, 2015, 2020, 2025 and 2030 as projected in the 2011 projection and 2012 projection. It can be seen that while the initial point is close to identical, the two projections differ already from 2015. The most significant change is for manufacturing industries and construction, where the consumption is projected far lower in the 2012 projection than in the 2011 projection.

Table 2.2 Comparison of final energy consumption in the 2011 energy projection (DEA, 2011) and the 2012 energy projection (DEA, 2012).

		2012	2015	2020	2025	2030
2011 projection	**Total**	**643**	**651**	**660**	**674**	**693**
2011 projection	Non-energy use	11	11	11	11	11
2011 projection	Transport	214	220	228	238	247
2011 projection	Manufacturing industry	139	144	151	156	166
2011 projection	Services	87	87	87	88	90
2011 projection	Households	192	188	184	181	178
2012 projection	**Total**	**646**	**636**	**632**	**641**	**649**
2012 projection	Non-energy use	12	12	12	12	12
2012 projection	Transport	213	219	229	236	245
2012 projection	Manufacturing industry	139	137	135	134	132
2012 projection	Services	85	81	79	79	78
2012 projection	Households	197	187	176	179	181

2.2 Transport projection

Fleet and mileage data for the road transport projections are provided by DTU Transport. The data for the projection period 2012-2035 are based on detailed fleet and mileage data for historical years set up in a COPERT IV format, and aggregated projections of total mileage and fleet numbers made with the econometric model ART developed by DTU Transport.

In order to obtain fleet and mileage data for Danish road transport in historical years, total mileage data from the Danish Road Directorate split into different vehicle categories are used together with vehicle fleet numbers for corresponding vehicle categories taken from the Danish vehicle register kept by Statistics Denmark. Fleet and mileage data are subsequently split into the detailed vehicle categories comprised by the COPERT IV model by using different statistical sources as described by Jensen (2012).

Aggregated fleet and mileage data for passenger cars, vans, trucks and buses are forecasted for the years 2012-2030 with the ART model. Output data has been extended until 2035 in ART by using the average growth from 2025-2030.

As a first step in different vehicle categories, historical scrapping curves determine the fleet numbers, year by year in the forecast period, as a function of first registration year. Next, in each forecast year, the difference between the fleet sum and the ART estimated fleet total determine vehicle new sales. The category “vehicle new sales” is split further into vehicle categories below the ART level (fuel type, engine size etc.) according to vehicle new sales in the last historical year (i.e. 2011).

Year by year in the forecast period, the total mileage is then split into vehicle categories by using the projected fleet numbers and the vehicle age distribution of annual mileage from the last historical year. Subsequently, all annual mileages are proportionally scaled in order to equal total mileage with the total mileage estimated by the ART model.

2.3 References

DEA, 2011: Danmarks Energifremskrivning 2011 (In Danish). Available at: http://www.ens.dk/info/tal-kort/fremskrivninger-analyser-modeller/fremskrivninger/fremskrivninger-tidligere-ar (23-08-2013).

DEA, 2012: Danmarks Energifremskrivning 2012 (In Danish). Available at: http://www.ens.dk/sites/ens.dk/files/info/tal-kort/fremskrivninger-analyser-model-ler/fremskrivninger/danmarks_energifremskrivning_2012_endelig_v1.2.pdf (18-07-2013).

Jensen, T.C., 2012: Dokumentation af konvertering af trafiktal til emissions-opgørelser, arbejdsnotat, 22 pp. DTU Transport, 2012.

3 Stationary combustion

Annual emissions are available for the years until 2011, while the presented emissions for 2012-2035 are projections.

For the years 2012-2035, emissions from stationary combustion will make up around 70 % of the national SO_2 emissions but the NH_3 emission will not exceed 0.5 %. The NO_x emission from stationary combustion is about the same in 2012 as in 2035, but the decreasing national emissions causes the contribution from stationary combustion to increase from 29 % in 2012 to 53 % in 2035.

The NMVOC and particle emissions from stationary combustion decrease throughout the projected time series. NMVOC, TSP, PM_{10} and $PM_{2.5}$ make up for 21 %, 50 %, 60 % and 74 % of the national emission in 2012, respectively, and 11 %, 32 %, 43 % and 62 % in 2035, respectively.

3.1 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 is, just as the Danish emission inventory for stationary combustion plants, based on the CORINAIR system described in the EMEP/CORINAIR Guidebook (EMEP-/CORINAIR, 2002). The projections are based on official activity rates forecast from the Danish Energy Agency (DEA) and on emission factors that are either emission factors for 2011 or projected 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. References for the 2011 emission factors are included in the latest IIR (Nielsen et al., 2013) and the projected emission factors that differ from the historic emission factors are discussed in Chapter 3.3.

Some of the large plants, such as power plants and waste incineration plants are registered individually as large point sources. Projected data for fuel consumption and emission are included for these plants. Projected fuel consumption refers to RAMSES, which is a plant specific projection of fuel consumptions estimated by the DEA as part of the energy projection. Projected plant specific emission factors are either based on 2011 emission data from annual environmental reports/PRTR data or projected emission factors provided by plant owners.

3.1.1 Sources

The combustion of fossil fuels is one of the most important sources of emission of SO_2, NO_x, NMVOC and PM. This chapter covers all sectors, which use fuels for energy production, with the exception of mobile combustion. Table 3.1 shows the sector categories used and the relevant classification.

Table 3.1 Sectors included in stationary combustion.

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

Fugitive emissions and emissions from flaring in oil refinery, and flaring in gas and oil extraction are estimated in Chapter 5.

3.1.2 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 2012-2035' and the overall construction of the database is shown in Figure 3.1 and Figure 3.2.

The model consists of input data collected in tables containing 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. In Table 3.2 the names and the content of the tables are listed.

Table 3.2 Tables in the 'Fremskrivning 2012-2035' database.

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 3.3.

Table 3.3 Queries for calculating the total emissions.

Name	Function
EmissionArea	Calculation of the emissions from small combustion plants.
	Input: tblActArea and tblEmfArea
EmissionPoint	Calculation of the emissions from large combustion plants.
	Input: tblActPoint and tblEmfPoint
EmissionAll	Union of EmissionArea and EmissionPoint

Based on some of the queries a number of summation queries are available in the 'Fremskrivning 2012-2035' database. Output from the summation queries is in the form of Excel Pivot tables.

Table 3.4 Summation queries.

Name	Output
xlsBrændselsforbrug fordelt på snap_Crosstab	Query containing total fuel consumptions for SNAP groups and years
xlsBrændselsforbrug fordelt på fuel_Crosstab	Query containing fuel consumptions for each fuel and years
xls_Brændselsforbrug fordelt på fuel punkt-kilder_Crosstab	Query containing fuel consumptions for large combustion plants for each fuel and years
xlsEmissionAll	Query containing emissions for SNAP groups, pollutants and years
xlsEmissionArea	Query containing emissions for small combustion plants for SNAP groups, years and pollutants
xlsEmissionPoint	Query containing emissions for large combustion plants for SNAP groups, years and pollutants

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

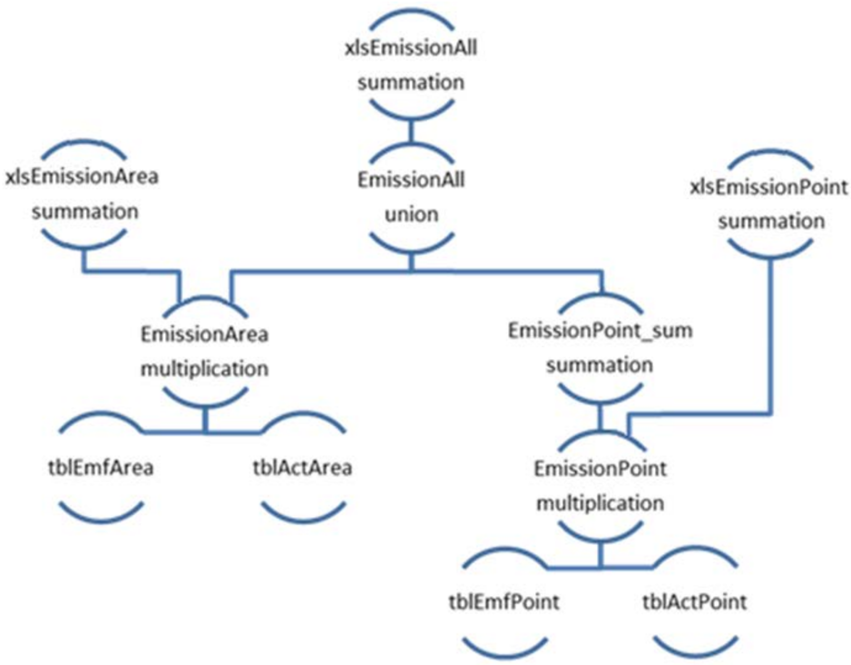

Figure 3.1 Overall construction of the database and calculation of emissions.

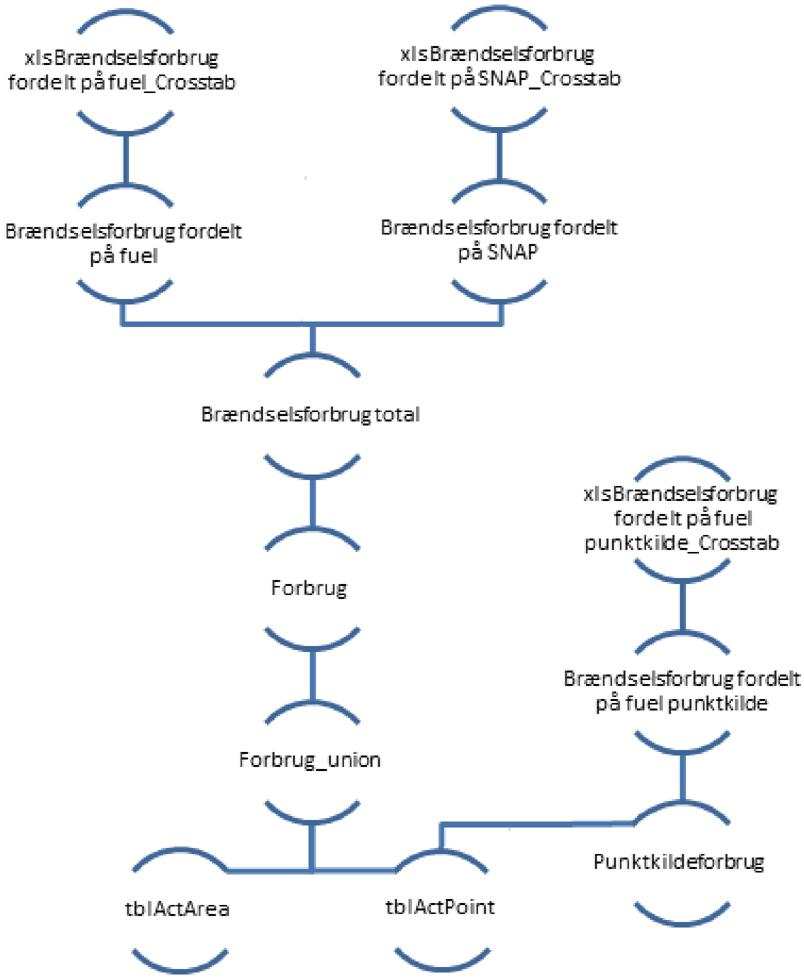

Figure 3.2 Overall construction of the database and calculation of fuel consumptions.

3.2 Activity data

The fuel consumption data in the model are based on the general projection of the energy consumption by the Danish Energy Agency (DEA, 2013a), and the projection for large combustion plants, Ramses (DEA, 2013b), from 2012 to 2035. For this report a projection from 2012 has been utilised.

For the purpose of emission calculation, data is split according to area and point sources. Point sources are plants larger than 25 MW_e and selected industrial point sources. The fuel consumption for the area sources is calculated by subtracting the point sources and the mobile sources from the general energy projection from the DEA. The projection is based on the amount of fuel which is expected to be combusted in Danish plants, and therefore has not been corrected for any international trade in electricity.

Fuel consumption data distributed according to fuel types is shown in Table 2.2 and Figure 2.1.

Throughout the time series, the most important fuel is natural gas, the second most important is coal in 2012 and 2013 after which wood takes over as the second most important. This switch is not so much due to an increase in wood as it is to a decrease in coal. Actually, the use of coal is projected to decrease with 57 % from 2012 to 2035 and the coal consumption will reach the same level as municipal waste in the years 2031-2035. The largest variations are seen for coal use and renewable energy use. Coal use peaks in 2012 and decreases significantly until 2035. For wood, the projected consumption increases from 2012 to 2013 and from there stays relatively constant. The use of biogas is projected to increase drastically throughout the time series by approximately 700 % from 2012 to 2035, however from a very low level. The projection of the future energy consumption is highly dependent on the development in fuel prices as well as structural changes in the Nordic electricity market. The decrease in total fuel consumption from 2012 to 2015 is mainly caused by a significant increase in the share of renewable energy, primarily wind power.

Table 3.5 Fuel consumption for stationary combustion, TJ.

	2012	2015	2020	2025	2030	2035
Natural gas	165 023	139 316	115 209	114 383	116 168	112 850
Steam coal	119685	75 345	69 179	53 792	55 444	51 643
Wood and similar	76 891	93 037	92 821	92 895	96 455	96 732
Municipal waste	39 656	39 584	43 667	45 062	48 317	51 748
Gas oil	20 626	14 390	5 070	7 165	6 897	6 953
Agricultural waste	18 923	16 590	15 593	15 612	15 606	12 627
Refinery gas	14 958	14 958	14 958	14 958	14 958	14 958
Residual oil	10 464	8 608	6 916	5 986	5 981	10 806
Petroleum coke	6 529	6 343	6 326	6 072	5 783	5 545
Biogas	5 000	9 300	16 800	24 300	31 800	35 000
LPG	1 345	1 312	1 396	1 417	1 372	1 334
Coke	721	531	196	177	153	134
Kerosene	49	49	51	54	56	59
Total	479 869	419 364	388 183	381 872	398 991	400 388

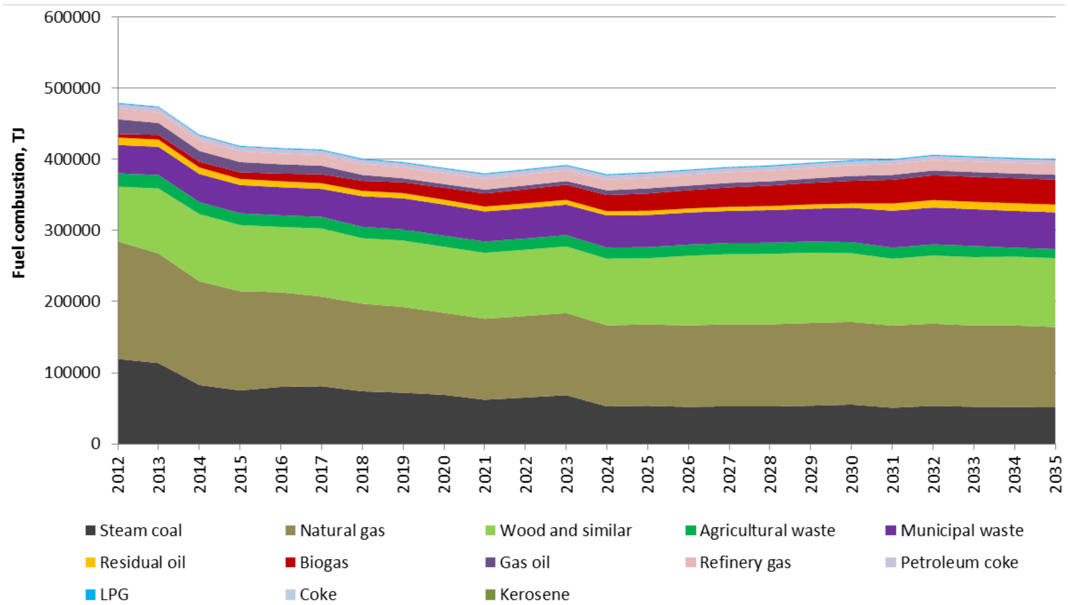

Figure 3.3 Fuel consumption distributed according to fuel type.

The sectors consuming the most fuel are public power, residential plants, manufacturing industries, off-shore and district heating. According to the energy projection the fuel consumption in the off-shore sector will increase with 49 % from 2012 to 2035. It is common that older extraction fields have higher energy consumption due to e.g. increased water production and energy use for reinjection of water.

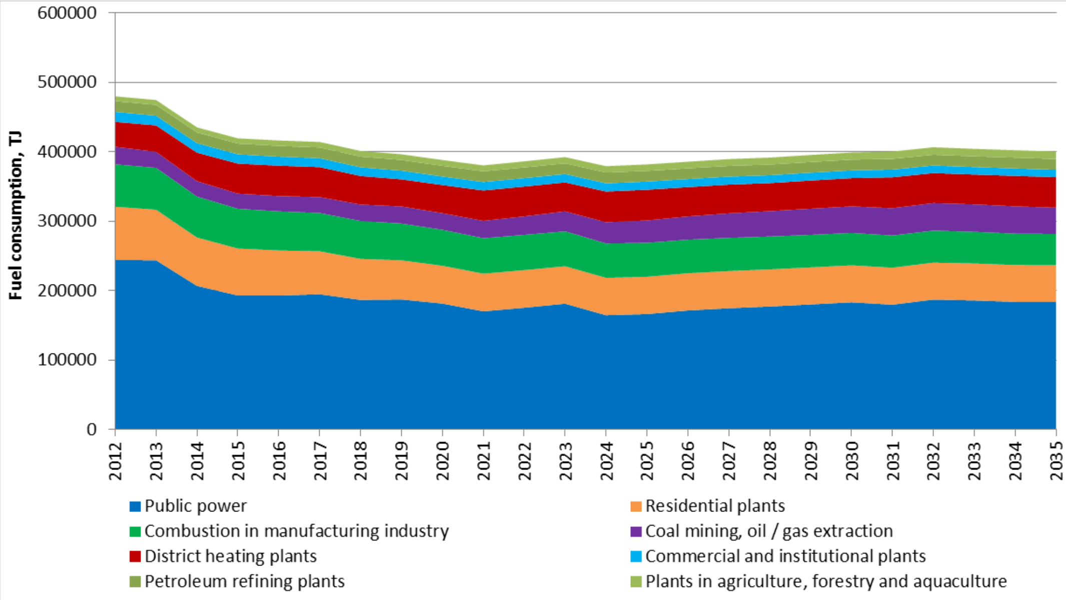

Figure 3.4 Fuel consumption distributed by sector.

Power plants larger than 25 MW_e use between 43 % and 51 % of total fuel. The fuel consumption in these sources is expected to decline from 2012 to 2021, thereafter the consumption increases slightly from 2024 to 2032 and then remain relatively stable. The consumption at large point sources is to a large extent dependent on expected import/export of electricity and major changes to the Scandinavian energy market, e.g. new wind farms or new nuclear power plants. This is the reasons behind the projected decrease in fuel consumption from 2012 to 2021. The amount of wood combusted by large point sources is expected to increase whereas the coal and natural gas consumption decreases.

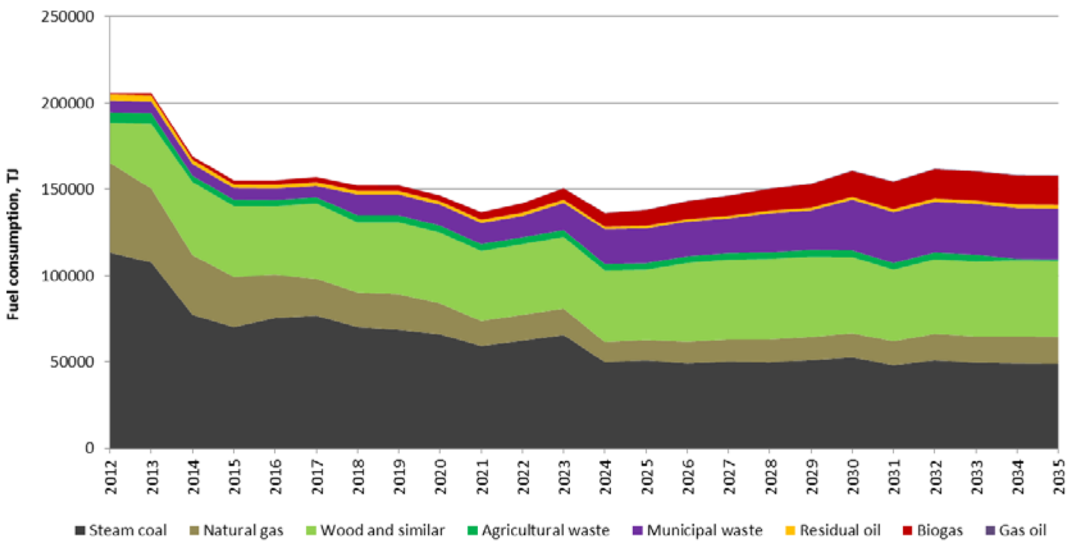

Figure 3.5 Fuel consumption for plants > 25 MW_e.

3.3 Emission factors

3.3.1 NO_X

In general, the applied NO_x emission factors are the emission factors used for the 2011 inventory. References for the emission factors and the related assumptions are reported in the Annual Danish Informative Inventory Report to UNECE (Nielsen et al. 2013).

The disaggregation to different technologies is less detailed in the projection model than in the historic inventories. Implied emission factors based on 2011 data have been estimated for the projection source categories that include different technology specific emission factors in the historic inventories.

The following legislation that will result in other emission factors than applied for 2011 has been incorporated:

Lov nr 1385 af 28/12/2011: Lov om ændring af lov om afgift af kvælstofoxider, lov om energiafgift af mineralolieprodukter m.v. og lov om afgift af naturgas og bygas (DMT 2011).
The NOx tax increased a factor 5 in July 2012. This increase is expected to cause plant improvements that will cause lower emission from large power plants. The power plant owners Vattenfall and DONG Energy have stated revised projection data for the power plants, see below (Jørgensen, 2013; Hvidbjerg, 2013).

In addition, the economically optimal regulation of some of the gas fuelled engines is expected change and result in a decline of NO_x emission and an increase of unburned hydrocarbon emission (Kristensen, 2013; Kvist et al., 2012). The emission factor for natural gas fuelled engines is currently 135 per GJ. In 2013, changes of engine settings are expected for 50 % of engines > 5 MW_{th}. The emission factor for these engines is estimated to 78 g per GJ (Kristensen, 2013; Kvist et al., 2012). The NO_x emission limit for natural gas fuelled engines > 5 MW is lowered in 2021 as discussed below and a linear decrease from 2013 to 2021 have been assumed.

Emission reductions caused by the increased NO_x tax have only been included in the projections for power plants and gas engines. The quantification of NO_x emission reductions for other plants has not been possible.

Lov 722 af 25/06/2010: Lov om ændring af lov om afgift af elektricitet, lov om kuldioxidafgift af visse energiprodukter og forskellige andre love (DMT 2010).
The legislation includes taxes for methane emission. The emission of methane is large for engines, but the tax is low compared to the NO_x tax and the economically optimal engine setting will reduce the NO_x emission and increase the CH_4 emission (Kristensen, 2013; Kvist et al., 2012).

Bekendtgørelse 1450 af 20/12/2012: Bekendtgørelse om begrænsning af emission af nitrogenoxider og carbonmonooxid fra motorer og turbiner, (DEPA, 2012).
The revised emission limit value for NO_x from natural gas fuelled engines > 5 MW_{th} have been implemented in the projections from 2021.

For biogas fuelled engines, the current emission factor is below the emission limit for existing plants < $5MW_{th}$. The emission limit value for plants > 5 MW_{th} valid for the years 2021 onwards is lower than the current emission factor. Only ~15 % of the consumption of biogas was applied in plants > $5MW_{th}$ in 2011. For existing biogas plants, the emission limit have been implemented for 15 % of the consumption in public power plants.

For new biogas fuelled engines, the revised emission limit is applicable for all years and has been implemented in the projections.

The emission limit for gas oil fuelled engines is much lower than the current emission factor. However, the engines operate less than 500 h/year and engines at plants > 50 MW (power plants) are exempted and the limit value is not applied in the projections.

'Godkendelsesbekendtgørelsen'/'Luftvejledningen' (DEPA 2001).
The legislation includes an emission limit that is below the current emission factor for new small natural gas fuelled boilers (non-residential boilers, 120 kW – 50 MW). The emission limit value for new plants has been applied for 2020 onwards[2]

Directive on industrial emissions 2010/75/EU (EU 2010).

Some of the emission limits in the EU Directive on Industrial Emissions (IED) are below the current emission factors.

- District heating plants > 100MW combusting coal: The current emission factor is above the limit in IED. However, coal was not applied in district heating plants without electricity production in 2011 and the energy projection does not include any consumption in these plants.
- Residual oil > 50 MW combusting residual oil: The current emission factor is almost equal to the future limit. All NO_x data for large plants are plant specific and the emission factor has not been applied in the projection.
- Combustion of biomass in plants 50-100 MW: The 2011 emission factor is above the future emission limit for some biomass fuels/plant capacities. The plant specific emission factors for most plants are however below the future limit. The emission limit value for wood and straw has been applied for 2020-2035 for public power producing plants included as point sources.
- Combustion of natural gas in boilers > 50MW: The 2011 emission factor is above the future emission limit. The emission limit value for natural gas has been applied for 2020-2035 for the public power producing plants included as point sources. However, plant specific data are available for all plants and thus the reduced emission limit and BREF is included in the projection by applying revised plant specific projections from Vattenfall and Dong Energy.

Plant specific data
NO_x emission factors for centralised power plants are based on plant specific information from DONG Energy and Vattenfall (Hvidbjerg, 2013; Jørgensen, 2013). Implied emission factors for NO_x emission in 2011 have been applied for other large combustion plants included as point sources in the projection.

Emission data for Aalborg Portland and Nordic Sugar have been implemented in the applied emission factors for coal, petroleum coke and waste used in industrial combustion.

[2] The 2011 emission factor for boilers for plants in commercial/institutional plants and plants in agriculture/forestry is almost identical to the emission limit for new plants and the current emission factor have been applied for the whole time series.

3.3.2 SO_2

In general, the applied SO_2 emission factors are the emission factors used for the 2011 inventory. References for the emission factors and the related assumptions are reported in the Annual Danish Informative Inventory Report to UNECE (Nielsen et al. 2013).

The emission factor for residual oil applied in refineries has been estimated based on plant specific emission data for 2011.

Emission factors for biogas have been aggregated based on emission factors for engines and other plants respectively.

Some of the emission limits in the EU directive on industrial emissions (EU 2010) are below the current emission factors.

- District heating plants > 50MW combusting coal: The current emission factor is above the limit in IED. However, coal was not applied in district heating plants without electricity production in 2011 and the energy projection does not include any consumption in these plants.
- Residual oil > 50 MW combusting residual oil: The current emission factor is above the future limit. However, the main part of residual oil combustion in large boilers takes place as secondary fuel in combination with another main fuel and hence contributing little to the total emission of the specific plant. Thus, the emission factor for residual oil might continue to be above the future emission limit for liquid fuels.

Plant specific data have not been implemented for power plants in the projection. However, the emission factor applied for coal in the projection is based on plant specific emission data for 2011.

Emission data for Aalborg Portland and Nordic Sugar have been implemented in the applied emission factors for coal and petroleum coke used in industrial combustion.

3.3.3 NMVOC

In general, the NMVOC emission factors applied for the projections are the emission factors used for the 2011 inventory. References for the emission factors and the related assumptions are reported in the Annual Danish Informative Inventory Report to UNECE (Nielsen et al., 2013).

Some of the emission factors applied in the projection model are aggregated based on emission factors for different technologies. The technology distribution in 2011 has been applied for the aggregation of implied emission factors.

Residential wood combustion is the main emission source category for NMVOC. A decreasing emission factor time series for residential wood combustion have been estimated based on the gradual implementation of units with improved technology, see Chapter 3.3.6.

The increased NO_x taxation (DMT, 2011) will change the economically optimal set point for gas engines. The NMVOC emission factor will increase as a result of the changed engine setting (Kristensen, 2013; Kvist et al., 2012). The increase has been implemented from 2013.

3.3.4 TSP, PM_{10} & $PM_{2.5}$

In general, the emission factors applied for particulate matter are the emission factors used for the 2011 inventory. References for the 2011 emission factors and the assumptions behind are reported in the Annual Danish Informative Inventory Report to UNECE (Nielsen et al., 2013).

Some emission factors have been aggregated for several plant types.

Residential wood combustion is the main emission source category for PM. A decreasing emission factor time series for residential wood combustion have been estimated based on the gradual implementation of units with improved technology, see Chapter 3.3.6.

3.3.5 NH_3

Stationary combustion is a small source category for NH_3 emission. The emission factors for NH_3 all refer to the 2011 emission inventory. The NH_3 emission is only estimated for waste incineration and residential combustion of coal, coke, wood and straw.

References for the emission factors have been reported in the Annual Danish Informative Inventory Report to UNECE (Nielsen et al., 2013).

3.3.6 Residential wood combustion

Residential wood combustion is a large emission source for PM and NMVOC. 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 number of wood stoves in Denmark is estimated to be around 750 000 excluding fireplaces (Evald, 2010; Evald, 2012). The number of fireplaces is estimated to be around 16 000 (Illerup et al., 2007). The number of residential wood boilers is estimated to be around 47 000 (Illerup et al., 2007).

For wood stoves, the following assumptions are made:

- Prior to 2004 and after 2008 a replacement rate of 25 000 wood stoves per annum (Hessberg, 2012)
- Between 2004 and 2008 the replacement rate was higher peaking with 40 000 in 2006 (Hessberg, 2012)
- Before 2007, the replacements are 75 % modern stoves and 25 % new stoves (Hessberg, 2012)
- From 2007, the replacements are 90 % eco-labelled stoves and 10 % modern stoves (Hessberg, 2012)
- Until 2020, the replaced stoves distributes to 60 % old stoves, 30 % new stoves and 10 % modern stoves (Hessberg, 2012)
- The stock distribution in 2010 has been estimated as 27 % old stoves, 42 % new stoves, 16 % modern stoves and 15 % eco-labelled stoves (Evald, 2010; Evald, 2012; Hessberg, 2012)
- The number of other stoves has been constant for all years (Nielsen, 2013)

For wood boilers the following assumptions are made:

- The annual replacement is 5 % (Illerup et al., 2007)
- The replacements are all new boilers and 80 % with accumulation tank (Illerup et al., 2007)
- The number of wood boilers has been constant for all years (Nielsen, 2013).

For pellet boilers/stoves, the energy statistics provides directly the consumption of wood pellets. Emissions are calculated directly based on the amount of wood pellets in the energy statistics and no breakdown into different technologies are made.

The wood consumption is calculated by multiplying the number of appliances with the estimated wood consumption per appliance. This bottom-up calculated consumption is then scaled to match the total wood consumption as reported by the DEA in the energy statistics.

The technology specific emission factors applied for the projections are equal to the technology specific emission factors applied for the historic emission inventories. The replacement of old technologies with new technologies results in a decreasing implied emission factors for NMVOC and particulate matter, which causes the emissions from residential wood combustion to decrease substantially from 2012 to 2035.

3.4 Emissions

Emissions are calculated using equation 2.1, where A is the fuel consumption for sector 's' in the year 't'. $EF_s(t)$ is the aggregated emission factor for a sector s in the year t.

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

3.4.1 NO_x

The estimated NO_x emission is shown in Table 3.6 and in Figure 3.6.

The total NO_x emission decreases from 2012 to 2020 due to decreasing fuel consumption, with natural gas experiencing the largest fall in consumption. The projected decrease in emission from combined heat and power (CHP) plants and residential plants from 2012 to 2020 is caused by a decrease in consumption of natural gas and coal. The following increase from 2021 to 2035 brings the emission back to 2012 level with increases in natural gas and biogas.

Table 3.6 NO_X emissions from stationary combustion, Mg.

Sector	1990	2005	2010	2011	2012	2015	2020	2025	2030	2035
Public power	85 503	35 759	16 146	13 927	12 840	9 341	9 424	9 439	10 701	11 500
District heating plants	5 112	1 899	2 766	2 450	2 499	2 713	2 180	2 356	2 203	2 790
Petroleum refining plants	1 462	1 288	1 544	1 594	1 404	1 404	1 404	1 404	1 404	1 404
Oil/gas extraction	2 371	6 999	6 490	6 259	6 330	5 454	6 007	8 039	9 555	9 452
Commercial and institutional plants	1 332	1 047	878	716	739	699	667	647	625	602
Residential plants	4 955	5 830	6 617	5 658	5 990	5 519	4 726	4 751	4 796	4 859
Plants in agriculture, forestry and aquaculture	1 179	1 164	705	613	643	747	892	1 056	1 220	1 292
Combustion in industrial plants	12 362	12 887	5 941	5 930	5 181	4 843	4 150	3 965	3 782	3 647
Total	114 265	66 873	41 087	36 947	35 625	30 719	29 450	31 659	34 287	35 546

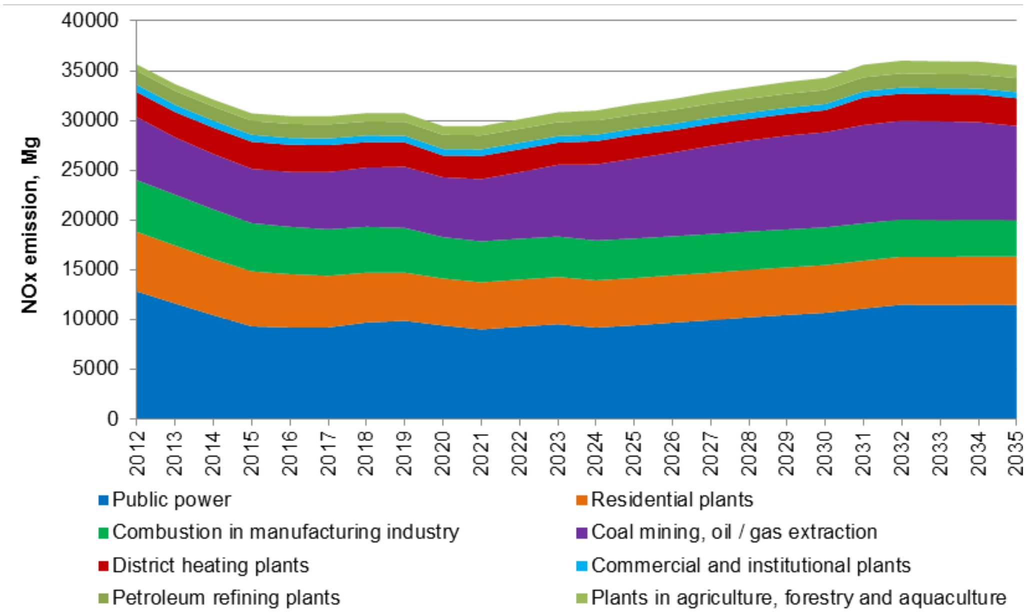

Figure 3.6 Projected NO_X emissions by sector.

NO_x emissions from gas turbines used in the offshore sector are projected to increase significantly. From 2012 to 2035 the emission increases by 49 % due to increasing fuel consumption. The high emission factor and the projected increase in fuel consumption mean that the offshore sector will account for about 27 % of the total NO_x emission from stationary combustion in 2035.

3.4.2 SO_2

The estimated SO_2 emission is shown in Table 3.7 and in Figure 3.7.

The total SO_2 emission decreases from 2012 to 2024 due to a decrease in coal and residual coal, and then remains relatively constant until 2030. From 2030 to 3031, residual oil used in district heating plants increases significantly (4.1 PJ). The emission from manufacturing industries is expected to decrease due to conversion from fossil fuels with higher SO_2 emission factor, e.g. coal, coke and residual oil to biofuels. The SO_2 emission from public power remains somewhat constant.

Table 3.7 SO_2 emissions from stationary combustion, Mg.

Sector	1990	2005	2010	2011	2012	2015	2020	2025	2030	2035
Public power	119 144	6 829	2 622	1 835	2 708	1 971	1 937	1 790	2 042	2 066
District heating plants	7 001	869	997	835	1 323	1 383	1 315	1 304	1 201	2 693
Petroleum refining plants	1 059	224	231	321	321	321	321	321	321	321
Oil/gas extraction	4	12	11	11	8	7	7	10	11	11
Commercial and institutional plants	1 876	263	119	94	110	105	102	100	98	95
Residential plants	6 291	1 288	1 158	994	1 520	1 380	1 142	1 155	1 172	1 194
Plants in agriculture, forestry and aquaculture	3 191	1 590	1 087	1 008	1 166	1 202	1 177	1 201	1 229	1 246
Combustion in industrial plants	16 077	6 189	3 071	3 197	4 179	3 441	2 208	2 096	1 966	1 863
Total	154 642	17 264	9 296	8 295	11 334	9 809	8 209	7 977	8 040	9 488

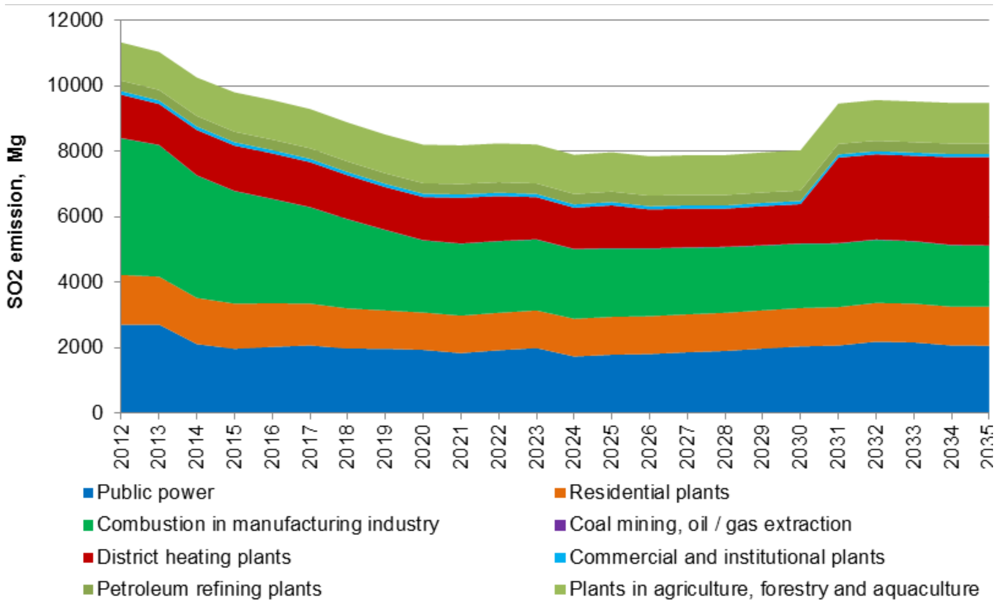

Figure 3.7 Projected SO_2 emissions by sector.

3.4.1 NMVOC

The estimated NMVOC emission is shown in Table 3.8 and in Figure 3.8.

From 2012 to 2035 the NMVOC emission is projected to decrease due to a lower emission factor for wood combustion in residential plants. This is due to the replacement of old wood stoves and boilers with new technologies that have considerably lower emissions. The residential sector will account for between 70 % and 81 % of the total NMVOC emission from stationary combustion plants.

Table 3.8 NMVOC emissions from stationary combustion, Mg.

Sector	1990	2005	2010	2011	2012	2015	2020	2025	2030	2035
Public power	338	2 495	2 244	1 870	2 517	1 316	977	794	893	981
District heating plants	112	92	137	129	133	140	134	139	131	139
Petroleum refining plants	23	23	21	22	22	22	22	22	22	22
Oil/gas extraction	13	45	42	40	41	35	38	51	61	60
Commercial and institutional plants	131	262	262	242	234	216	198	190	183	176
Residential plants	11 407	13 599	14 869	12 830	13 274	11 019	8 140	7 131	6 127	5 117
Plants in agriculture, forestry and aquaculture	826	728	507	491	516	530	518	527	538	545
Combustion in industrial plants	1 100	425	298	305	340	327	313	298	284	274
Total	13 951	17 670	18 379	15 930	17 076	13 605	10 339	9 152	8 239	7 313

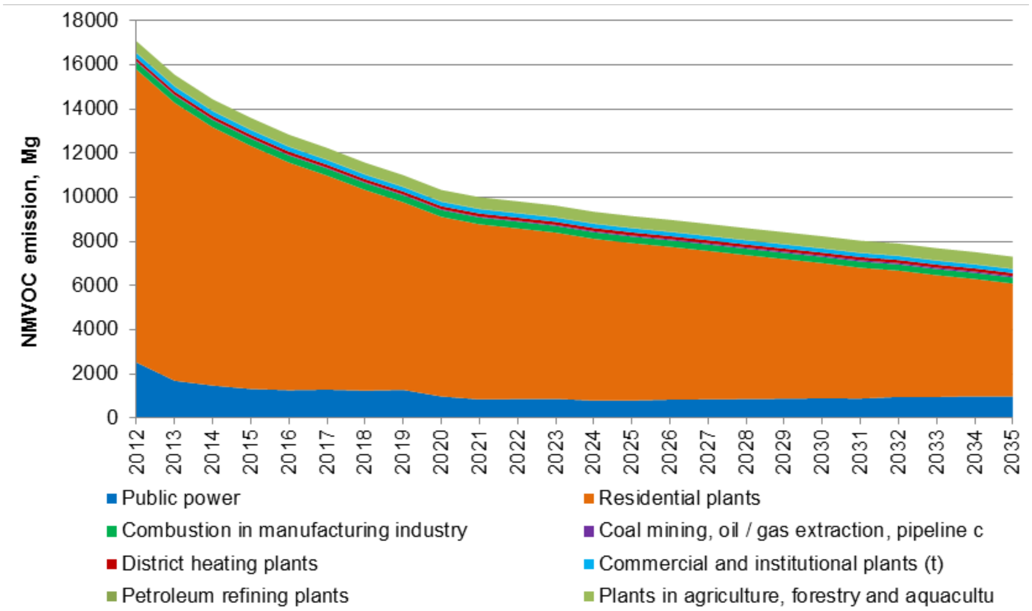

Figure 3.8 Projected NMVOC emissions by sectors.

3.4.1 TSP, PM_{10}, $PM_{2.5}$

The estimated TSP emission is shown in Table 3.9 and in Figure 3.9.

The TSP emission has increased in the historic years due to increasing wood combustion in residential plants. However, from 2012 to 2035 the TSP emission is expected to decrease due to a lower emission factor for wood combustion in residential plants. This is due to the replacement of old wood stoves and boilers with new technologies that have considerably lower emissions. The residential sector will account for between 78 % (2035) and 89 % (2012) of the total TSP emission from stationary combustion.

Table 3.9 TSP emissions from stationary combustion, Mg.

Sector	2005	2010	2011	2012	2015	2020	2025	2030	2035
Public power	948	455	429	652	683	667	630	687	677
District heating plants	224	322	305	307	262	232	246	239	251
Petroleum refining plants	111	94	100	100	100	100	100	100	100
Oil/gas extraction	3	3	3	3	2	2	3	4	4
Commercial and institutional plants	157	160	168	162	150	138	133	129	125
Residential plants	17 100	19 323	16 596	17 054	13 980	10 992	9 758	8 532	7 300
Plants in agriculture, forestry and aquaculture	517	506	502	526	539	520	524	530	535
Combustion in industrial plants	421	283	300	357	358	375	363	351	342
Total	19 481	21 145	18 404	19 162	16 075	13 028	11 758	10 573	9 334

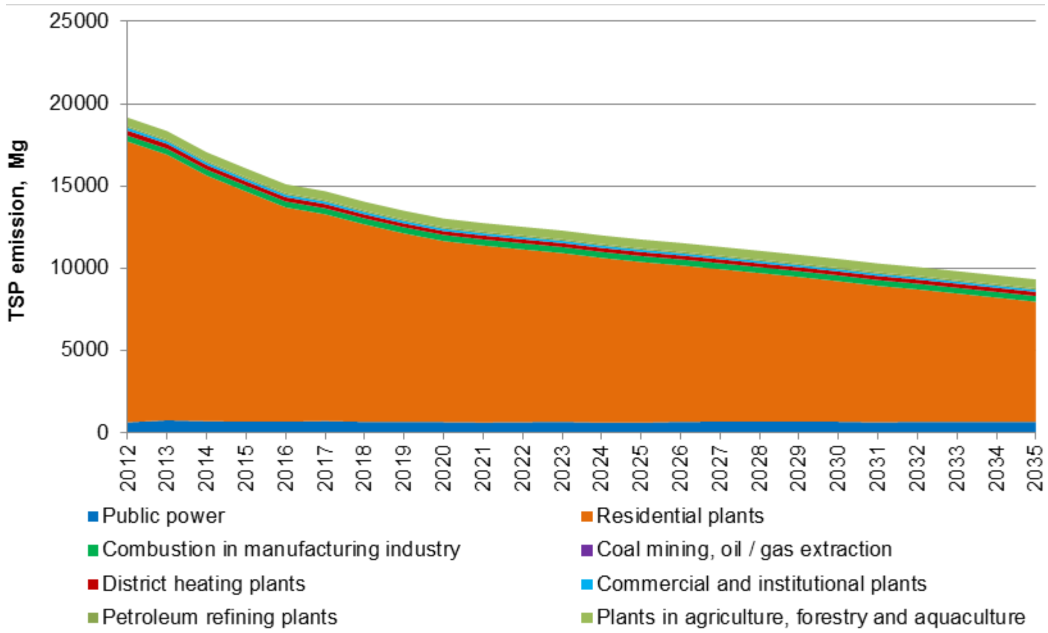

Figure 3.9 Projected TSP emissions distributed by sector.

The estimated PM_{10} emission is shown in Table 3.10 and in Figure 3.10.

The PM_{10} emission has increased in the historic years due to increasing wood combustion in residential plants. However, from 2012 to 2035 the PM_{10} emission is expected to decrease due to a lower emission factor for wood combustion in residential plants. This is due to the replacement of old wood stoves and boilers with new technologies that have considerably lower emissions. The residential sector will account for between 70 % and 81 % of the total PM_{10} emission from stationary combustion plants in the period 2012-2035 with the share being highest in the beginning of the period. This is the same trend as projected for TSP.

Table 3.10 PM_{10} emissions from stationary combustion, Mg.

Sector	2005	2010	2011	2012	2015	2020	2025	2030	2035
Public power	516	374	356	522	531	518	476	511	500
District heating plants	160	230	215	224	191	166	179	173	186
Petroleum refining plants	104	90	95	95	95	95	95	95	95
Oil/gas extraction	2	2	2	2	1	1	2	2	2
Commercial and institutional plants	150	158	166	161	149	137	131	127	123
Residential plants	16 296	18 401	15 802	16 241	13 318	10 474	9 303	8 139	6 969
Plants in agriculture, forestry and aquaculture	479	473	471	493	504	486	488	492	496
Combustion in industrial plants	285	209	222	252	251	261	253	244	238
Total	17 993	19 936	17 328	17 990	15 041	12 138	10 926	9 785	8 610

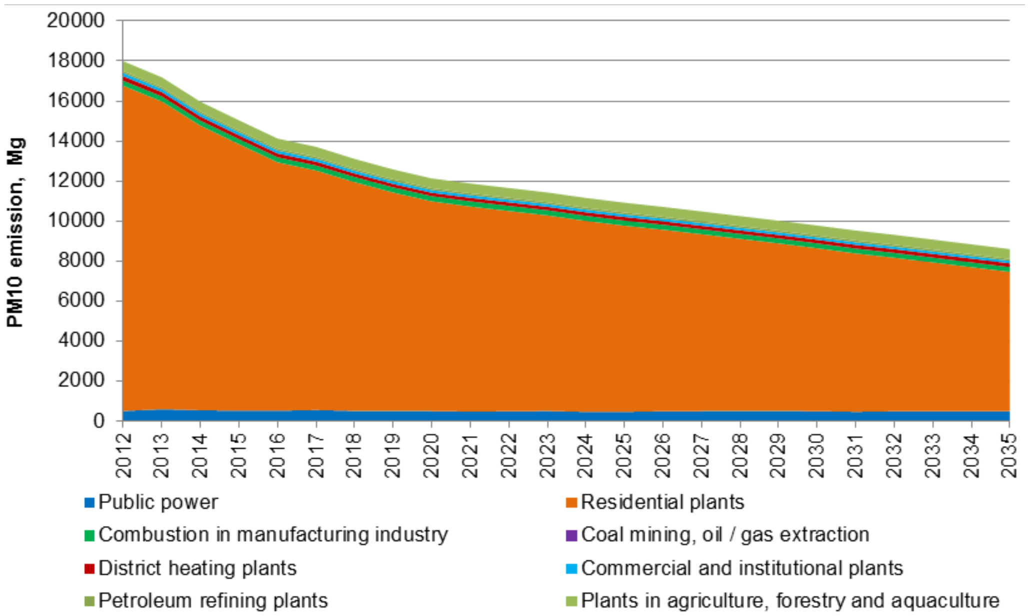

Figure 3.10 Projected PM_{10} emissions by sector.

The estimated $PM_{2.5}$ emission is shown in Table 3.11 and in Figure 3.11.

The $PM_{2.5}$ emission has increased in the historic years due to increasing wood combustion in residential plants. However, from 2012 to 2035 the $PM_{2.5}$ emission is expected to decrease due to a lower emission factor for wood combustion in residential plants. This is due to the replacement of old wood stoves and boilers with new technologies that have considerably lower emissions. The residential sector will account for between 70 % and 81 % of the total $PM_{2.5}$ emission from stationary combustion plants in the period 2010-2030 with the share being highest in the beginning of the period. The same trend that is observed for TSP and PM_{10} can be seen for $PM_{2.5}$.

Table 3.11 $PM_{2.5}$ emissions from stationary combustion, Mg.

Sector	2005	2010	2011	2012	2015	2020	2025	2030	2035
Public power	414	297	285	394	380	369	335	359	351
District heating plants	127	185	170	184	157	134	146	142	152
Petroleum refining plants	101	87	93	93	93	93	93	93	93
Oil/gas extraction	1	1	1	1	1	1	2	2	2
Commercial and institutional plants	140	149	157	152	140	129	124	120	116
Residential plants	16 025	18 148	15 572	16 050	13 199	10 381	9 211	8 048	6 879
Plants in agriculture, forestry and aquaculture	445	443	441	462	472	454	456	460	464
Combustion in industrial plants	159	142	156	165	168	183	178	173	169
Total	17 412	19 452	16 875	17 500	14 610	11 745	10 545	9 397	8 227

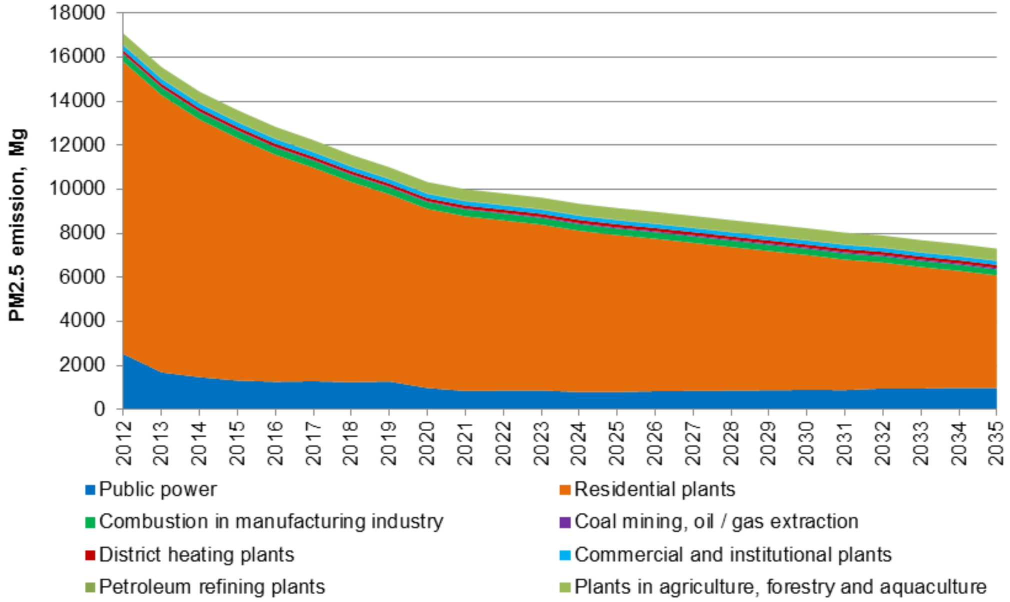

Figure 3.11 Projected $PM_{2.5}$ emissions by sector.

3.4.1 NH_3

The estimated NH_3 emission is shown in Table 3.12.

The total NH_3 emission remains relatively constant in the projection compared with recent historical years. The NH_3 emission from stationary combustion mainly originates from wood combustion in residential plants. Other small contributions are from waste incineration and coal and coke combustion in residential plants.

Table 3.12 NH_3 emissions from stationary combustion, Mg.

Sector	1990	2005	2010	2011	2012	2015	2020	2025	2030	2035
Public power	0	8	9	12	11	11	12	12	13	14
District heating plants	0	1	1	1	0	0	0	0	0	0
Residential plants	67	143	196	176	188	183	169	172	175	179
Total	67	152	206	190	199	194	181	184	189	194

3.5 Changes since previous projection

3.5.1 Activity data

The energy projection and RAMSES data have been updated by DEA and implemented in the emission projections.

The consumption of biogas applied in new gas engines is now specified in the energy projections[3].

3.5.2 Emission factors

The emission factors have been updated according to the emission factors applied for 2011.

The higher NO_x tax has been included in the estimated emission factor for both natural gas fuelled engines and biogas fuelled engines.

[3] Included in RAMSES.

The revised legislation for gas fuelled engines has been implemented.

The projection data for residential wood combustion have been updated including the improved data for technology distribution and technology specific emission factors. The improved data result in revised emission factor time series and decreasing emissions from residential wood combustion.

Plant specific NO_x emission factors have been updated for all large plants. Vattenfall and DONG Energy have both forwarded updated emission factor projections. For other large plants, the NO_x emission factors have been updated according to implied emission factors for 2011.

Emission data for Aalborg Portland and Nordic Sugar have been implemented in the applied emission factors for SO_2 and NO_x from industrial combustion.

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4 Road transport and mobile sources

In the projection model all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution) according to the CollectER system. The aggregation to the sector codes used for both the UNFCCC and UNECE Conventions is based on a correspondence list between SNAP and CFR/NFR classification codes shown in Table 4.1 (mobile sources only). With the exception of NH_3, mobile combustion is a large source of emissions for all the remaining pollutants.

Table 4.1 SNAP – CRF/NFR correspondence table for transport.

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

Military transport activities (land and air) refer to the CRF/NFR sector Other (1A5), while the Transport-Navigation sector (1A3d) comprises national sea transport (ship movements between two Danish ports) and recreational crafts (SNAP code 0803). For aviation, LTO (Landing and Take Off)[4] refers to the part of flying, which is below 1000 m. The working machinery and equipment in industry (SNAP code 0808) is grouped in Industry-Other (1A2f), while 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. 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.

4.1 Road Transport

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

[4] 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.

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.

4.1.1 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 4.2 gives an overview of the different model classes and sub-classes and the layer level with implementation years are shown in Annex 4.I.

Table 4.2 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	2-stroke
Mopeds	Gasoline	4-stroke
Motorcycles	Gasoline	2 stroke
Motorcycles	Gasoline	< 250 cc.
Motorcycles	Gasoline	250 – 750 cc.
Motorcycles	Gasoline	> 750 cc.

To support the emission projections fleet and mileage data have been prepared by DTU Transport for the vehicle categories present in COPERT IV (Jensen & Kveiborg, 2012). 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 (Ekman, 2005). Additional data for the moped fleet and motorcycle fleet disaggregation information is given by The National Motorcycle Association (Markamp, 2013).For information on the historical vehicle stock and annual mileage, please refer to Nielsen et al. (2013).

In addition DTU Transport has provided information of the total mileage driven by foreign trucks on Danish roads for rigid trucks and truck-trailer/articulated truck combinations, respectively. This mileage contribution has been added to the total mileage for Danish trucks on Danish roads, for trucks in comparable gross vehicle weight size classes. The data from DTU Transport was estimated for the years 1999-2011 and by using appropriate assumptions the mileage has been back-casted to 1985 and forecasted to 2035.

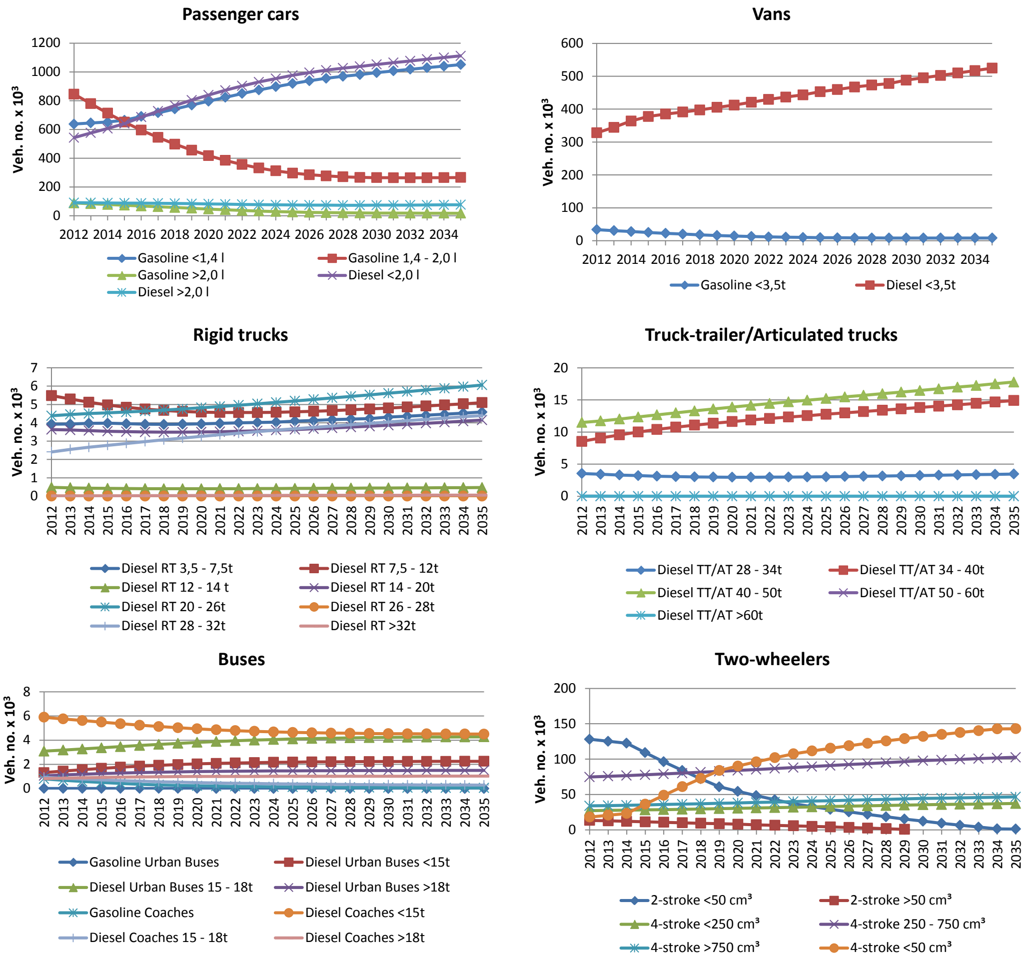

Figure 4.1 Number of vehicles in sub-classes from 2012-2035.

The vehicle numbers per sub-class are shown in Figure 4.1. The engine size differentiation is associated with some uncertainty.

The vehicle numbers are summed up in layers for each year (Figure 4.2) by using the correspondence between layers and first registration year:

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

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.

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

Vehicle numbers and weighted annual mileages per layer are shown in Annex 4.1 for 2012-2035. The trends in vehicle numbers per EU layer are also shown in Figure 4.2 for the 2012-2035 periods. The latter figure clearly shows how vehicles complying with the gradually stricter EU emission levels (EURO V and VI) are introduced into the Danish motor fleet in the forecast period.

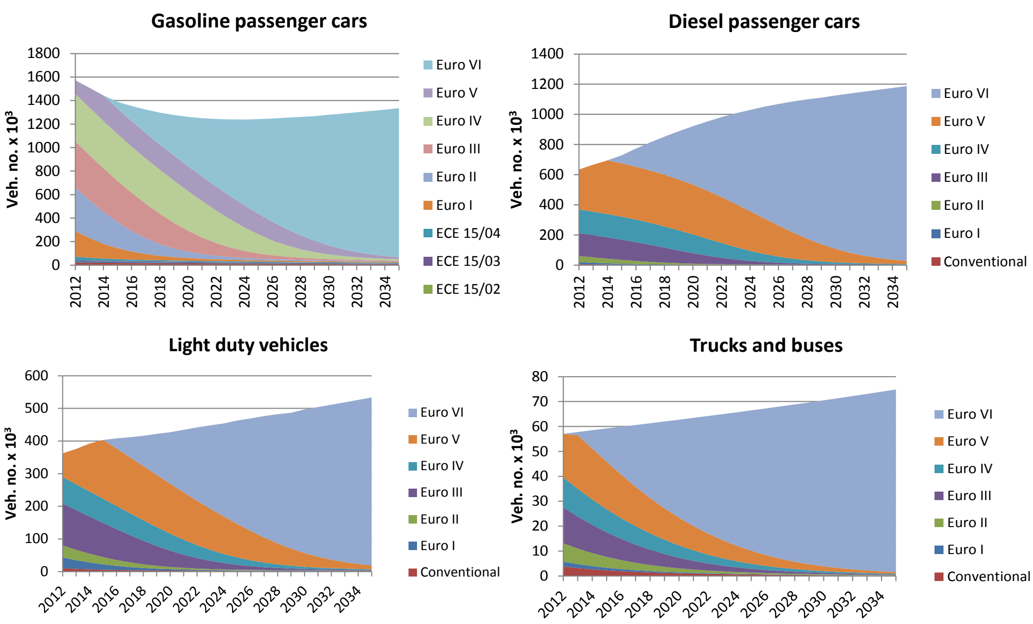

Figure 4.2 Layer distribution of vehicle numbers per vehicle type in 2012-2035.

4.1.2 Fuel and emission legislation

For Euro 1-4 passenger cars and light duty trucks, the chassis dynamometer test cycle used in the EU for emission approval is the NEDC (New European Driving Cycle), see Nørgaard and Hansen (2004). 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 cycle5 (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

[5] For Euro 3 and on, the emission approval test procedure was slightly changed. The 40 s engine warm up phase before start of the urban driving cycle was removed.

consumption under rural and highway driving conditions. The driving length of EUDC is 7 km at an average speed of 63 km pr h. More information regarding the fuel measurement procedure can be found in the EU-directive 80/1268/EØF.

For 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 4.3. The emission directives distinguish between three vehicle classes according to vehicle reference mass[6]: 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 (2012).

In practice, the emissions from vehicles in traffic are different from the legislation limit values and, therefore, the latter figures are considered to be too inaccurate for total emission calculations. A major constraint is that the emission approval test conditions reflect only to a small degree the large variety of emission influencing factors in the real traffic situation, such as cumulated mileage driven, engine and exhaust after treatment maintenance levels and driving behaviour.

Therefore, in order to represent the Danish fleet and to support average national emission estimates, emission factors must be chosen which derive from numerous 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).

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

In terms of the sulphur content in the fuels used by road transportation vehicles, the EU Directive 2003/17/EC describes the fuel quality standards agreed by the EU. In Denmark, the sulphur content in gasoline and diesel was reduced to 10 ppm in 2005 by means of a fuel tax reduction for fuels with 10 ppm sulphur content.

[6] Reference mass: net vehicle weight + mass of fuel and other liquids + 100 kg.

Table 4.3 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		0
	ECE 15/00-01	70/220 - 74/290	1972[a]
	ECE 15/02	77/102	1981[b]
	ECE 15/03	78/665	1982[c]
	ECE 15/04	83/351	1987[d]
	Euro I	91/441	1.10.1990[e]
	Euro II	94/12	1.1.1997
	Euro III	98/69	1.1.2001
	Euro IV	98/69	1.1.2006
	Euro V	715/2007	1.1.2011
	Euro VI	715/2007	1.9.2015
Passenger cars (diesel and LPG)		Conventional	0
	ECE 15/04	83/351	1987[d]
	Euro I	91/441	1.10.1990[e]
	Euro II	94/12	1.1.1997
	Euro III	98/69	1.1.2001
	Euro IV	98/69	1.1.2006
	Euro V	715/2007	1.1.2011
	Euro VI	715/2007	1.9.2015
Light duty trucks (gasoline and diesel)		Conventional	0
	ECE 15/00-01	70/220 - 74/290	1972[a]
	ECE 15/02	77/102	1981[b]
	ECE 15/03	78/665	1982[c]
	ECE 15/04	83/351	1987[d]
	Euro I	93/59	1.10.1994
	Euro II	96/69	1.10.1998
	Euro III	98/69	1.1.2002
	Euro IV	98/69	1.1.2007
	Euro V	715/2007	1.1.2012
	Euro VI	715/2007	1.9.2016
Heavy duty vehicles	Euro 0	88/77	1.10.1990
	Euro I	91/542	1.10.1993
	Euro II	91/542	1.10.1996
	Euro III	1999/96	1.10.2001
	Euro IV	1999/96	1.10.2006
	Euro V	1999/96	1.10.2009
	Euro VI	595/2009	1.10.2013
Mopeds		Conventional	0
	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
Motorcycles		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

Notes 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.

4.1.3 Fuel consumption and emission factors

Trip speed dependent base factors for fuel consumption and emissions are taken from the COPERT IV model, using trip speeds representative for urban, rural and highway driving. The factors can be seen in Winther (2012). 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. Real measurement data lies behind the emission factors for passenger cars (Euro 4 and prior), vans (Euro 1 and prior), trucks and buses (Euro V and prior), and for mopeds and motorcycles (all technologies).

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

Adjustment for improvements in fuel efficiency

For each vehicle layer the baseline fuel consumption factors for Euro 4, 5 and 6 are constant values in COPERT IV, and adjustment of these factors need to be made in order to account for the trend towards more fuel efficient vehicles being sold in Denmark during the later years. This adjustment is made based on type approval and "in use" fuel economy values incorporated in the DTU Transport fleet and mileage statistics for new registered cars, fuel specific CO_2 emission factors, and the average 95 g CO_2 per km type approval EU target for new cars sold in 2020. The adjustment is explained in more details in Nielsen et al. (2013).

Adjustment for EGR, SCR and filter retrofits

COPERT IV comprises emission factors for Euro V heavy duty vehicles using EGR and SCR exhaust emission after treatment systems, respectively. The estimated new sales of Euro V diesel trucks equipped with EGR and SCR during the 2006-2010 time periods has been examined by Hjelgaard and Winther (2011). These inventory fleet data are used in the Danish inventory to calculate weighted emission factors for Euro V trucks in different size categories.

During the 2000's urban environmental zones have been established in Danish cities in order to bring down the particulate emissions from diesel fuelled heavy duty vehicles. Driving in these environmental zones prescribe the use of diesel particulate filters. The Danish EPA has provided the estimated number of Euro I-III urban buses and Euro II-III trucks and tourist buses which have been retrofitted with filters during the 2000's. These retrofit data are included in the Danish inventory by assuming that particulate emissions are lowered by 80 % compared with the emissions from the same Euro technology with no filter installed (Winther, 2011).

Adjustment for biofuel usage

A literature review carried out in the Danish research project REBECA revealed no significant changes in emission factors between neat gasoline and E5 gasoline-ethanol blends for the combustion related emission components; NO_x, CO and VOC (Winther et al., 2012). Hence, due to the current low ethanol content in today's road transport gasoline, and given that the ethanol content is not expected to exceed 10 % at any time in the future, no modifications of the neat gasoline based COPERT emission factors are made in the inventory projections in order to account for ethanol usage.

REBECa results published by Winther (2009) have also shown that the emission impact of using diesel-biodiesel blends is very small at low biodiesel blend ratios. Consequently no bio fuel emission factor adjustments are needed for diesel vehicles as well.

Deterioration factors

For three-way catalyst cars the emissions of NO_X, NMVOC and CO gradually increase due to catalyst wear and are, therefore, modified as a function of total mileage by the so-called deterioration factors. The adjustment is explained in more details in Winther (2012).

Adjustment for less NO_x emission efficient Euro 5 and 6 diesel passenger cars

Updated NO_x emission factors for diesel passenger cars are available in the COPERT IV model as documented in the EMEP/EEA emission inventory guidebook (EMEP/CORINAIR, 2013). As explained in the latter guidebook, due to tuneable emission control systems, which may alter their performance depending on operation conditions, Euro 5 diesel vehicles have been found to be very high emitters of NO_x under real-world driving. Further it is explained "that regulators are considering enhanced type-approval procedures at a Euro 6 level. However, such enhanced procedures are not going to be introduced before 2017 earliest. In any case, Euro 6 will appear in two major steps. One in the 2014/15 period and an additional step, today scheduled for the 2017/18 period. Different emission levels are to be expected for the two families of vehicles with the later implementation resulting to lower emissions."

Based on the above explanations COPERT IV propose updated emission reduction values relative to Euro 4 to be -23 % and 57 % for Euro 5 and 6 diesel passenger cars, in turn replacing the more environmentally optimistic values of 28 % and 68 % in the previous version of the COPERT IV model.

4.1.4 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 (Annex 4.1) and mileage road type shares. For additional description of the hot and cold start calculations and fuel balance approach, please refer to Winther (2012).

Fuel consumption and emission results per layer and vehicle type, respectively, are shown in Annex 4.2 from 2012-2035.

4.2 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.

4.2.1 Activity data

Air traffic

For historical years, the activity data for air traffic consists of air traffic statistics provided by the Danish Civil Aviation Agency (CAA-DK) and Copenhagen Airport. For 2001-2011, records are given per flight by CAA-DK as data for aircraft type and origin and destination airports. For inventory years prior to 2001 detailed LTO/aircraft type statistics are obtained from Copenhagen Airport (for this airport only) while information of total take-off numbers for other Danish airports is provided by CAA-DK. Fuel statistics for jet fuel consumption and aviation gasoline are obtained from the Danish energy projections (DEA, 2012).

Prior to emission calculations for historical years, the aircraft types are grouped into a smaller number of representative aircrafts for which fuel consumption and emission data exist in the EMEP/CORINAIR databank. In this procedure the actual aircraft types are classified according to their overall aircraft type (jets, turbo props, helicopters and piston engine). Secondly, information on the aircraft Maximum Take-Off Mass (MTOM) and number of engines are used to append a representative aircraft to the aircraft type in question. A more thorough explanation is given in Winther (2001a, b).

No forecast of air traffic movements is available as input to the emission projection calculations. Instead, the official Danish national fuel consumption projections from the DEA (2012) are used as activity data in the projection period.

Non road working machinery and recreational craft

Non road working machinery and equipment are used in agriculture, forestry and industry as well as for household/gardening purposes, and recreational craft belong to the inventory group inland waterways. The specific machinery types comprised in the Danish inventory are shown in Table 4.4.

Table 4.4 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	Silv. tractors, harvesters, forwarders, chippers	-
Industry	Construction machinery, forklifts, building and construction, airport GSE, other	Forklifts (LPG), building and construction, other
Household/ gardening	-	Lawn & garden tractors, lawn-mowers, chainsaws, cultivators, shrub clearers, hedge cutters, trimmers, other

Please refer to the reports by Winther et al. (2006) and Nielsen et al. (2013) for detailed information of the number of different types of machines, their load factors, engine sizes and annual working hours.

National sea transport

An internal model is used to estimate the fuel consumption figures for national sea transport based on fleet activity estimates for regional ferries, local ferries, sailing activities between Denmark and Greenland/Faroe Islands, and other national sea transport (Winther, 2008a; Nielsen et al., 2013).

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

Table 4.5 lists the most important domestic ferry routes in Denmark in the period 1990-2011. For these ferry routes and the years 1990-2005, the following detailed traffic and technical data have been gathered by Winther (2008a): Ferry name, year of service, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size and sailing time (single trip).

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

Table 4.5 Ferry routes comprised in the Danish inventory.

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

Other sectors

The activity data for military, railways, international sea transport and fishery consists of fuel consumption information from DEA (2012). For international sea transport, the basis is expected fuel sold in Danish ports for vessels with a foreign destination, as prescribed by the IPCC guidelines. For all other mobile sectors, fuel consumption figures are given in Annex 4.3 for the years 2012-2035 in both CollectER and NFR formats.

4.2.2 Emission legislation

For non-road working machinery and equipment, recreational craft, railway locomotives/motor cars and ship engines, 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 the date the engine is placed on the market).

For diesel, Directives 1997/68/EC and 2004/26/EC relate to non-road machinery other than agricultural and forestry tractors and the directives have different implementation dates for machinery operating under transient and under constant loads. The latter directive also comprises emission limits for railway machinery. For tractors, the relevant directives are 2000/25/EC and 2005/13/EC. For gasoline, Directive 2002/88/EC distinguishes between handheld (SH) and non-handheld (NS) 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 type of machinery in question, and the test cycles are described in more detail in the relevant directives.

Table 4.6 Overview of EU emission directives relevant for diesel fuelled non road machinery.

Stage/Engine size [kW]	CO	VOC	NO_X	$VOC+NO_X$	PM	Diesel machinery			Tractors	
							Implement. date			
	[g pr kWh]					EU directive	Transient	Constant	EU Directive	Implement. Date (dd/mm/yy)
Stage I										
37<=P<75	6.5	1.3	9.2	-	0.85	97/68	1/4 1999	-	2000/25	01.07.2001
Stage II										
130<=P<560	3.5	1	6	-	0.2	97/68	1/1 2002	1/1 2007	2000/25	01.07.2002
75<=P<130	5	1	6	-	0.3		1/1 2003	1/1 2007		01.07.2003
37<=P<75	5	1.3	7	-	0.4		1/1 2004	1/1 2007		01.01.2004
18<=P<37	5.5	1.5	8	-	0.8		1/1 2001	1/1 2007		01.01.2002
Stage IIIA										
130<=P<560	3.5	-	-	4	0.2	2004/26	1/1 2006	1/1 2011	2005/13	01.01.2006
75<=P<130	5	-	-	4	0.3		1/1 2007	1/1 2011		01.01.2007
37<=P<75	5	-	-	4.7	0.4		1/1 2008	1/1 2012		01.01.2008
19<=P<37	5.5	-	-	7.5	0.6		1/1 2007	1/1 2011		01.01.2007
Stage IIIB										
130<=P<560	3.5	0.19	2	-	0.025	2004/26	1/1 2011	-	2005/13	01.01.2011
75<=P<130	5	0.19	3.3	-	0.025		1/1 2012	-		01.01.2012
56<=P<75	5	0.19	3.3	-	0.025		1/1 2012	-		01.01.2012
37<=P<56	5	-	-	4.7	0.025		1/1 2013	-		01.01.2013
Stage IV										
130<=P<560	3.5	0.19	0.4	-	0.025	2004/26	1/1 2014		2005/13	01.01.2014
56<=P<130	5	0.19	0.4	-	0.025		1/10 2014			01.10.2014

Table 4.7 Overview of the EU emission directive 2002/88 for gasoline fuelled non road machinery.

	Category	Engine size [ccm]	CO [g pr kWh]	HC [g pr kWh]	NO_X [g pr kWh]	HC+NO_X [g pr kWh]	Implement. date
	Stage I						
Hand held	SH1	S<20	805	295	5.36	-	01.02.2005
	SH2	20=<S<50	805	241	5.36	-	01.02.2005
	SH3	50=<S	603	161	5.36	-	01.02.2005
Not hand held	SN3	100=<S<225	519	-	-	16.1	01.02.2005
	SN4	225=<S	519	-	-	13.4	01.02.2005
	Stage II						
Hand held	SH1	S<20	805	-	-	50	01.02.2008
	SH2	20=<S<50	805	-	-	50	01.02.2008
	SH3	50=<S	603	-	-	72	01.02.2009
Not hand held	SN1	S<66	610	-	-	50	01.02.2005
	SN2	66=<S<100	610	-	-	40	01.02.2005
	SN3	100=<S<225	610	-	-	16.1	01.02.2008
	SN4	225=<S	610	-	-	12.1	01.02.2007

For recreational craft, Directive 2003/44 comprises the emission legislation limits for diesel 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 given in the calculation formulas in Table 4.6. 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.

Table 4.8 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 4.9 Overview of the EU emission directive 2004/26 for railway locomotives and motor cars.

	Engine size [kW]		CO [g pr kWh]	HC [g pr kWh]	NO_X [g pr kWh]	HC+NO_X [g pr kWh]	PM [g pr kWh]	Impl. date
Locomotives	Stage IIIA							
	130<=P<560	RL A	3.5	-	-	4	0.2	01.01.2007
	560<P	RH A	3.5	0.5	6	-	0.2	01.01.2009
	2000<=P and piston displacement >= 5 l/cyl.	RH A	3.5	0.4	7.4	-	0.2	01.01.2009
	Stage IIIB	RB	3.5	-	-	4	0.025	01.01.2012
Motor cars	Stage IIIA							
	130<P	RC A	3.5	-	-	4	0.2	01.01.2006
	Stage IIIB							
	130<P	RC B	3.5	0.19	2	-	0.025	01.01.2012

For non-road machinery, the limit value of 50 ppm sulphur in diesel from 2005, given by EU directive 2003/17/EC, is lowered to 10 ppm from 2011.

For NO_X, the emission legislation is relevant for diesel engines with a power output greater than 130 kW installed on a ship constructed on or after 1 January 2000, and diesel engines with a power output greater than 130 kW, which underwent major conversion on or after 1 January 2000. For engine type approval, the NO_X emissions are measured using a test cycle (ISO 8178) which consists of several steady-state modes with different weighting factors.

The NO_x emission limits for ship engines in relation to their rated engine speed (n) given in RPM (Revolutions Pr Minute) are the following:

- 17 g pr kWh, n < 130 RPM
- 45 x n-0.2 g pr kWh, 130 ≤ n < 2000 RPM
- 9.8 g pr kWh, n ≥ 2000 RPM

Further, the Marine Environment Protection Committee (MEPC) of IMO has agreed amendments to MARPOL Annex VI in October 2008 in order to strengthen the emission standards for NO_x and the sulphur contents of heavy fuel oil used by ship engines.

For NO_x emission regulations, a three tiered approach is considered, which comprises the following:

- Tier I: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2000 and prior to 1 January 2011
- Tier II: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2011
- Tier III[7]: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2016

As for the existing NO_x emission limits, the new Tier I-III NO_x legislation values rely on the rated engine speeds. The emission limit equations are shown in Table 4.10.

Table 4.10 Tier I-III NOx emission limits for ship engines (amendments to MARPOL Annex VI).

	NO_x limit	RPM (n)
Tier I	17 g pr kWh	n < 130
	45 · n-0.2 g pr kWh	130 ≤ n < 2000
	9,8 g pr kWh	n ≥ 2000
Tier II	14.4 g pr kWh	n < 130
	44 · n-0.23 g pr kWh	130 ≤ n < 2000
	7.7 g pr kWh	n ≥ 2000
Tier III	3.4 g pr kWh	n < 130
	9 · n-0.2 g pr kWh	130 ≤ n < 2000
	2 g pr kWh	n ≥ 2000

The Tier I emission limits are identical with the existing emission limits from MARPOL Annex VI.

Also agreed by IMO in October 2008, the NO_x Tier I limits are to be applied for existing engines with a power output higher than 5000 kW and a displacement pr cylinder at or above 90 litres, installed on a ship constructed on or after 1 January 1990 but prior to 1 January 2000.

[7] For ships operating in a designated Emission Control Area. Outside a designated Emission Control Area, Tier II limits apply.

In relation to the sulphur content in heavy fuel and marine gas oil used by ship engines, Table 4.11 shows the current legislation in force, and the amendment of MARPOL Annex VI agreed by IMO in October 2008.

Table 4.11 Current legislation in relation to marine fuel quality.

Legislation		Heavy fuel oil		Gas oil	
		S- %	Impl. date (dd/mm/yy)	S- %	Impl. date (dd/mm/yy)
EU-directive 93/12		None		0.2[1]	01.10.1994
EU-directive 1999/32		None		0.2	01.01.2000
EU-directive 2005/33[2]	SECA - Baltic sea	1.5	11.08.2006	0.1	01.01.2008
	SECA - North sea	1.5	11.08.2007	0.1	01.01.2008
	Outside SECA's	None		0.1	01.01.2008
MARPOL Annex VI	SECA – Baltic sea	1.5	19.05.2006		
	SECA – North sea	1.5	21.11.2007		
	Outside SECA	4.5	19.05.2006		
MARPOL Annex VI amendments	SECA's	1	01.03.2010		
	SECA's	0.1	01.01.2015		
	Outside SECA's	3.5	01.01.2012		
	Outside SECA's	0.5	01.01.2020[3]		

[1] Sulphur content limit for fuel sold inside EU.

[2] From 1.1.2010 fuel with a sulphur content higher than 0.1 % must not be used in EU ports for ships at berth exceeding two hours.

[3] Subject to a feasibility review to be completed no later than 2018. If the conclusion of such a review becomes negative the effective date would default 1 January 2025.

Aircraft engine emissions of NO_X, CO, VOC and smoke are regulated by the ICAO (International Civil Aviation Organization). The legislation is relevant for aircraft engines with rated engine thrust larger than 26.7 kN. A further description of the emission legislation and emission limits is given in ICAO Annex 16 (1993).

4.2.3 Emission factors

The SO_2 emission factors are fuel related, and rely on the sulphur contents given in the relevant EU fuel directives or in the relevant Danish legislation. However, for jet fuel the default factor from the IPCC (1996) is used. Road transport diesel is assumed to be used by engines in military and railways, and road transport gasoline is assumed to be used by non-road working machinery and recreational craft. Hence, these types of machinery have the same SO_2 emission factors as for road transport.

The NH_3 emission factors are taken from the EMEP/CORINAIR guidebook (EMEP/EEA, 2013).

For military ground machinery, aggregated emission factors (gasoline and diesel) are derived from the road traffic emission simulations (all emission components). For aviation gasoline (civil aviation and military), aggregated emission factors (fuel based) for conventional cars are used (all emission components).

For railways, specific Danish measurements from the Danish State Railways (DSB), see Delvig (2012), are used to calculate the emission factors for NO_X, VOC and PM in today's conditions, and a $NMVOC/CH_4$ split is made in the present analysis based on own judgment. For 2020 DSB provides average emission factors, based on expectations relating to the machinery stock and the engine emission levels in these two years. Emission factor interpolations are made for the years in between, and for the years after 2020 the emission factors for 2020 are used.

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

The source for civil and military aviation (jet fuel) and navigation emission factors is the EMEP/CORINAIR guidebook (EMEP/EEA, 2009).

For national sea transport and fisheries, the NO_x emission factors predominantly come from the engine manufacturer MAN Diesel, as a function of engine production year. The CO, VOC and TSP emission factors come from the Danish TEMA2000 emission model (Ministry of Transport, 2000), whereas the PM_{10} and $PM_{2.5}$ size fractions are obtained from MAN Diesel.

Specifically for the ferries used by Mols Linjen new NO_x, VO and CO emission factors are provided by Kristensen (2008), originating from measurement results by Hansen & Jensen (2004), Wismann (1999) and PHP (1996).

For ship engines VOC/CH_4 splits are taken from EMEP/EEA (2013).

4.2.4 Calculation method

Air traffic

For aviation the estimates are made separately for landing and take-off (LTOs < 3000 ft) and cruise (> 3000 ft). The calculations furthermore distinguish between national and international flights. As prescribed by the UNECE inventory reporting rules the national total for civil aviation consist of the emissions from LTO irrespective of destination. For more details regarding the calculation procedure please refer to Winther (2001a, 2001b and 2008).

Non-road working machinery and recreational craft

Fuel consumption and emissions are calculated as the product of the number of engines, annual working hours, average rated engine size, load factors, 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 taken into consideration by using average transient factors. For more details regarding the calculation procedure please refer to Winther (2006).

National sea transport

For Danish regional ferries fuel consumption and emissions 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. The fuel consumption from local ferries is estimated using a baseline 1996 figure and the relative difference in annual round trips as given in the activity data. The fuel consumption for the remaining national sea transport comes from a Danish survey.

The difference between the DEA statistical fuel sales and the sum of estimated fuel consumption in local and regional ferries and remaining national sea transport, gives the amount of fuel allocated to the sub-sector other national sea. For years when this fuel amount becomes smaller than zero, no fuel is allocated to other national sea, and the ferry results are adjusted in order to obtain a fuel balance, as prescribed by convention rules.

Please refer to Nielsen et al. (2013) for more details regarding the calculations for national sea transport.

Other sectors

For fishing vessels, military and railways, the emissions are estimated with the simple method using fuel-related emission factors and fuel consumption from the DEA.

For all other mobile sectors, emission results are given in Annex 4.3 for the years 2012-2035 in both CollectER and NFR formats.

Energy balance between DEA statistics and inventory estimates

Following convention rules, the DEA statistical fuel sales figures are the basis for the full Danish inventory. However, in some cases for mobile sources the DEA statistical sectors do not fully match the inventory sectors. This is the case for non-road machinery, where relevant DEA statistical sectors also include fuel consumed by stationary sources.

In other situations, fuel consumption figures estimated by DCE from specific bottom-up calculations are regarded as more reliable than DEA reported sales. This is the case for national sea transport.

In the following the transferral of fuel consumption data from DEA statistics into inventory relevant categories is explained for national sea transport and fisheries, non-road machinery and recreational craft, and road transport. A full list of all fuel consumption data, DEA figures as well as intermediate fuel consumption data, and final inventory input figures is shown in Annex 2.B.14.

National sea transport and fisheries

For national sea transport in Denmark, the bottom up fuel consumption estimates obtained by DCE are regarded as more accurate than the DEA fuel sales data, since the large fluctuations in reported fuel sales cannot be explained by the actual development in the traffic between different national ports. The latter fuel sales fluctuations are most likely explained by inaccurate costumer specifications (national sea transport/fisheries for gas oil and national sea transport/industry for heavy fuel oil) made by the oil suppliers. As a consequence, the DCE bottom-up estimates are used in the Danish inventory for national sea transport.

The bottom up estimate for national sea transport consists of fuel consumption by regional ferries, local ferries and other national sea transport between Danish ports. Also included in the national sea transport total is the fuel sold for vessels sailing between Denmark and Greenland/Faroe Islands, based on fuel sales investigations made by DCE (Nielsen et al., 2013).

On the same time it must be noted that the fuel sold for vessels sailing between Denmark and Greenland/Faroe Islands are reported as international in the DEA statistics.

Following this, for fisheries and industry the bottom up estimated fuel consumption time series for national sea transport lead, in turn, to changes in the fuel activity data for fisheries (gas oil), industry (heavy fuel oil) and international sea transport, so the national energy balance can remain unchanged.

Further, for fisheries small amounts of small amounts of gasoline and diesel are transferred to recreational craft.

Non-road machinery and recreational craft

For diesel and LPG, the non-road fuel consumption estimated by DCE is partly covered by the statistical fuel sales amounts in the following DEA sectors: agriculture and forestry, market gardening, and building and construction. The remaining quantity of non-road diesel and LPG is taken from other "gap filling" DEA sectors. From 2020 onwards, however, the DCE bottom up diesel fuel consumption estimates exceeds the amount of fuel sales from the DEA statistics in these "gap filling" statistical sectors.

The amounts of diesel and LPG in gap filling statistical sectors not being used by non-road machinery is included in the sectors, "Combustion in manufacturing industry" (0301) and "Non-industrial combustion plants" (0203) in the Danish emission inventory. From 2020 onwards, the DCE bottom up estimates of fuel consumption and emissions related to diesel machinery are scaled downwards in order to achieve a fuel balance between bottom up fuel consumption and statistical sales.

For gasoline, the DEA residential sector, together with the DEA sectors mentioned for diesel and LPG, contribute to the non-road fuel consumption total. In addition, a certain amount of gasoline from road transport is needed to fill the gasoline fuel gap.

For recreational craft, the bottom up calculated fuel consumption for diesel and gasoline are subsequently subtracted from the DEA fishery sector. For gasoline, the DEA reported fuel consumption for fisheries is far too small to fill the fuel gap, and hence the missing fuel amount is taken from the DEA road transport sector.

4.3 Fuel consumption and emission results

An overview of the fuel consumption and emission results for all mobile sources in Denmark is given in Table 4.12.

Table 4.12 Summary table of fuel consumption (PJ) and emissions (tonnes) for mobile sources in Denmark.

	Category	1990	2005	2010	2011	2012	2015	2020	2025	2030	2035
Energy	Industry - Other (1A2f)	11.5	13.0	14.2	13.8	13.8	13.8	13.3	12.1	11.2	10.3
	Civil Aviation nat. (1A3a)	3.2	3.5	3.5	3.6	3.8	3.9	4.4	4.6	4.3	4.3
	Road (1A3b) - exhaust	126.4	166.1	165.2	165.2	166.3	170.1	174.6	180.4	191.8	205.8
	Railways (1A3c)	4.0	3.1	3.3	3.4	3.3	3.3	3.3	3.3	3.3	3.3
	Navigation (1A3d)	10.5	7.8	7.9	7.5	7.5	7.5	7.5	7.5	7.3	7.3
	Comm./Inst. (1A4a)	1.0	2.2	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.3
	Residential (1A4b)	0.5	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8
	Agriculture/forestry (1A4c)	17.7	15.0	17.6	18.0	18.0	17.9	17.3	16.0	14.9	13.7
	Fisheries (1A4c)	8.0	8.7	7.8	7.8	7.3	8.3	9.5	10.8	12.4	14.2
	Military (1A5)	1.6	3.7	1.5	2.7	2.1	2.1	2.1	2.1	2.1	2.1
	Navigation int. (1A3d)	39.1	30.7	27.0	27.4	27.5	27.5	27.5	27.5	27.5	27.5
	Civil Aviation int. (1A3a)	24.3	34.1	32.3	33.0	34.5	36.3	41.3	42.7	40.1	40.1
SO_2	Industry - Other (1A2f)	952	28	31	6	6	6	6	5	5	4
	Civil Aviation nat. (1A3a)	74	81	80	83	86.3	90.3	101.6	104.9	98.9	98.9
	Road (1A3b) - exhaust	5767	77	76	74	73	74	73	75	80	86
	Railways (1A3c)	376	1	2	2	2	2	2	2	2	2
	Navigation (1A3d)	6429	2339	1439	1385	1395	339	339	339	332	332
	Comm./Inst. (1A4a)	2	1	1	1	1	1	1	1	1	1
	Residential (1A4b)	1	0	0	0	0	0	0	0	0	0
	Agriculture/forestry (1A4c)	1561	34	40	8	8	8	8	8	7	6
	Fisheries (1A4c)	742	817	364	365	343	387	446	504	580	663
	Military (1A5)	48	57	20	37	28	28	28	28	28	28
	Navigation int. (1A3d)	41317	34283	8200	8853	8892	1323	1323	1323	1323	1323
	Civil Aviation int. (1A3a)	558	784	743	759	793	834	949	982	921	921
NO_x	Industry - Other (1A2f)	11081	10664	8540	7947	7547	6646	4942	3843	3549	3312
	Civil Aviation nat. (1A3a)	1095	1205	1166	1212	1265.7	1323.2	1488.1	1535.2	1448.0	1448.0
	Road (1A3b) - exhaust	109036	69430	48538	46175	45380	36636	23803	18121	15667	15397
	Railways (1A3c)	4913	3724	2818	2501	2293	1935	1338	1338	1338	1338
	Navigation (1A3d)	13649	8634	9581	9086	9106	9053	8311	7535	5871	4412
	Comm./Inst. (1A4a)	70	177	217	215	219	219	219	219	219	219
	Residential (1A4b)	34	72	87	89	92	92	93	93	93	93
	Agriculture/forestry (1A4c)	12679	12233	10145	9833	9168	7114	4263	2457	1335	860
	Fisheries (1A4c)	8387	11776	10670	10586	9838	10646	8333	5745	4741	3775
	Military (1A5)	485	1292	448	778	625	552	450	411	389	382
	Navigation int. (1A3d)	60639	56540	51065	52516	52782	52746	46112	38406	30459	23283
	Civil Aviation int. (1A3a)	7043	10404	9567	9832	10276	10799	12296	12723	11932	11932
NH_3	Industry - Other (1A2f)	2	2	3	2	2	2	2	2	2	2
	Civil Aviation nat. (1A3a)	0	0	0	0	0.1	0.1	0.1	0.1	0.1	0.1
	Road (1A3b) - exhaust	72	2404	1731	1601	1549	1322	1150	1265	1461	1640
	Railways (1A3c)	1	1	1	1	1	1	1	1	1	1
	Navigation (1A3d)	0	0	0	0	0	0	0	0	0	0
	Comm./Inst. (1A4a)	0	0	0	0	0	0	0	0	0	0
	Residential (1A4b)	0	0	0	0	0	0	0	0	0	0
	Agriculture/forestry (1A4c)	3	3	4	4	4	4	4	4	3	3
	Fisheries (1A4c)	0	0	0	0	0	0	0	0	0	0
	Military (1A5)	0	1	0	0	0	0	0	1	1	1
	Navigation int. (1A3d)	0	0	0	0	0	0	0	0	0	0
	Civil Aviation int. (1A3a)	0	0	0	0	0	0	0	0	0	0
NMVOC	Industry - Other (1A2f)	2266	1620	1173	1115	1071	955	790	714	672	641
	Civil Aviation nat. (1A3a)	274	252	183	179	193.8	199.4	215.6	220.2	211.6	211.6
	Road (1A3b) - exhaust	78131	26780	14456	12201	10973	8903	7002	6734	6923	7233
	Railways (1A3c)	321	235	189	175	151	98	10	10	10	10
	Navigation (1A3d)	1686	1423	937	842	791	713	707	709	704	704
	Comm./Inst. (1A4a)	2303	5775	4423	3636	3636	3598	3598	3598	3598	3598

Continued											
	Residential (1A4b)	1801	2084	2032	1993	1953	1801	1716	1716	1716	1716
	Agriculture/forestry (1A4c)	5744	2216	1931	1797	1718	1507	1317	1216	1126	1091
	Fisheries (1A4c)	405	496	446	453	427	485	562	635	731	835
	Military (1A5)	53	106	40	59	48	45	42	42	42	42
	Navigation int. (1A3d)	2060	1792	1628	1668	1685	1718	1763	1793	1803	1803
	Civil Aviation int. (1A3a)	243	373	294	303	316	332	378	391	367	367
TSP	Industry - Other (1A2f)	1577	1002	686	646	611	501	320	252	217	195
	Civil Aviation nat. (1A3a)	5	5	5	5	5.0	5.2	5.7	5.9	5.6	5.6
	Road (1A3b) - exhaust	4938	2499	1662	1495	1341	973	582	400	355	362
	Road (1A3b) - non exhaust	1794	2458	2477	2524	2558	2687	2963	3308	3673	4012
	Railways (1A3c)	202	124	95	78	67	42	1	1	1	1
	Navigation (1A3d)	898	425	307	291	288	227	221	221	217	217
	Comm./Inst. (1A4a)	24	65	67	67	67	67	67	67	67	67
	Residential (1A4b)	11	13	14	15	15	15	15	15	15	15
	Agriculture/forestry (1A4c)	2444	1011	793	762	693	477	240	150	93	69
	Fisheries (1A4c)	184	203	167	168	158	178	205	232	267	305
	Military (1A5)	12	36	10	16	12	9	5	4	3	3
	Navigation int. (1A3d)	5531	5761	934	975	978	609	609	609	609	609
	Civil Aviation int. (1A3a)	28	40	37	38	40.0	42.1	47.9	49.5	46.5	46.5
PM_{10}	Industry - Other (1A2f)	1577	1002	686	646	611	501	320	252	217	195
	Civil Aviation nat. (1A3a)	5	5	5	5	5.0	5.2	5.7	5.9	5.6	5.6
	Road (1A3b) - exhaust	4938	2499	1662	1495	1341	973	582	400	355	362
	Road (1A3b) - non exhaust	1144	1566	1572	1601	1620	1701	1874	2089	2318	2530
	Railways (1A3c)	202	124	95	78	67	42	1	1	1	1
	Navigation (1A3d)	890	422	305	289	286	226	219	219	216	216
	Comm./Inst. (1A4a)	24	65	67	67	67	67	67	67	67	67
	Residential (1A4b)	11	13	14	15	15	15	15	15	15	15
	Agriculture/forestry (1A4c)	2444	1011	793	762	693	477	240	150	93	69
	Fisheries (1A4c)	182	201	166	166	156	176	203	230	264	302
	Military (1A5)	12	36	10	16	12	9	5	4	3	3
	Navigation int. (1A3d)	5476	5703	925	965	968	603	603	603	603	603
	Civil Aviation int. (1A3a)	28	40	37	38	40	42	48	50	46	46
$PM_{2.5}$	Industry - Other (1A2f)	1577	1002	686	646	611	501	320	252	217	195
	Civil Aviation nat. (1A3a)	5	5	5	5	5.0	5.2	5.7	5.9	5.6	5.6
	Road (1A3b) - exhaust	4938	2499	1662	1495	1341	973	582	400	355	362
	Road (1A3b) - non exhaust	624	857	863	879	890	936	1031	1150	1277	1394
	Railways (1A3c)	202	124	95	78	67	42	1	1	1	1
	Navigation (1A3d)	886	421	304	288	285	225	219	219	215	215
	Comm./Inst. (1A4a)	24	65	67	67	67	67	67	67	67	67
	Residential (1A4b)	11	13	14	15	15	15	15	15	15	15
	Agriculture/forestry (1A4c)	2444	1011	793	762	693	477	240	150	93	69
	Fisheries (1A4c)	181	199	165	165	155	175	202	228	263	300
	Military (1A5)	12	36	10	16	12	9	5	4	3	3
	Navigation int. (1A3d)	5448	5675	920	960	964	600	600	600	600	600
	Civil Aviation int. (1A3a)	28	40	37	38	40	42	48	50	46	46

4.3.1 Road transport

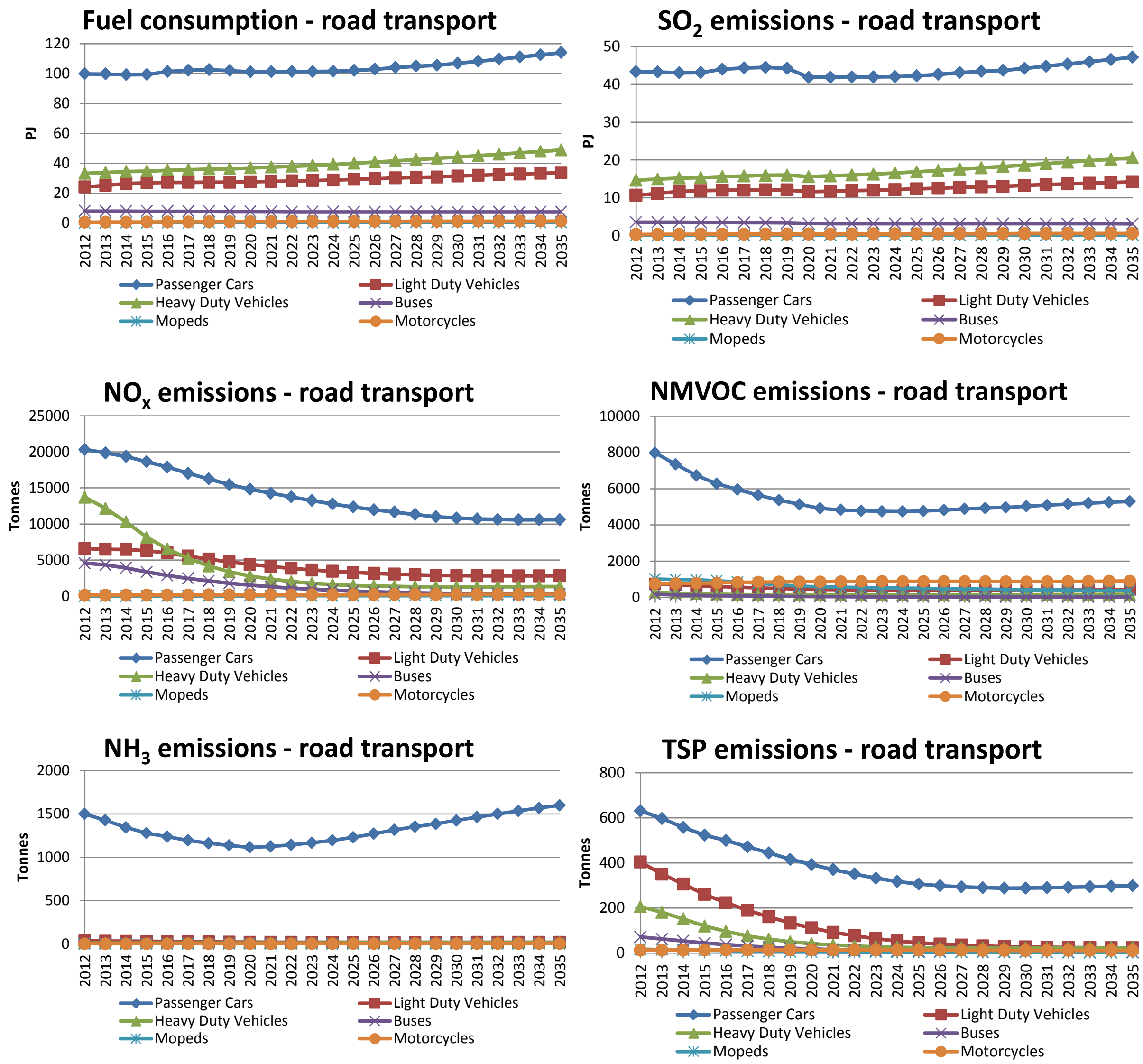

Figure 4.3 Fuel consumption, NO_X, SO_2, NMVOC, NH_3 and TSP ($PM_{2.5}$) emissions from 2012-2035 for road traffic.

Total fuel consumption for road traffic is projected to increase by 24 % from 2012 to 2035. Passenger cars will have the largest fuel consumption share, followed by heavy duty vehicles, light duty vehicles, buses and two-wheelers in decreasing order. The SO_2 emission is dependent on the fuel consumption and the content of sulphur in the fuel. The content of sulphur in neat diesel and gasoline is 10 ppm, however, the average sulphur content of diesel and gasoline slightly decreases due to the increasing share of zero sulphur biofuel (10 % in 2020) for the fuel sold at gas filling stations.

The majority of the NMVOC and NH_3 emission from road transport comes from gasoline passenger cars (Figure 4.3). The NMVOC emission is projected to decrease around 40 % from 2012 to 2024 for passenger cars is explained by the introduction of gradually more efficient catalytic converters for gasoline cars. From 2024 onwards the emissions increase proportionally with the total mileage for these vehicles. The same explanation goes for the 41 % reduction of NH_3 emissions for passenger cars calculated from 2010 to 2020, and the emission increase from 2020 onwards.

The NO_X emission for road transport declines by 66 % from 2012 to 2035, and for the most NOx emission important vehicle categories passenger cars, light duty vehicles and heavy duty vehicles significant emission reductions are expected at least until the beginning of the 2030's due to the automatic fleet turnover towards newer EU emission standards which in most cases reduce the emission factors. Most significantly is the emission decline for heavy duty trucks due to the introduction of the Euro VI emission standard in 2015.

In terms of TSP, the total emission is expected to decline by 73 % from 2012 to 2035, and emission reductions are calculated for all vehicle types. From 2022 the emission share for motorcycles becomes larger than the emission share for buses, mostly due to a large increase in total mileage for motorcycles during the forecast period.

4.3.2 Other mobile sources

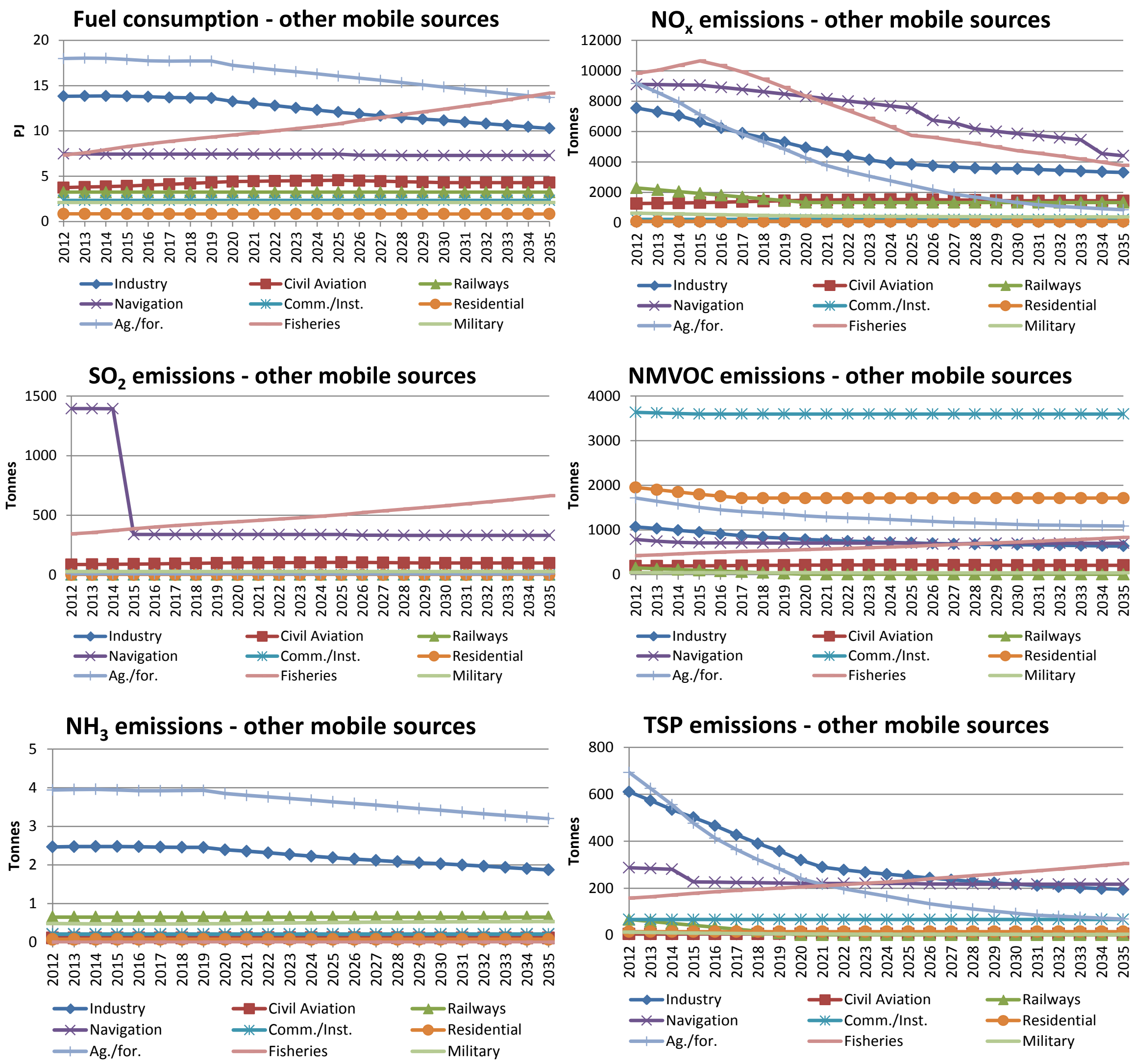

Figure 4.4 Fuel consumption, NO_X, SO_2, NMVOC, NH_3 and TSP emissions from 2012-2035 for other mobile sources.

From 2012-2035 the total fuel consumption decreased by 1 %. The emissions of SO_2, NO_x, NMVOC, NH_3, TSP decreased by 39 %, 61 %, 11 %, 16 % and 60 %, respectively, for other mobile sources.

The development in fuel consumption is forecasted by the DEA (2012). Agriculture/forestry/fisheries is by far the largest fuel consumption source followed by Industry and Navigation. Rather small fuel consumption totals are noted for Railways, Domestic aviation, Military, Residential and Commercial/Institutional.

The fuel consumption decreases for industry and agriculture/forestry from 2020 onwards are predominantly due to the scaling of results in order to achieve the previously described (Section 4.2.4) fuel balance between bottom up fuel consumption and statistical sales. Small fuel gains for the two inventory categories are also achieved due to a gradual phase-out of old and less fuel efficient technologies. For fishing activities DEA (2012) expect a significant increase in fuel consumption throughout the forecast period and generally this trend is not affected by the fuel transferal between fisheries and national sea transport also described in Section 4.2.4.

The SO_2 emissions for other mobile sources are insignificant except for seagoing vessels. For navigation and fisheries, the reduction of the sulphur content in heavy fuel oil used in the Baltic and North Sea SOx emission control areas (SECAs) will have a visible emission impact from 2015. For other mobile sources the NH_3 emissions are very small. The most important emission source is Agriculture/forestry, followed by Industry.

By far the most of the NMVOC emission comes from gasoline gardening machinery (Commercial/institutional). The same gasoline equipment types give considerable contributions for Residential. For Railways, Civil aviation and military only small emission contributions are noted. The projected NMVOC emission reductions for Commercial/institutional, Residential and Navigation are due to the introduction of the cleaner gasoline stage II emission technology (Commercial/-institutional; Residential), and the gradual shift from 2-stroke to 4-stroke engines for recreational craft (Navigation). For Agriculture/forestry and Industry, the gradually stricter emission standards for diesel engines and the decrease in fuel consumption will cause the NMVOC emission to decrease during the forecast period.

For TSP, Agriculture/forestry is the largest emission source in the beginning of the forecast period followed by Industry, Navigation and Fisheries. By the end of the forecast period the order of significance for these sources becomes reverse. Due to the penetration of cleaner engine technologies, in compliance with future emission standards, the emissions from Agriculture/forestry and industry decrease substantially throughout the forecast period. The emissions from Agriculture/forestry, however, are projected to decrease more rapidly than the emissions from industry, mainly due to the decline in the number of agricultural tractors and harvesters.

The TSP emissions from fishing vessels rely on the fuel consumption development, and show a stable increase throughout the forecast period. The reductions in sulphur content for heavy fuel oil in 2015 bring visible TSP emission reductions for Navigation in this year.

For Agriculture/forestry, Industry, Navigation, Fisheries and Railways, substantial NO_x emission improvements are expected during the course of the forecast period due to the penetration of cleaner engine technologies, in compliance with future emission standards. Rather small NO_x emissions are calculated for Railways (1A3c), Domestic aviation, Military, Residential and Commercial/Institutional.

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5 Fugitive emissions from fuels

The projection of fugitive emissions from fuels includes sources related to extraction, refining, storage, handling, and transport of fuels. The projection include emissions of SO_2 from sulphur recovery in oil refineries and flaring of oil and gas, NO_X from flaring of oil and gas, particulate matter (PM) from storage of coal and flaring of oil and gas, and NMVOC from refining of oil, extraction, storage and transport of oil and gas, venting of gas, and flaring of oil and gas. All fugitive sources are listed in Table 5.1 with the relevant fuel and pollutants.

The following chapters describe the methodology, activity data, emission factors and emissions in the projection. Further, descriptions of changes from the previous projection are included. For a detailed description of the emission inventory for the historical years, please refer to Plejdrup et al. (2009) and Nielsen et al. (2013).

Table 5.1 List of the SNAP codes and corresponding NFR sectors for the categories included in the Danish emission inventory model for greenhouse gases.

SNAP code	NFR sectors	SNAP name	Activity	Pollutants
04		Production processes		
040101	1B2a iv	Petroleum products processing	Oil	NMVOC
040103	1B2a iv	Sulphur recovery plants	Oil	SO_2
05		Extraction and distribution of fossil fuels and geothermal energy		
050103	1B1a	Storage of solid fuels	Coal	PM
050201	1B2a i	Land-based activities	Oil	NMVOC
050202 *	1B2a i	Off-shore activities	Oil	NMVOC
050503	1B2a v	Service stations	Oil**	NMVOC
050601	1B2b	Pipelines	Natural gas / Transmission	NMVOC
050603	1B2b	Distribution networks	Natural gas / Distribution	NMVOC
050699	1B2c	Venting in gas storage	Venting and flaring	NMVOC
09		Waste treatment and disposal		
090203	1B2c	Flaring in oil refinery	Venting and flaring	SO_2, NO_x, NMVOC, PM
090206	1B2c	Flaring in oil and gas extraction	Venting and flaring	SO_2, NO_x, NMVOC, PM

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

** Gasoline refuelling.

5.1 Methodology

The methodology for the emission projection correspond the methodology in the annual emission inventory, based on the EMEP/EEA Guidebook (EMEP/EEA, 2009).

Activity data are based on official forecasts by the Danish Energy Agency on fuel consumption (the energy consumption prognosis; DEA, 2012a) and on offshore production and flaring of oil and natural gas (the oil and gas prognosis; DEA, 2012b)).

Emission factors are either based on the EMEP/EEA guidelines (EMEP/EEA, 2009) or are country-specific based on data for one or more of the historical years.

The majority of the emissions are calculated due to the standard formula (Equation 5.1).

Equation 5.1: standard formula for calculating emissions.

$$E_{s,t} = AD_{s,t} * EF_{s,t}$$

where E is the emission, AD is the activity data and EF is the emission factor for the source ‘s’ in the year ‘t’.

An exception is emissions from extraction of oil and gas. According to the EMEP/EEA Guidebook (EMEP/EEA, 2009) the total fugitive emissions of volatile organic compounds (VOC) from extraction of oil and gas can be estimated by means of equation 5.2.

Equation 5.2: standard formula for calculating emissions from oil and gas extraction.

$$E_{extraction,VOC} = 40.2 \times N_p + 1.1 \times 10^{-2} \times P_{gas} + 8.5 \times 10^{-6} \times P_{oil}$$

where $E_{extraction,VOC}$ is the emission of VOC in Mg pr year, N_p is the number of platforms, P_{gas} is the production of gas, 10^6 Nm^3 and P_{oil} is the production of oil, 10^6 tonnes.

where $E_{extraction,VOC}$ is the emission of VOC in Mg pr year, N_p is the number of platforms, P_{gas} is the production of gas, 10^6 Nm^3 and P_{oil} is the production of oil, 10^6 tonnes.

For a number of sources the emissions are given in annual reports, e.g. environmental reports, self-regulation reports and green accounts, and these are adopted in the Danish emission inventory and used as basis for the projection.

5.2 Activity data

5.2.1 The oil and gas production prognosis

Activity data from the prognosis for the production of oil and gas (DEA, 2012b) is shown in Figure 5.1. The prognosis includes reserves (production at existing facilities and including justified projects for development), technological resources (estimated additional production due to new technological initiatives, e.g. CO_2 injection) and prospective resources (estimated production from new discoveries). The oil and gas production prognosis shows fluctuating production rates over the projection period, but the overall trend is decreasing for both oil and gas production for the years 2012-2035. The oil production is expected to increase from 2016 to 2031, followed by a decreasing trend. The gas projection decreases in the first years (2012-2015) and then peaks in the years 2016-2019. The remaining part of the projection period shows a more steady decrease of the gas production. Increases in the production amounts are due to development of new fields and further development of a number of existing fields.

The oil and gas prognosis also includes offshore flaring. It is expected that the flaring amounts is going to decrease over the projection period and only small fluctuations are included in the projection.

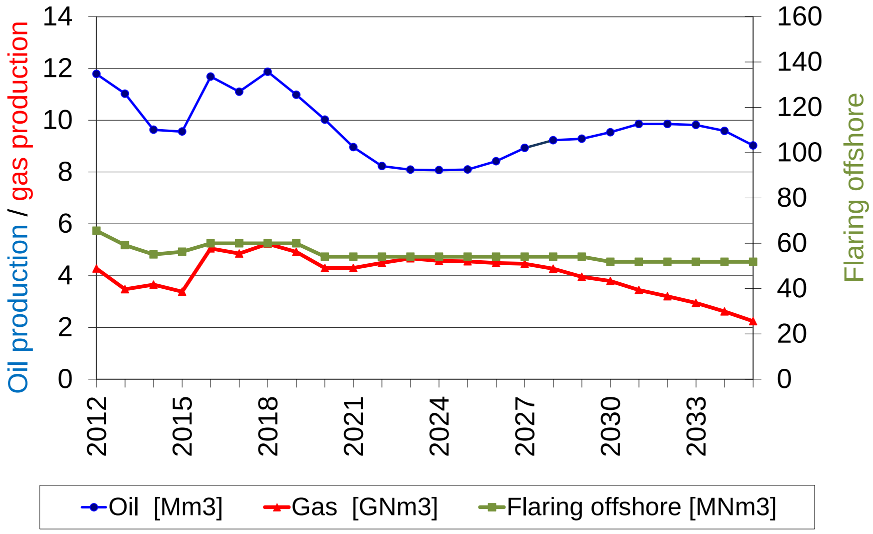

Figure 5.1 Prognosis for the production of oil and gas (DEA, 2012b).

The DEA prognosis of the production of oil and gas are used in projection of a number of sources: extraction of oil and natural gas, the raw oil terminal, onshore and offshore loading of ships and offshore flaring. The same methodology is applied to estimating activity data for these sources. The methodology applied is to estimate the amount in the projection year as the amount in the latest historical year multiplied by the share of the oil production in the projection year and the latest historical year. Equation 5.3 shows the estimation methodology for onshore loading.

Eq. 5.3 Formula for estimating onshore loading amount in projection year p

$$\mathrm{OL}_p = \mathrm{OL}_h \times \frac{\mathrm{OP}_p}{\mathrm{OP}_h}$$

where OL = onshore loading, OP = oil production, p = projection year and h = latest historical year

5.2.2 The energy consumption prognosis

Data from the energy consumption prognosis by the DEA (2012a) are applied in the projection of fugitive emissions from fuels. The annual prognosis of consumption of natural gas as a total for all sectors is used as proxy to project transmission of natural gas. Emissions from transmission and distribution of natural gas and town gas show variations from year to year, because of varying extent of leakages due to maintenance and accidental excavations. In order to include these unpredictable events, the emissions from transmission and distribution of natural gas and town gas is estimated as the average emissions in the last five historical years scale to the annual total natural gas consumption from the energy consumption prognosis by the DEA (2012a).

Summarised gasoline and coal consumptions for all sectors are used as proxy activity data to project emissions from service stations and storage of solid fuels, respectively.

5.2.3 Large point sources

The sector fugitive emissions from fuels cover only few large point sources (LPS). These are the two Danish refineries and the natural gas storage and treatment plants. Fugitive emissions from refineries are related to three sources; fugitive losses from tanks, pipes, valves etc., sulphur recovery, and flaring. Projection of emissions from these two sources is associated with large uncertain, as the emissions are not related to the production amounts or other well-known parameters. Fugitive losses are dependent of the number and character of leakages and the maintenance conditions. SO_2 emissions form sulphur recovery show large annual variations due to interruptions of the recovery system. When the sulphur recovery plant does not work optimally, the gas is lead to the flare, which results in larger SO_2 emissions from the flare. Due to these unpredictable variations, fugitive emissions from refineries are estimated as the average of the annual emissions for the last five historical years, which is applied for all projection years. Fugitive emissions from the natural gas storage and treatment plants are very limited and owe to flaring and venting. The amounts of natural gas that is vented and flared vary from year to year. The emission from flaring and venting in gas storage and treatment plants are estimated as the average emission in the last five historical years and the same emission is applied for all projection years.

5.3 Emission factors

Emission factors from the EMEP/EEA Guidebook (EMEP/EEA, 2009) are used to estimate emissions from exploration of oil and gas, loading of ships and offshore flaring.

The guidebook provides emission factors for loading of ships for different countries. The Norwegian emission factors are assumed to be the best applicable to Danish conditions. The NMVOC emission factor for onshore loading given in the guidebook has been reduced by 25 % from 2010 and onwards due to introduction of new vapour recovery unit (VRU) at the Danish raw oil terminal (Miljøcenter Odense, 2010). The NMVOC emission factors for the projection years 2010 to 2035 are listed in Table 5.2.

The emission factor for service stations are the summarised emission factors for reloading of tanker trucks and refuelling of cars based on the EMEP/EEA Guidebook (EMEP/EEA, 2009). The NMVOC emission factor for service stations is listed in Table 5.2.

Table 5.2 NMVOC emission factors for 2010-2035.

Source	EF	Unit	Reference
Ships offshore	0.001	Fraction of loaded	EMEP/EEA, 2009
Ships onshore	0.00015	Fraction of loaded	EMEP/EEA, 2009 & Miljøcenter Odense, 2010
Service stations	0.703	Kg NMVOC/Mg gasoline	EMEP/EEA, 2009

Emission factors for offshore flaring are listed in Table 5.3. The SO_2 emissions are calculated using a country specific SO_2 emission factor for Danish natural gas. The emission factor for NO_x is based on a survey by the Danish Environmental Protection Agency (Danish EPA, 2008). Emission factors for NMVOC and PM are based on the EMEP/EEA Guidebook (2009).

Table 5.3 SO_2, NO_x and PM emission factors for offshore flaring.

Pollutant	EF	Unit	Reference
SO_2	0.014	g/Nm3	EMEP/EEA, 2009
NO_x	1.227	g/Nm3	Danish EPA, 2008
NMVOC	0.100	g/Nm3	EMEP/EEA, 2009
TSP	0.042	g/Nm3	EMEP/EEA, 2009
PM_{10}	0.042	g/Nm3	EMEP/EEA, 2009
$PM_{2.5}$	0.042	g/Nm3	EMEP/EEA, 2009

Emissions of particulate matter (PM) from coal storage are estimated by the emission factors used in the emission inventory of Poland (Olendry´nski et al., 2004). The emission factors are listed in Table 5.4.

Table 5.4 Emission factors for PM emissions from coal storage.

Pollutant	EF	Unit	Reference
TSP	150	g/Mg	Olendry´nski et al., 2004
PM_{10}	60	g/Mg	Olendry´nski et al., 2004
$PM_{2.5}$	6	g/Mg	Olendry´nski et al., 2004

Emissions from the raw oil terminal include emissions from oil transport in pipelines and storage in tanks and are given annually in the self-regulating report. A new degassing system was built and taken into use in 2009. This has reduced the NMVOC emissions from the raw oil terminal by approximately 60 % (DONG Oil Pipe, 2011; Spectrasyne Ltd, 2010). Estimation of emissions from the oil terminal in the projection years is based on the average emission in the years 2010-2011 scaled to the annual oil production given in the oil and gas production prognosis (DEA, 2012a).

A similar approach has been applied for transmission and distribution of natural gas and distribution of town gas as for the oil terminal. The emission in the projection years are estimated as the average emission in the last five historical years scaled to the annually gas consumption given in the energy consumption prognosis (DEA, 2012a).

Emissions from refineries (processes and flaring) and from venting in gas storage plants are calculated as the average emission of the last five historical years, and consequently no emission factors have been used to estimate projected emissions.

Emissions from flaring in the gas treatment plant are calculated as the average emission of the last two historical years, and consequently no emission factors have been used to estimate projected emissions.

5.4 Emissions

Figure 5.2 shows emissions of SO_2 for every fifth historical year (1990-2010), the latest historical year (2011), the first projection year (2012) and every fifth projection year (2015-2035). The SO_2 emissions are high in the first years of the time series, mainly for refineries, due to the presence of a third refinery. SO_2 emissions from refineries show large annual fluctuations due to unpredictable circumstances and therefore the projected emissions must be expected to have large uncertainties. By using a five-year mean, part of the annual variations are taken into account.

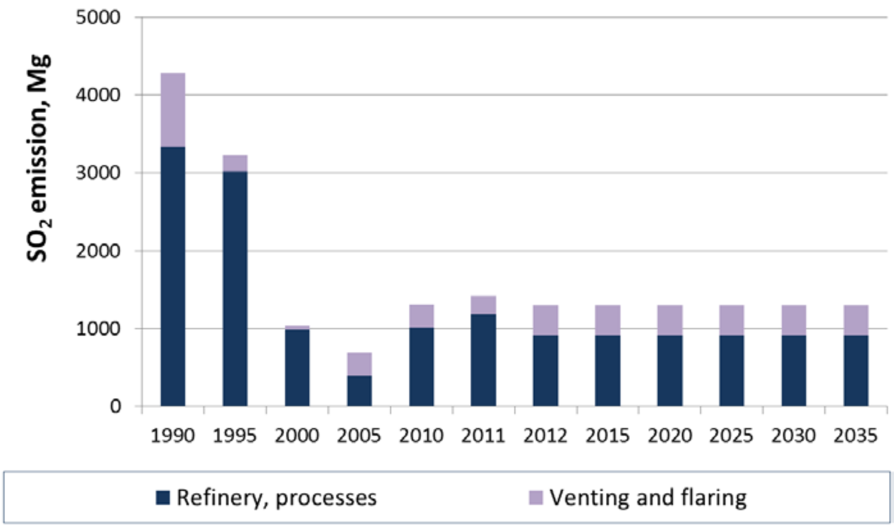

Figure 5.2 SO_2 emissions for selected historical years (1990-2011) and projection years (2012-2035).

Projected SO_2 emissions are listed more detailed in Table 5.5. The major source is refinery processes followed by flaring in refineries and flaring in oil and gas production, the latter being of only minor importance.

Table 5.5 Projected SO_2 emissions for selected historical years (1990-2011) and projection years (2012-2035).

NFR code	Source	1990	1995	2000	2005	2010	2011	2012	2015	2020	2025	2030	2035
							Unit, Mg						
1B2a iv	Refinery, processes	3335	3022	981	390	1019	1179	919	919	919	919	919	919
1B2c	Refinery, flaring	943	203	51	296	288	242	378	378	378	378	378	378
1B2c	Flaring in oil and gas production	1,51	2,14	3,51	2,59	1,68	1,10	0,94	0,80	0,77	0,77	0,74	0,74

The only source to emissions of NO_x in the fugitive sector is flaring, which occur in refineries, offshore and at the gas treatment plant (Figure 5.3). Emissions of NO_x peaked around year 2000 and have been decreasing until the latest historical year 2011 due to the decreasing trend for offshore flaring.

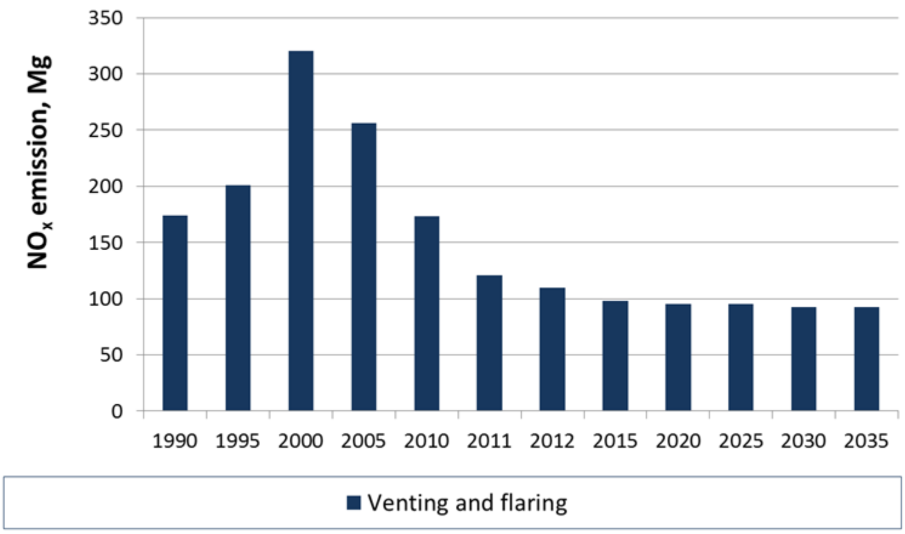

Figure 5.3 NO_x emissions for selected historical years (1990-2011) and projection years (2012-2035)

The most important source is offshore flaring in oil and gas extraction, which account for 96 % in year 2000, 79 % in 2011 and 69 % in 2035. Table 5.6 lists NO_x emissions in more detail for selected historical and projection years. Emissions from flaring in oil and gas extraction include offshore flaring and flaring in gas storage and treatment plants.

Table 5.6 Projected NO_x emissions for selected historical years (1990-2011) and projection years (2012-2035).

NFR code	Source	1990	1995	2000	2005	2010	2011	2012	2015	2020	2025	2030	2035
							Unit, Mg						
1B2c	Refinery, flaring	41	13	11	26	19	18	21	21	21	21	21	21
1B2c	Flaring in oil and gas production	133	188	310	231	155	103	89	78	75	75	72	72

The fugitive sector is an important source of NMVOC emissions. In 2011 the sector accounted for 11 % of the national total NMVOC emission. The major fugitive NMVOC sources are refinery processes, onshore and offshore activities and service stations (Figure 5.4). In the later historical years and in the projection years, refinery processes are by far the major single source. As mentioned, fugitive emissions from refineries are highly unpredictable and only very few measurements are available as basis for the emission estimation. Improvement of the emission estimation and projection for refinery processes require more measurements at the refineries.

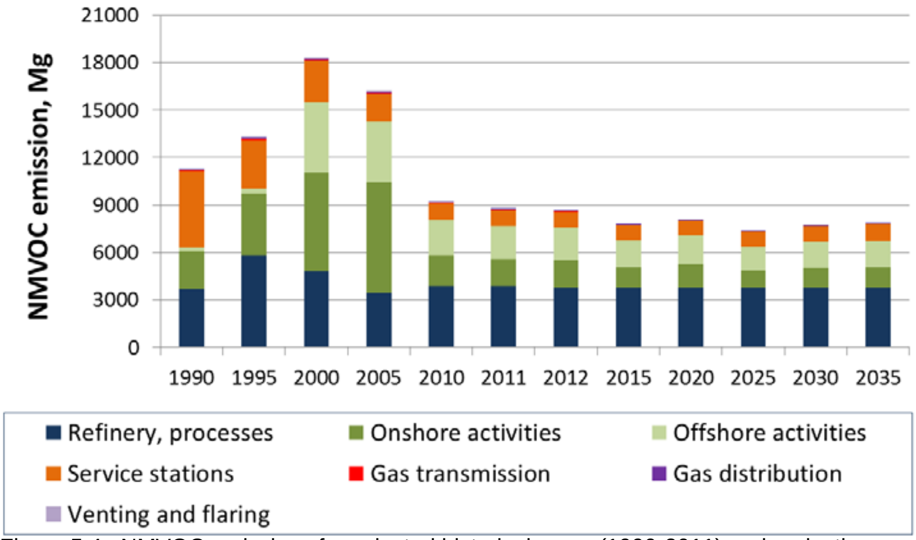

Figure 5.4 NMVOC emissions for selected historical years (1990-2011) and projection years (2012-2035).

Emissions of NMVOC are listed in more detail in Table 5.7. Emissions from onshore and offshore loading, oil/gas extraction and the oil terminal fluctuates in the projection years according to the oil and gas production prognosis. These sources have a decreasing trend in the projection years. Emissions from service stations, and gas transmission and distribution follow the prognosis for consumption of gasoline and natural gas, respectively. Emissions from service stations decrease in the first part of the projection years, followed by an increase in the latter part of the projection, ending up at the same level as in the latest historical year 2011. Consumption of natural gas are decreasing in the projection period, leading to decreasing NMVOC emissions. Venting fluctuates in an unpredictable way venting occur due to safety reasons in connection with construction work, inspection and maintenance.

Table 5.7 Projected NMVOC emissions for selected historical years (1990-2011) and projection years (2012-2035).

NFR code	Source	1990	1995	2000	2005	2010	2011	2012	2015	2020	2025	2030	2035
							Unit, Mg						
1B2a iv	Refinery, processes	3667	5815	4845	3442	3867	3868	3795	3795	3795	3795	3795	3795
1B2a i	Onshore loading	678	1249	2183	2494	1187	1071	1071	804	916	674	775	800
1B2a i	Oil terminal	1726	2664	4000	4500	763	638	638	473	539	396	456	471
1B2a i	Extraction of oil and gas	236	330	455	536	566	562	557	554	557	558	557	552
1B2a i	Offshore loading	*NO*	*NO*	4021	3337	1658	1525	1525	1123	1280	941	1082	1118
1B2a v	Service stations	4856	3016	2616	1742	1090	1013	989	969	913	924	986	1063
1B2b	Gas transmission	36	121	52	36	6	43	11	9	7	6	6	5
1B2b	Gas distribution	57	69	66	61	35	62	69	60	48	45	43	42
1B2c	Venting	0	27	24	14	22	24	22	22	22	22	22	22
1B2c	Refinery, flaring	34	31	26	32	27	25	29	29	29	29	29	29
1B2c	Flaring in oil and gas production	11	20	30	23	13	9	7	6	6	6	6	6

NO: not occurring.

PM emissions are reported for the years 2000 and onwards. The major fugitive source of emissions of particulate matter (PM) is coal storage, while PM emissions from flaring are of only minor importance (Figure 5.5 and Table 5.8). PM emissions from coal storage follow the trend of the annual coal consumption, which are decreasing in the projection years.

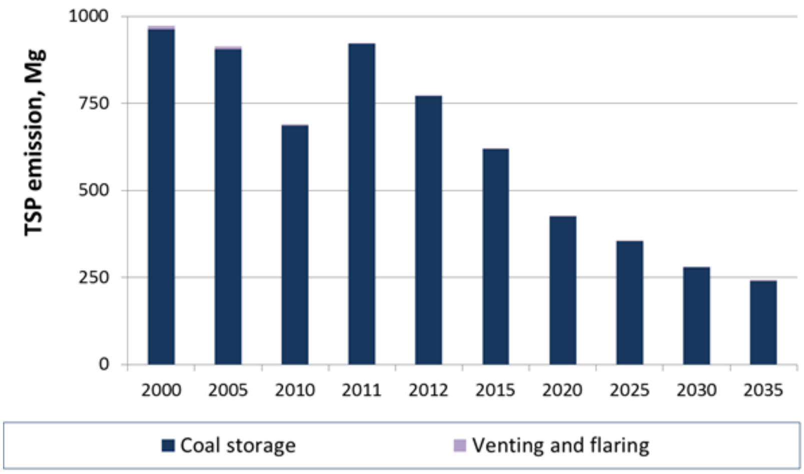

Figure 5.5 TSP emissions for selected historical years (2000-2011) and projection years (2012-2035).

Table 5.8 Projected TSP emissions for selected historical years (1990-2011) and projection years (2012-2035).

NFR code	Source	2000	2005	2010	2011	2012	2015	2020	2025	2030	2035
						Unit, Mg					
1B1a	Coal storage	962	905	686	920	770	619	424	354	278	240
1B2c	Refinery, flaring	0,3	0,4	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3
1B2c	Flaring in oil and gas production	10,5	7,8	5,0	3,3	2,8	2,4	2,3	2,3	2,2	2,2

5.5 Changes since previous projection

Only minor changes have been applied since the last projection in 2011. Most changes of the projected emissions owe to use of updated versions of the oil and gas production prognosis (DEA, 2012b) and the energy consumption prognosis (DEA, 2012a). The largest percentage-wise change has been for PM emissions from coal storage, as the coal consumption has been downscaled in the prognosis used in the present projection. The largest difference of 1.2 % occurs in 2030, which was the latest projection year in the previous projection.

Emissions from transmission and distribution of gas have changed according to use of the updated version of the energy consumption prognosis. The change according to the previous projection are 0.5 % – 0.6% for the projection years.

The projection of SO_2 emissions from processes in refineries have changed by 0.6 % since the previous projection. SO_2 emissions in the projection years are estimated as the average of the last five historical years, and therefore the projection changes when a new historical year is included.

The methodology for estimating emissions from flaring in refineries has been changed. In the previous projection the emissions were based on the activity data in the latest historical year and standard emission factors. In the present projection, the emissions are estimated as the average for the last five years, which corresponds with the methodology applied for sulphur recovery in refineries. This is more reasonably as the variations at the sulphur recovery plant influence the SO_2 emission from flaring, as gas are lead to flare when the recovery plant does not run properly. The methodological change has led to changes of emissions from flaring and venting of -0.2 % - 0.1 %, the largest change being for SO_2 (-0.2 %).

5.6 References

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6 Industrial processes

A range of sources are covered in the projection of process emissions to 2035 (see Table 6.1). The contribution in 2011 to the National emissions is for SO_2 6 %, NMVOC 6 %, NO_x < 1 %, NH_3 < 1 %, and TSP < 1 %.

The emissions from industrial energy consumption are included in the chapter on stationary combustion.

Table 6.1 Sources/processes included in the projection of process emissions.

NFR code		Sources/processes	SNAP code
2A	Mineral products	2A2 Lime production	03 03 12
		2A5+6 Asphalt products	
		- Roof covering with asphalt products	04 06 10
		- Road surfacing with asphalt	04 06 11
		2A7d Other mineral products	
		- Glass wool[1]	03 03 16
		- Mineral wool	03 03 18
		- Production of yellow bricks	04 06 91
		- Expanded clay products	04 06 92
2B	Chemical industry	2B2 Nitric acid production	04 04 02
		2B5a Other chemical industry	
		- Sulphuric acid production	04 04 01
		- Catalyst/fertiliser production	04 04 16
		- Pesticide production	04 05 25
2C	Metal production	2C1 Iron and steel production	04 02 07/08
		2C5	
		- Lead production	03 03 07
		- Zinc production	03 03 08
2D	Other	2D2 Food and drink	
		- Bread	04 06 05
		- Beer	04 06 07
		- Spirits	04 06 08
		- Meat curing	04 06 27
		- Margarine and solid cooking fat	04 06 98
		- Coffee roasting	04 06 99
2G	Other production	2G	
		- Treatment of slaughterhouse waste	04 06 17

1. Emissions from glass industry are included in the energy sector.

For some sectors it is not possible to distinguish between energy and process related emissions e.g. cement production and glass production. These sectors are included in the chapter on stationary combustion.

The projection of emissions from industrial processes is based on the national emission inventory prepared for UNECE (Nielsen et al., 2013).

6.1 Methodology

The projections are generally based on projection of production values for different sectors (Danish Energy Agency, 2012) combined with the actual emission in 2011 (Nielsen et al., 2013).

$$E_{year\ n} = E_{2011} \times f_{year\ n}$$

Where:

$E_{year\ n}$ = the emission in the year n and

$f_{year\ n}$ = the extrapolation factor for the year n

The extrapolation values with 2011 as base year ($f_{year\ n}$) for the relevant sectors are shown in Figure 6.1. The changes from the previous extrapolation values are presented and discussed in Section 6.5.

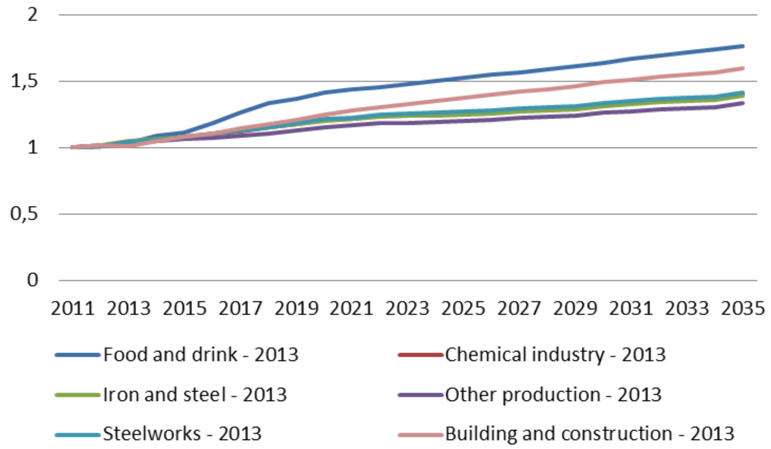

Figure 6.1 Extrapolation factors applied for projections in 2013.

6.2 Activity data

The activity data has not been projected separately, cf. Section 6.1.

6.3 Emission factors

The emission factors have not been projected separately, cf. Section 6.1.

6.4 Emissions

The projected emissions within the different sectors are presented in the following sections.

6.4.1 Mineral products

Manufacturing of mineral products covers the following processes:

- Lime production
- Roof covering with asphalt products
- Road surfacing with asphalt
- Glass wool
- Mineral wool
- Production of yellow bricks
- Expanded clay products

The projected emissions are presented in Table 6.2.

Table 6.2 Projected emissions from manufacturing of mineral products (2A).

	1990	2005	2010	2011	2012	2015	2020	2025	2030	2035
Tonnes NMVOC	567	573	591	612	620	652	712	744	783	830
Tonnes SO_2	1 407	1 494	764	823	840	889	1 030	1 132	1 227	1313
Tonnes NH_3	489	335	311	295	301	319	369	406	440	470
Tonnes $PM_{2.5}$		143	74.6	85.4	87.1	92.2	107	117	127	136
Tonnes PM_{10}		194	103	116	118	125	144	158	171	182
Tonnes TSP		226	123	140	143	151	174	189	204	218

6.4.2 Chemical industry

Chemical industry covers the following processes:

- Nitric acid production
- Sulphuric acid production
- Catalyst/fertiliser production
- Pesticide production

The projected emissions for chemical industry are presented in Table 6.3. The significant decrease in NO_x and SO_2 from 2000 to 2005 and from 1990 to 2000 can be explained by closing of nitric acid production in 2004 and by phasing out of sulphuric acid production until 1997.

Table 6.3 Projected emissions from chemical industry (2B).

	1990	2005	2010	2011	2012	2015	2020	2025	2030	2035
Tonnes NO_x	842	30.2	21.0	26.0	26.3	28.0	31.3	32.9	34.6	36.6
Tonnes NMVOC	490	39.7	26.9	26.9	27.2	29.0	32.4	34.0	35.8	37.9
Tonnes SO_2	636	402	10.8	26.6	26.9	28.6	32.0	33.6	35.4	37.5
Tonnes NH_3	13.0	79.0	123	20.3	20.5	21.8	24.5	25.7	27.0	28.6
Tonnes $PM_{2.5}$		14.0	16.0	4.10	4.14	4.41	4.94	5.18	5.46	5.78
Tonnes PM_{10}		18.0	21.0	5.40	5.46	5.81	6.51	6.83	7.19	7.61
Tonnes TSP		23.0	26.0	6.80	6.87	7.32	8.19	8.60	9.05	9.58

6.4.1 Metal industry

Metal industry covers the following processes:

- Iron and steel production
- Lead production
- Zinc production

The projected emissions are presented in Table 6.4. The significant decrease in emission of TSP from 2000 to 2005 can be explained by closing of the electro steelwork in 2001; rolling mill has been in operation afterwards.

Table 6.4. Projected emissions from metal industry (2C).

	2000	2005	2010	2011	2012	2015	2020	2025	2030	2035
Tonnes $PM_{2.5}$	34.8	11.0	6.01	6.04	6.12	6.53	7.31	7.65	8.05	8.52
Tonnes PM_{10}	98.8	57.4	25.1	25.2	25.5	27.2	30.5	32.0	33.6	35.6
Tonnes TSP	236	180	73.2	73.2	74.1	79.1	88.8	93.0	98.0	104

6.4.2 Food and beverage

Production of food and beverage covers the following processes:

- Bread

- Beer
- Spirits
- Meat curing
- Margarine and solid cooking fat
- Coffee roasting

The projected emission is presented in Table 6.5.

Table 6.5. Projected emissions from production of food and beverage (2D).

	1990	2005	2010	2011	2012	2015	2020	2025	2030	2035
Tonnes NMVOC	4 774	4 911	4 321	4 242	4 326	4 731	5 999	6 558	6 959	7 495

6.4.3 Other production

"Other production" covers treatment of slaughterhouse waste. The projected emission is presented in Table 6.6.

Table 6.6. Projected emissions from other production (treatment of slaughterhouse waste) (2G).

	1990	2005	2010	2011	2012	2015	2020	2025	2030	2035
Tonnes NH_3	24.2	132	89.0	86.2	87.3	91.6	100	104	109	115

6.5 Changes since previous projection

The consequences of the change in extrapolation methodology as well as of changes in the basis for the projections are presented in Figure 6.2 - Figure 6.4 and Table 6.7 – Table 6.8.

The extrapolation factors applied in 2011 were based on expected energy consumption within different sectors and the extrapolation factors applied in 2013 are based on production values within the different sectors (Danish Energy Agency, 2012).

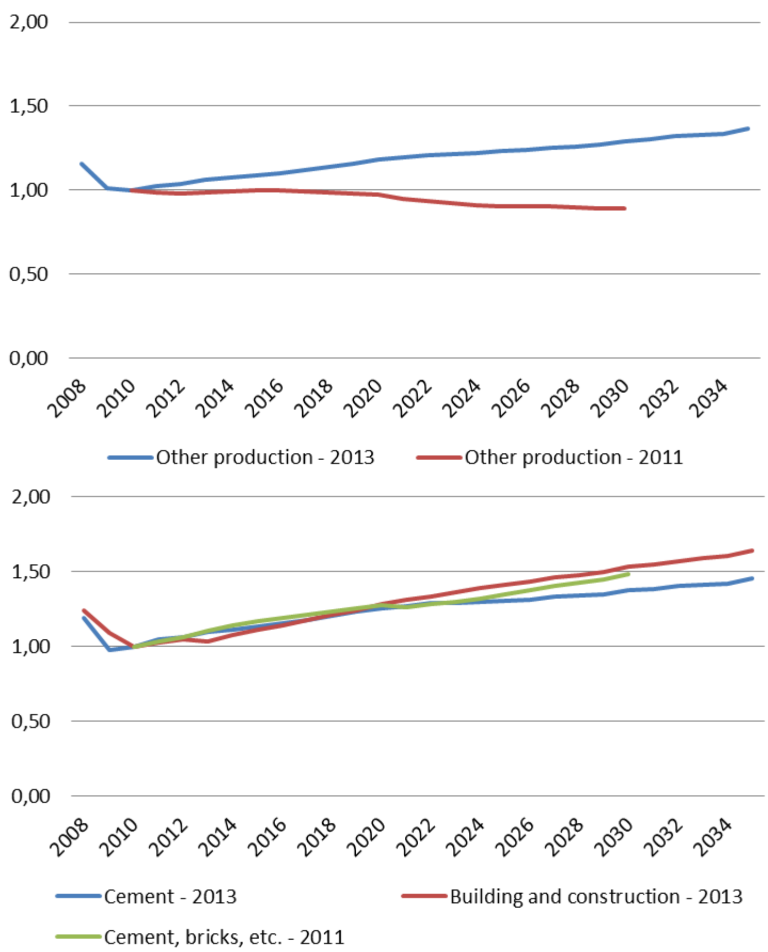

Figure 6.2 Extrapolation factors applied for ”Other production” and “Building and construction” etc. in the projection in 2011 and in 2013.

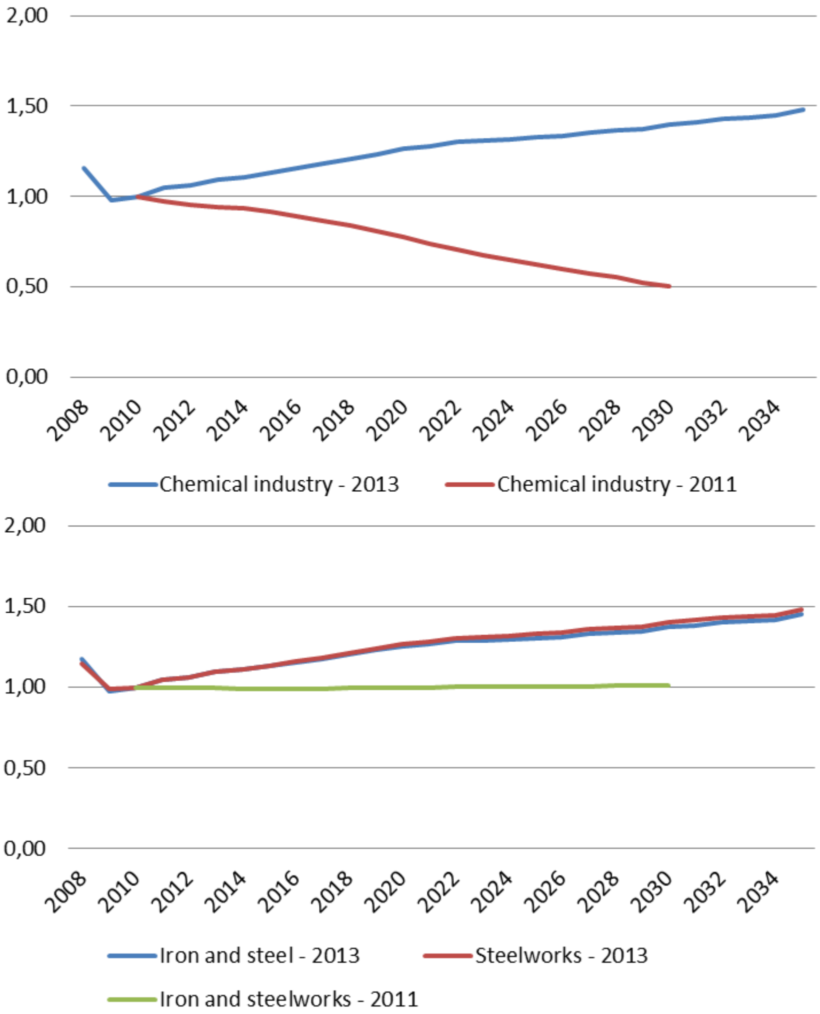

Figure 6.3 Extrapolation factors applied for ”Chemical industry” and “Iron and steelworks” in the projection in 2011 and in 2013.

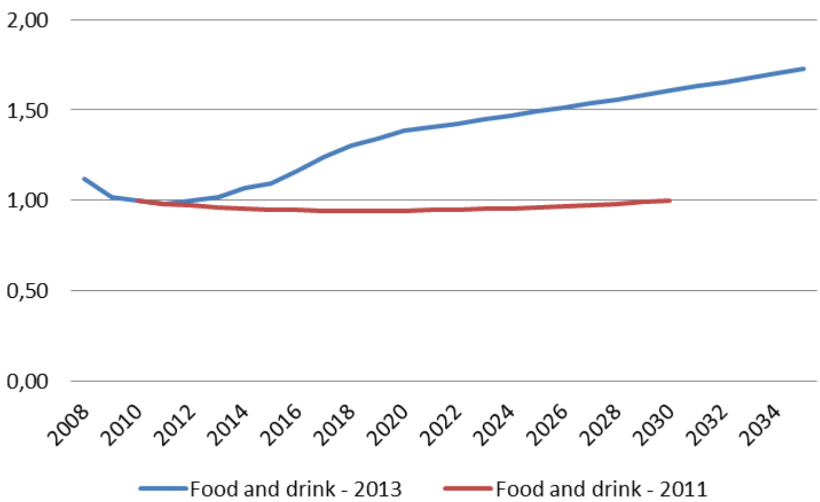

Figure 6.4 Extrapolation factors applied for ”Food and drink” in the projection in 2011 and in 2013.

Table 6.7 Changes in projected emissions of SO_2, NO_x, NMVOC and NH_3 from the 2011 projection to the 2013 projection.

Tonnes	Substance	2015	2020	2025	2030
2011 projection	SO_2	829	829	829	829
2013 projection	SO_2	918	1 062	1 166	1 263
Difference, %	SO_2	10.8	28.1	40.7	52.4
2011 projection	NO_x	16.5	14.0	11.2	9.05
2013 projection	NO_x	28.0	31.3	32.9	34.6
Difference, %	NO_x	69.6	124	192	282
2011 projection	NMVOC	8 690	8 639	8 805	9 133
2013 projection	NMVOC	5 412	6 744	7 239	7 778
Difference, %	NMVOC	-37.7	-21.9	-17.8	-14.8
2011 projection	NH_3	244	221	196	178
2013 projection	NH_3	432	493	535	575
Difference, %	NH_3	76,9	123	173	223

The changes in the projected emissions from 2011 to 2013 can be explained by:

- SO_2: Emission of SO_2 has been re-allocated from energy to process for mineral industry e.g. glass wool and stone wool combined with new extrapolation factors.
- NO_x: The difference can be explained by application of new extrapolation factors. The change is significant, however, the contribution of process emission to the total emission constitutes less than 1 % in 2011.
- NMVOC: Emission factors have been improved for food and drink.
- NH_3: Emission of NH_3 has been re-allocated from energy to process for mineral industry e.g. glass wool and stone wool.

Table 6.8 Changes in projected emissions of TSP, PM_{10} and $PM_{2.5}$ from the 2011 projection to the 2013 projection.

	Substance	2015	2020	2025	2030
2011 projection	TSP	17.3	15.1	12.7	10.8
2013 projection	TSP	238	271	291	311
Difference, %	TSP	1 271	1 691	2 188	2 787
2011 projection	PM_{10}	14.3	12.5	10.5	8.96
2013 projection	PM_{10}	158	181	197	211
Difference, %	PM_{10}	1 008	1 353	1 766	2 260
2011 projection	$PM_{2.5}$	10.6	9.23	7.73	6.52
2013 projection	$PM_{2.5}$	103	119	130	140
Difference, %	$PM_{2.5}$	871	1 189	1 580	2 052

The changes in the projected emissions from 2011 to 2013 can be explained by:

- TSP: Emission of TSP has been re-allocated from energy to process for e.g. lime production, iron and steel etc.
- PM_{10}: do.
- $PM_{2.5}$: do.

6.6 References

Danish Energy Agency, 2012: Anne Lund Bender, DEA, personal communication, 6 July 2012.

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7 Solvent and other product use

The projection includes NMVOC emissions from solvents and other product use in industrial processes and households that are related to the source categories Paint application (CRF sector 3A), Degreasing and dry cleaning (CRF sector 3B), Chemical products, manufacture and processing (CRF sector 3C) and Other (CRF sector 3D). The sector constitutes 33 % of the total national NMVOC emissions in 2011. The methodology for the Danish NMVOC emission inventory for solvent use is done for the period 1995 – 2011 based on the detailed approach described in EMEP/CORINAIR (2004) and emissions are calculated for industrial sectors, households in the CRF categories mentioned above, as well as for individual chemicals and/or chemical groups. Further details on the inventory methodology can be seen in Nielsen et al. (2013).

7.1 Emission projections

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

The 2011 NMVOC emissions from CRF 3 and its SNAP sub-categories are shown in Table 7.1. Zero emission is stated either because there is no NMVOC use in the sub-category or, e.g. for pharmaceutical manufacturing and leather tanning, because the use is not reflected in the SPIN database. The total amount of used NMVOC is however still accounted for. The most prominent sub-categories 060412 Other use: Other, 060408 Other use: Domestic solvent use and 060314 Chemical products, manufacturing and processing: Other, comprise 52 %, 13 % and 13 %, respectively, of the total CRF 3 NMVOC emissions. These sub-categories constitute highly diverse and diffuse activities and product uses, each comprising a number of chemicals.

Table 7.1 2011 NMVOC emission in Gg from CRF 3 Solvents and other product use and its sub-categories.

SNAP	Category description	NMVOC emission 2011 (Gg)	Fraction of total 2011 emission
060101	Manufacture of Automobiles	0,041	0,0015
060102	Car Repairing	0,25	0,0094
060103	Constructions and Buildings	0,33	0,012
060104	Domestic Use	0,48	0,018
060105	Coil Coating	0,019	0,00072
060106	Boat Building	0,34	0,013
060107	Wood	0,089	0,0033
060108	Other Industrial Paint Applications	1,25	0,046
060109	Other Non-Industrial Paint Application	0,072	0,0027
	Paint Application (sum of above SNAP sub-categories)	2.9	0.11
060201	Metal Degreasing	0	0
060202	Dry Cleaning	1,1E-05	4E-07
060203	Electronic Components Manufacturing	0	0
060204	Other Industrial Dry Cleaning	0	0
	Degreasing and Dry Cleaning (sum of above SNAP sub-categories)	1.1E-05	4E-07
060301	Polyester Processing	0	0
060302	Polyvinylchlorid Processing	1,5E-05	6E-07
060303	Polyurethan Foam Processing	0,22	0,0082
060304	Polystyrene Foam Processing	1,02	0,038
060305	Rubber Processing	0	0
060306	Pharmaceuticals Products Manufacturing	0	0
060307	Paints Manufacturing	6,2E-05	2E-06
060308	Inks Manufacturing	0,0002	7E-06
060309	Glues Manufacturing	0	0
060310	Asphalt Blowing	0	0
060311	Adhesive, Magnetic Tapes, Film & Photographs Manufacturing	2,6E-06	1E-07
060312	Textile Finishing	0	0
060313	Leather Tanning	0	0
060314	Other	3,6	0,13
	Chemical Products Manufacturing & Processing (sum of above SNAP sub-categories)	4.8	0.18
060401	Glass Wool Enduction	5,4E-06	2E-07
060402	Mineral Wool Enduction	0,00057	2E-05
060403	Printing Industry	0,01	0,00038
060404	Fat, Edible and Non-Edible Oil Extraction	0	0
060405	Application of Glues and Adhesives	1,7	0,063
060406	Preservation of Wood	0	0
060407	Underseal Treatment and Conservation of Vehicles	0	0
060408	Domestic Solvent Use (Other Than Paint Application)	3,5	0,13
060409	Vehicles Dewaxing	0	0
060411	Domestic Use of Pharmaceutical Products	0	0
060412	Other (Preservation of Seeds a.o.)	14	0,52
0606	Other (Use of fireworks, tobacco & charcoal for BBQs)	0.064	0.003
	Other use (sum of above SNAP sub-categories)	19	0.71
	Total	26.9	1.0

The processes and activities that are covered by the Danish Ministry of the Environment statutory order BEK 1452/2012 and the associated fraction of the total 2011 NMVOC emissions are shown in Table 7.2. They cover 9.1 % of the total NMVOC emissions in CRF 3.

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

The predominant emissions in the inventory thus represent diffuse uses, which cannot be attributed to an industrial sector or trade organisation and it is not feasible to perform projections according to the above directives. The emission projection of all categories will be based on extrapolation of historic 1995-2011 emissions.

In addition to NMVOC, the following pollutants are emitted from the source category of other product use; SO_2, NO_x, NH_3 and particles. These pollutants are emitted as a result of the use of fireworks, tobacco, charcoal for barbeques and candles. The projected emissions are shown in Table 7.4.

Table 7.2 Processes and activities (categories) that are covered by BEK 1452, associated SNAP subcategories, NMVOC emissions in 2011 and fraction of 2011 emissions from BEK 1452 category.

Categories in BEK 1452	Corresponding SNAP categories	NMVOC emission 2011 (Gg)	Fraction of total 2011 emission
Adhesive coating	060405	1.7	0.063 (also includes diffuse use)
Coating activity and vehicle refinishing	060101, 060102, 060106, 060107	0.72	0.027
Coil coating and winding wire coating	060105	0.019	0.0007
Dry cleaning	060202	0.000011	0.0000004
Footwear manufacture	nd	nd	nd
Manufacturing of coating preparations, varnishes, inks and adhesives	060307, 060308, 060309, 060311	0.00026	0.00001
Manufacture of pharmaceutical products	060306	0	0
Printing	060403	0.01	0.0004
Rubber conversion	060305	0	0
Surface cleaning	nd	nd	nd
Vegetable oil and animal fat extraction and vegetable oil refining activities	060404	0	0
Wood impregnation	060406	0	0
Wood and plastic lamination	nd	nd	nd
Total covered by BEK 1452		2.4	0.091

nd: Not defined in SNAP and may be a fraction of different SNAP categories.
0: Some of the emissions that are reported as zero, e.g. rubber conversion, may have a NMVOC use and emissions. The categories in Statistics Denmark (2013) and SPIN (2013) that include rubber may cover more materials than rubber and the use therefore falls under a different SNAP category, e.g. softeners in plastic and rubber products enters SNAP 060302 Polyvinylchloride processing.

Table 7.3 shows the extrapolation of the historic NMVOC emissions from 1990 to 2011 for the four CRF 3 categories; CRF 3A Paint application, CRF 3B Degreasing and dry cleaning, CRF 3C Chemical products, manufacture and processing and CRF 3D Other. An exponential fit gives the best approximation with R^2 values of 0.91, 0.80, 0.81 and 0.91, respectively. All projected CRF 3 categories show a decrease in NMVOC emissions, however, a decrease in use and emissions is only realistic to a certain point in time, either because the use becomes zero or because a minimum of solvent use has been reached. There is stagnation in the latest five years of the historic emissions; i.e. the four CRF categories show approximately constant emissions during the latest five years (2007 to 2011). The most realistic projection from 2012 to 2035 is assumed to represent 25 % of the exponential fit and 75 % of the, approximately constant, historic 2007 - 2011 estimates.

Table 7.3 Projected NMVOC emissions from CRF 3 Solvent and Other Product Use. NMVOC projections are calculated as 25 % of the exponential fit and 75 % of the constant historic 2007 - 2011 estimates.

	Unit	2011	'2011'[1)]	2012	2015	2020	2025	2030	2035
NMVOC emissions									
3A Paint Application	Gg	2.87	2.86	2.92	2.82	2.67	2.57	2.49	2.43
3B Degreasing and Dry Cleaning	Gg	1E-05	1E-05	1E-051	1E-05	1E-05	1E-05	1E-05	1E-05
3C Chemical Products, Manufacturing and Processing	Gg	4.81	5.04	5.19	5.07	4.89	4.75	4.63	4.53
3D Other Use	Gg	19.3	19.1	18.5	18.1	17.5	16.9	16.5	16.1
Total NMVOC	Gg	27.0	27.0	26.6	26.0	25.0	24.2	23.6	23.1

1) Mean emission (2009 – 2013).

Table 7.4 Projected SO_2, NO_x, NH_3 and particles emissions from CRF 3D3 Other Product Use.

	Unit	2011	2012	2015	2020	2025	2030	2035
SO_2	Gg	0.041	0.046	0.047	0.048	0.050	0.051	0.052
NO_x	Gg	0.042	0.047	0.047	0.046	0.045	0.044	0.043
NH_3	Gg	0.038	0.038	0.036	0.034	0.032	0.029	0.027
TSP	Gg	0.411	0.407	0.424	0.454	0.483	0.512	0.541
PM_{10}	Gg	0.411	0.407	0.424	0.454	0.483	0.512	0.541
$PM_{2.5}$	Gg	0.411	0.407	0.424	0.454	0.483	0.512	0.541

Emission projections have been elaborated in more detail for the industrial sectors; Auto paint and repair, plastic industry, graphic industry and lacquer and paint industry. Their emissions are not directly derivable from the above tables, but an estimate is that they represent between <1 and 4% of the total 2011 emissions for the Solvent and Other Product Use category.

In the graphic industry there has been increased investments in UV hardening facilities, and furthermore 80% of the production volume is produced at "svanemærke" printing works (offset method). During the latest years this has led to a significant decrease in VOC emissions. The demands for environmental labels such as "Svanen" and "EU-Blomsten" are continuously being more restrictive, which is also expected to influence the VOC emissions.

The plastic industry covers three main activities; production of expanded polystyrene products (EPS), production of fibreglass-reinforced polyester products (composite) and production of polyurethane products (PUR). Production of plastic materials does not take place in Denmark, only manufacturing and processing of plastic containing products are relevant. Emission reducing measures have already been implemented; i.e. a general shift from open to closed processes, replacing solvent-based with water-based cleaning agents, instalment of coal filters and combustion of solvent waste. Polystyrene products are manufactured from imported polystyrene pellets, which contain 6 % pentane. To comply with limit values in Luftvejledningen (EPA, 2001) and NEC directive there has been focus on reducing the pentane emissions during the EPS manufacturing and processing phase. However, due to technical barriers these initiatives will not be implemented. Pentane is also used in foaming of rigid PUR. In this process the pentane remains in the product except for a small amount, 1-4% of the added amount, which is emitted during production. There are no planned emission reducing initiatives for EPS and PUR production, technologies or used solvents. However, an increase in PUR production of 1-2% per year is anticipated. EPS production has decreased during the financial crisis and a constant or maybe slightly increasing production is anticipated in the coming years. For composite there are on-going initiatives on reducing the use of styrene, mainly due to exposure in the work place. However, it is not possible to quantify their effect on styrene emissions.

For the auto paint and repair sector no new emission reducing initiatives are planned in the near future or have been implemented since 2007, where a general shift to water soluble and high solid products was made.

In the lacquer and paint industry most companies are hoping for increased production and sales but they are strongly dependent on the demand from other industries and from consumer use (Dahl, 2013). Product use constitutes the predominant emissions from lacquers and paints so the industrial and consumer demand is the primary driver for NMVOC emissions from the lacquer and paint sector. Companies are continuously working on developing better products, which inter alia implies limiting and substituting the use of NMVOCs, however, always accounting for the technical quality of the product. In sectors where the products traditionally have been solvent based, the trend goes towards increased use of water soluble products, more low-VOC products and high solid products. Furthermore, the development depends on emerging rules and regulations on products and their chemical content.

In conclusion Table 7.3 shows the projected NMVOC emissions for 2012 to 2035 for the UNFCCC source categories Paint application (CRF sector 3A), Degreasing and dry cleaning (CRF sector 3B), Chemical products, manufacture and processing (CRF sector 3C) and Other (CRF sector 3D). The projections show a 14 % decrease in total NMVOC emissions from 2011 to 2035. CFR 3A, 3C and 3D show a 15 %, 6 % and 17 % decrease, respectively. CRF 3B emissions are negligible.

7.2 Changes since previous projection

For NMVOC the main changes have been for the definition of the "realistic reduction scenario" in emissions from 2011 to 2035. Previously the emissions were calculated as:

Fifty percent of exponential fit of historic emissions up to 2009 + 50% of mean emission from 2007 to 2009.

An approximately constant emission trend from 2007 and onward is, however, still seen and consequently the most realistic projection from 2012 to 2035 is assumed to represent a larger fraction of this trend, thus:

Twenty-five percent of the exponential fit of historic emissions up to 2011 + 75 % of mean emission from 2007 to 2011.

7.3 References

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8 Agriculture

The projection of air pollutants from the agricultural sector includes emission of ammonia (NH_3), particulate matter (PM) given as TSP, PM_{10} and $PM_{2.5}$, non-methane volatile organic compounds (NMVOC) and other compounds related to field burning of agricultural residues such as sulphur dioxide (SO_2) and nitrogen oxide (NO_X). Table 8.1 shows the agricultural contribution of emissions to the national total in 2011. The main part of the NH_3 emission (96 %) is related to the agricultural sector, while the agricultural contribution of TSP and PM_{10} are 32 % and 21 %, respectively. The agricultural share of the total emissions of $PM_{2.5}$, NMVOC, SO_X and NO_X is low (<1 % - 4 %).

Table 8.1 Emission 2011, reported to UNECE in January 2013.

	NH_3	TSP	PM_{10}	$PM_{2.5}$	NMVOC	SO_X	NO_X
National total, Gg	74	38	29	23	81	15	132
Agricultural total, Gg	71	12	6	1	2	<1	<1
Agricultural part, %	96	31	20	6	2	<1	<1

The main part of the agricultural emission is related to the livestock production e.g. 87 % of the ammonia emission originates from manure management. The environmental policy implemented from the middle of the eighties is reflected in a 37 % reduction of the ammonia emission from 1990 to 2011. This development has mainly been driven by strong requirements to handling of animal manure during storage and application to the fields. The use of the nitrogen in animal manure is improved considerably, which has led to a significant decrease in the consumption of synthetic fertiliser. This development towards lower ammonia emission as a consequence of improvement in utilisation of nitrogen in manure is expected to continue. One of the main drivers for this development is the nitrogen application standards that are set 15 % below economical optimum. In future, environmental requirements will probably still be introduced due to a more nutrient efficient handling of animal manure in storage and during application. However, one of the largest reduction potentials in the future is in animal housing, which is a result of the establishment of ammonia reducing technology e.g. new housing systems, cooling of slurry, sulphuric acid treatment of slurry in housing, or air cleaning systems.

The establishment of ammonia reduction technology is driven by environmental requirements and presently one of the most important regulations is the law on environmental approval of animal holdings (Law no. 1572 of 20/12/2006 and BEK no. 1172 of 04/10/2013). If the farmer will expand the animal production or for other reasons need to build new housings, he will be met by a specific requirement of ammonia reduction. Other important initiatives for the future development of the agriculture are the Agreement on Green Growth (2009 and 2010) and the report from the Nature and Agricultural Commission (2013), which has come up with recommendations and suggestions to create a new regulation to reduce the unintended environmental effects and at the same time describe opportunities for development and growth in the agricultural production.

The projected emissions of air pollutants from the agricultural sector are regularly updated in line with new scientific knowledge. The present projection of NH_3 emissions replaces the latest basic projection published in DCE Technical Report No. 7 (Nielsen et al, 2012).

8.1 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 EMEP/EEA air pollutant emission inventory guidebook (EMEP 2009). Thus, the same database setup is used, same estimation approach and principally the same emission factors. In cases where the future conditions will change, e.g. by implementation of emission reducing technology, an adjustment of the emission factor will follow.

The main contributors in Danish agriculture are cattle, pigs and fur animals, which represents the most important variable in determining projected ammonia emissions. Very little information exists on how agriculture expect to develop in the future and the economic crisis starting in 2008 makes it even more difficult to predict. We have contacted the Knowledge Centre for Agriculture to discuss the future production conditions and development expectations providing the assumptions for the development of the number of animals, type of housing, N-excretion and implementation of technology. In this process the historical development is also taken into account.

The background used to provide the projection for 2020 is obviously more solid than the assumptions that are given after 2020. Particularly the pig production is highly dependent on the development of export conditions and therefore closely related to supply and demand on the world market, which makes the future assumptions even more uncertain.

8.2 Activity data

8.2.1 Livestock

Cattle

The total cattle production mainly depends on the production of dairy cattle which is related to the average milk yield and the total milk production. The total milk production is assumed to stay at the same level until 2015 due to the fixed EU milk quota. The milk yield is expected to increase, leading to a decrease in the number of dairy cattle from 2011 to 2015. After 2015 the EU milk quota system will be replaced by free competition on the world market. It is uncertain how Danish milk production will adjust to the competition, but due to the highly intensive production form it is expected that the number of dairy cattle can increase from 565 000 to 600 000 in 2020 and further to 625 000 in 2030 (Clausen, 2013).

Dairy cattle

In the projection a continuous increase in the production efficiency is expected in the form of improved milk yield per cow. From 2011 to 2035 an average increase of milk yield of 130 kg milk per cow per year is assumed, which is based on an assessment provided by the Knowledge Centre for Agriculture (Aaes, 2013). The increase in the efficiency gives an average milk yield of approximately 10 200 kg milk per cow per year in 2020 and 12 100 kg milk per cow per year in 2035.

Table 8.2 Number of dairy cattle and milk yield - figures used in the projection to 2035.

	2011	2015	2020	2025	2030	2035
Dairy cattle, 1000 unit	565	552	600	613	625	625
Milk yield, kg milk per cow per year	9 300	9 400	10 200	10 900	11 500	12 100

N-excretion – dairy cattle

The N-excretion is closely related to the milk yield level. According to the default values, N-excretion in 2011 for dairy cattle (large breed) was 141.4 kg N per animal per year (Poulsen, 2012). An increase of the milk yield to 10 200 kg milk per cow in 2020 is assumed to result in an N-excretion of 144.0 kg N per animal per year (large breed) and 154 kg N per animal per year in 2035 based on an assessment provided by the Knowledge Centre for Agriculture (Aaes, 2013). The N-excretion and milk yield is estimated for the years 2013, 2020, 2025, 2030 and 2035, in between is estimated by interpolation.

Table 8.3 N-excretion for dairy cows – figures used in the projection to 2035.

N-excretion dairy cattle	2011	2015	2020	2025	2030	2035
	kg N per animal per year					
Large breed	141.4	141.7	144.0	149.2	149.9	154.0
Jersey	119.8	121.3	124.9	129.7	130.6	134.5

Non-dairy cattle

The production of non-dairy cattle is based on the number of dairy cattle. No significant change in the allocation of the subcategories of non-dairy cattle (heifers, bulls and suckling cattle), is expected until 2035. Thus, the changes in number of non-dairy cattle reflect the number of dairy cattle.

The historic normative data for N-excretion for all cattle subcategories shows few changes until 2005. From 2005 an increase in N-excretion for heifers, bulls and suckling cattle is observed. For the years 2007-2011 the N-excretion was constant for calves and bulls and there have only been small changes for heifers and suckling cattle. In the projection no significant changes in N-excretion is expected and therefore kept at the same level as in 2011.

Swine

More than 90% of Danish pork production is exported and therefore the conditions in terms of supply and demand for the major exporting countries like Germany, England, Japan and Poland is very crucial when it comes to expectations of pig production in the future. The production is also dependent on the price of feed and regulation of environmental requirements. The development from 1990 shows an increase in production of pigs. However, it is also seen that production has been fluctuating from 2008-2011, which is probably caused by the economic crisis on the world marked. Despite this fluctuation during recent years, it is expected that the agricultural structural development towards larger farm units will continue and thus expand the pig production in future.

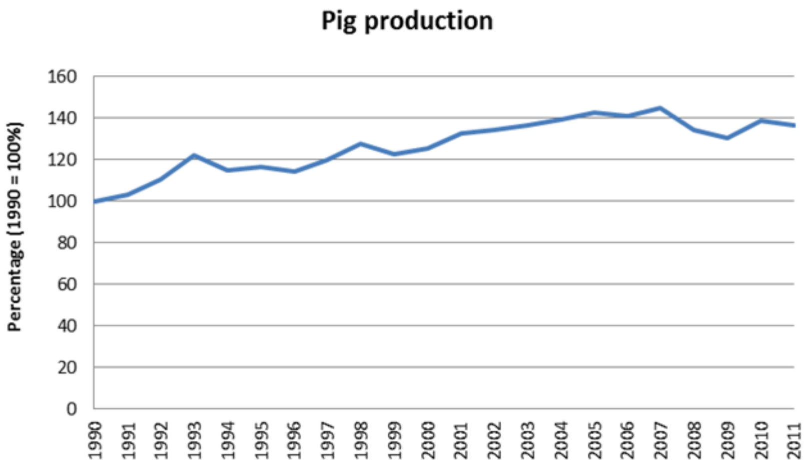


Figure 8.1 Development in the overall pig production 1990 – 2011 given as percentage, where 1990 is 100%. Source: Statistics Denmark

Sows

The number of sows is essential for the production of weaners and fattening pigs. The development in recent years shows a decrease in number of sows, which is due to a combination of increased production efficiency given as number of weaners per sow per year and the unfavourable economic situation. During the period 1990-2011 a significant increase in the number of weaners per sow was observed. The Pig Research Centre expects that this development will continue and assume a decrease from 1.06 million sows in 2011 to 1.05 million in 2020, remaining at the same level until 2035 (Tybirk, 2013). However, the production of weaners and fattening pigs will increase as a consequence of production efficiency. The question is whether this development can continue with the same growth rates or meets a genetic limitation?

Table 8.4 Increase in number of produced weaners per sow per year.

	1995-2010	1995-2011	2000-2011	2005-2011
Increase in number of weaners	0.3	0.5	0.6	0.8

The projected development is based on a relatively conservative judgement and is expected to increase by 0.5 piglets per sow per year until 2025 and 0.4 piglets per year for 2025-2030. This results in an average production of nearly 37 produced weaners per sow in 2030. No increase in the number of weaners per sow is estimated in 2030-2035. This is confirmed by the Pig Research Centre as a realistic estimate (Tybirk, 2013).

Weaners and fattening pigs

The production of fattening pigs depends on the production of weaners and the export of live weaners. Until 2004, nearly all weaners where fattened in Denmark, but from 2004 a significant increase in export of weaners (Statistics Denmark) is seen and this trend is expected to continue. The Danish production is competitive because of feed stability, efficient production conditions and high standards for disease control. An increase in exports also means an increase in the production, which require continued growth in demand and at the same time opportunity to establish financial loans to build new housing.

It is assumed that the export will increase from 8.5 million weaners in 2011 to 11 million in 2020 and 14 million in 2035. This results in an increase in produced number of weaners from 30.0 million in 2011 to 34.4 in 2020 and 39.1 in 2030, which corresponds to an increase in the production of weaners by 30 % from 2011 to 2035. The weaners, which are not exported, will be fattened in Denmark and the production level of fattening pigs is assumed to increase from 21.9 million in 2011 to 25.1 million in 2035. This corresponds to an increase of 15 % and is nearly at the same level as the production of fattening pigs in 2004.

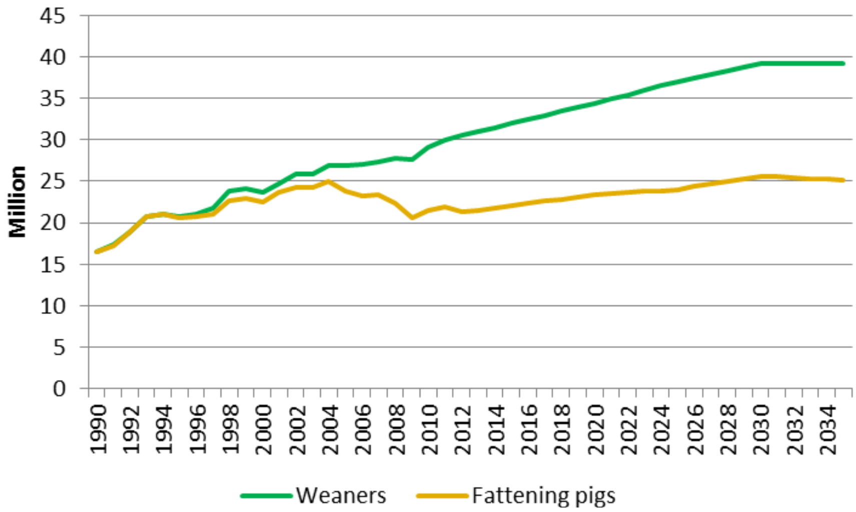


Figure 8.2 Historic and projected number of produced weaners and fattening pigs.

Table 8.5 Number of produced sows, weaners and fattening pigs.

Million produced	2011	2015	2020	2025	2030	2035
Sows	1.06	1.06	1.05	1.05	1.05	1.05
Weaners	30.0	31.9	34.4	37.0	39.1	39.1
Fattening pigs	21.9	22.0	23.4	24.0	25.6	25.1

N-excretion - swine

Due to improvements of feed efficiency a decrease in nitrogen excretion is expected. The assumptions applied in the projection are based on information from the Knowledge Centre for Agriculture. For sows the assumptions are based on a report from 2008 (Aaes et al., 2008) and the N-excretion for sows in 2020 is expected to be 22.81 kg N per sow per year, which corresponds to 9 % reduction compared to 2011.

The assumptions applied for weaners and fattening pigs are based on estimations made by Tybirk (2013). N-excretion for fattening pigs is expected to fall from 2.82 to 2.71 kg N per pig produced per year, which corresponds to a reduction of 4 %. For weaners an N-excretion at the same level as in 2011 is assumed in 2020.

In Table 8.6, the figures for N-excretion used in the projection are given.

Table 8.6 N-excretion for pigs – figures used in the projection to 2030.

N-excretion for pigs	2011	2015	2020	2025	2030	2035
	kg N per pig per year					
Sows	25.14	24.21	22.81	22.81	22.81	22.81
Weaners	0.49	0.49	0.48	0.47	0.46	0.46
Fattening pigs	2.82	2.77	2.71	2.73	2.74	2.74

Poultry

Assumption regarding the poultry production is based on information from The Danish Poultry Meat Association (Jensen, 2013).

The production of broilers has decreased significantly from 2005 to 2006 but has been rising again in recent years. The Danish Poultry Meat Association expects a further increase in production due to the introduction of a new technology, a heat exchanger to reduce the ammonia emission and thereby allowing production of more broilers. The number of broilers is expected to increase by 7 % from 2011 to 2020, corresponding to 124 million broilers in 2020. For the years 2020 to 2035 the number of broilers is kept at the same level as in 2020.

The production of hens is mainly produced to the domestic market and no significant changes are expected. The number of hens, turkeys, ducks and geese are based on a five years average (2007-2011) and is kept at the same level all years 2012-2035.

N excretion for all poultry is at the same level as in 2011 in all years 2012-2035. The Danish Poultry Meat Association expects no change in N-excretion. The efficiency improvements that will happen will properly be reflected in more eggs per hen and increased slaughter weight of broilers.

It should be noted that addition of synthetic amino acid in the feed will result in a lower nitrogen excretion. Presently the price is too high, but can become economically feasible if prices on crop production increase significantly.

Fur farming

DK produces almost 20 % of the total world market production of mink furs and thus the production are strongly related to the export conditions. Since year 2000 the production has increased, but a slight decrease is seen for 2008-2010. However, the number of mink is expected to increase significant by 20 % from 2011 to 2020 (Møller, 2013, Bækgaard, 2013), corresponding to 3.3 million mink in 2020. The expected positive development is a result of Denmark's competitive position and the increasing demand in China. Denmark has stable feeding conditions, which is important for a stable production and in addition Denmark can take advantage of the recently ban against fur production in the Netherlands.

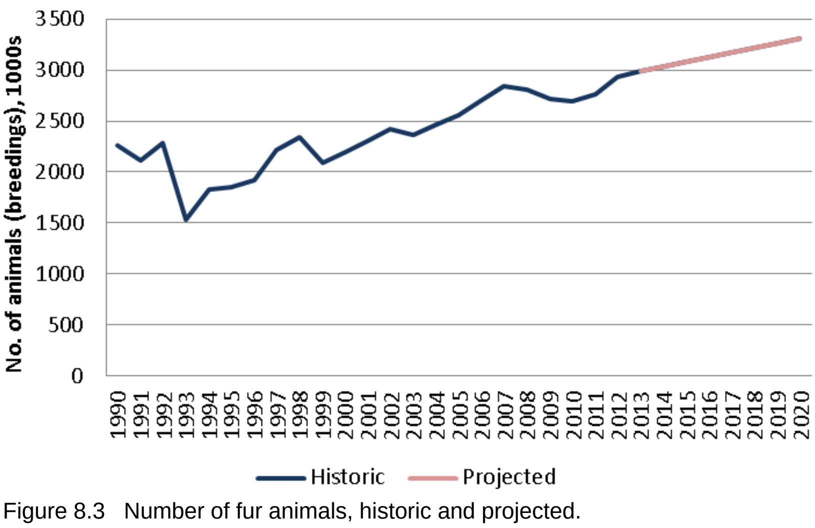


Figure 8.3 Number of fur animals, historic and projected.

From 2020 to 2035 the number of mink is kept at the same level as in 2020. The production of foxes is very stable and no change is expected.

N excretion for mink and foxes are at same level as in 2011 in all years 2012-2035.

8.2.2 Area

The size of agricultural land determined the demand of the total contribution of fertilizer. In addition to emissions from the manure is spread on fields, occurs also an emission during the growing season from growing crops. The size of the agricultural area is more important than the distribution of crop types, unless there is a significant increase in the grass area which has a higher emission factor. Changes in temperature and other climate conditions could lead to new kind of crop types, but probably not leads to a change of the proportion between grass and cash crops. In the projection, no major change in crop types is expected.

It is assumed that the agricultural area will continue to decrease with 90 000 hectare until 2020, which is equivalent to 10 000 ha per year. The development is mainly driven by establishment of environmental measures as set in the Green Growth Plan (2009); establishment of non-cultivated buffer zones of 50 000 hectares and establishment of wetlands to reduce the loss of nitrogen to aquatic environment and 25 000 hectare for afforestation. The remaining set-a-site area 15 000 hectare is for urban and road purposes.

Table 8.7 Projected agricultural land area.

Projected agricultural area	2011-2020	ha/year
Urban and roads	15 000	1 700
Non-cultivated buffer zones[1]	50 000	5 600
Afforestation	25 000	2 800
Total	90 000	10 000

[1] The non-cultivated buffer zones are to be established in 2013/2014

For comparison, a fall of 90 000 hectare from 2011 to 2020 represent a 3.4 % decrease, which corresponds to the same development as happened from 1995 to 2011.

It is difficult to predict any future measures that could lead to removal of agricultural land and thus predict the trend from 2020 to 2035. Therefore, a decrease of 5 000 ha per year is assumed from 2020 to 2035, which is half of the removal compared to the period 2011-2020.

Table 8.8 Historic and projected agricultural land area.

	1990	1995	2000	2005	2010	2011	2012	2015	2020	2025	2030	2035
1 000 ha	2 788	2 726	2 647	2 707	2 646	2 640	2 613	2 600	2 550	2 525	2 500	2 475

8.2.3 Use of Synthetic fertiliser

The use of fertiliser depends on the agricultural area and crop nitrogen demand. The amount of N needed, which is not covered by animal manure and sewage sludge applied as fertiliser to the soil must be covered with synthetic fertiliser. Amount of N from synthetic fertiliser are calculated as:

$$\text{N from synthetic fertiliser } (kg) = \text{Area fertilised land } (ha) \cdot \text{quota } \left(\frac{kg\ N}{ha}\right) - \left(\text{N in manure } (kg) + \text{N in sewage sludge } (kg)\right)$$

The projection of the agricultural area is described in Chapter 8.2.2. The amount of N in manure distributed on soil is based on amount of N ab storage and the coefficient of utilization of the manure. The coefficients of utilization provided by the Danish AgriFish Agency for 2011 are used for all years 2012-2035. The crop nitrogen needs are based on an average for the last five reported years (2007-2011). The total use of nitrogen in manure and fertilizers applied to the soil divided with the total agricultural area gives a total nitrogen need of 130 kg N per ha.

8.3 Emission factors

The emission regarding growing crops, sewage sludge, ammonia treated straw and field burning depends entirely on the agricultural area and for these sources no changes in the emission factor is assumed for 2001-2035. For grazing animals no adjustment are expected. The emission factor of 7 kg NH_3-N per kg N is unaltered, but changes in N-excretion are taken into account.

Changes in emission factor used to calculate the emission from manure management takes place as a consequence of expectations of the establishment of ammonia reducing technology.

8.3.1 Emission by use of ammonia reducing technology

The establishment of ammonia reduction technology is driven by environmental requirements, which constantly force the farmers to optimize the use of feedstuff and the utilisation of nutrients in animal manure and other fertilisers.

At present, one of the most important drivers regarding implementation of ammonia reducing technology in housing, is the Danish Law on environmental approval of animal holdings (Law no. 1572 of 20/12/2006). While in previous regulations major focus was on a general reduction, opens this legislation opens up for a more specific regulation depending on the geographical location and the size of the livestock production. In the consolidation Act of 2011 (BEK no. 1172 of 04/10/2013) a minimum of 30 % reduction of the ammonia emission is required from housing and storage when new housing is constructed or renovated. This means, that if a farmer will expand the animal production or for other reasons need to build new housing, he will be met by a requirement of 30 % reduction compared to a defined reference housing system. The 30 % requirement is the basic level, but for larger farms, more than 250 animal units, the reduction is higher, and for some livestock- or manure types the reduction level is lower.

Table 8.9 Ammonia reduction requirements (BEK 1172 of 04/10/2013).

Ammonia reduction requirement	Slurry	Deep litter
Dairy cattle, large breed	30 %	
Sow	30 %	30 %
Weaners	20 %	20 %
Fattening pigs	30 %	30 %
Fur farming	30 %	
Poultry; hens/other		30 % / 15 %

Ammonia reducing technology is included in the current projection in two ways. The first is the use of sulphur acid treatment of slurry before application to the soil, which is expected to be an important measure in future. The second is an assumption of the implementation of ammonia reducing technology in housing as a consequence of replacements. In this projection no specific assumption has been made regarding which technological solution the farmers choose to achieve the reduction. However, the overall assumption is regarding the share of the livestock production that is met with a 30 % reduction requirement in 2020 and 2030.

8.3.2 Replacement of animal housing – requirements of 30 % reduction

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

Cattle

Relatively few new barns are constructed for the last three years. Figure 8.4 provided by the Knowledge Centre for Agriculture, Department for Cattle shows that a high building activity for barns takes place from 1995 to 2005 (Westergaard, 2013). Lack of data in 2006 and 2007 is included in the 2008 number.

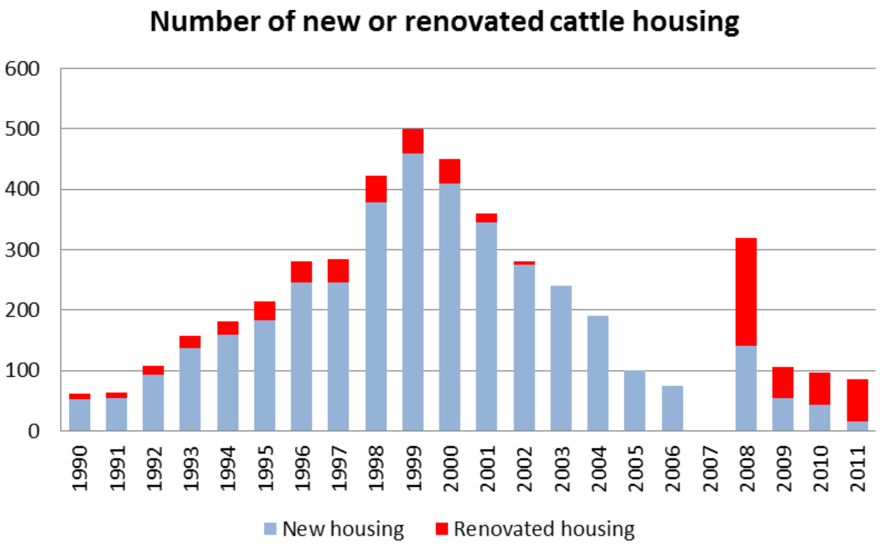


Figure 8.4 The development of cattle barns 1990-2011 ((Westergaard, 2013) - Knowledge Centre for Agriculture, Department for Cattle).

On average, 96 barns for dairy cattle were built and renovated from 2009-2011. No significant activity for the next five years is expected, the current economic situation taken into consideration. The same replacement level is assumed until 2020 and this will create space for approximately 160 000 cattle, which will all be met by a requirement of 30 % ammonia reduction in housing and storage.

The new housing built today have the sizes of approximately 200-300 place units, while the renovated housing include a smaller number of place units - 100 new place units are assumed.

50 new housing of 250 place units x 9 year = 112 500

50 renovated housing of 100 place units x 9 years = 45 000

In 2020 the production of dairy cattle is expected to reach 600 000 cattle, which means that 160 000 new place units with 30 % reduction requirements will be needed, corresponding to 25 % of the total production. The same assumptions are used for heifer housing.

The amount of housing built in the period 1995-2005 is expected to be replaced by 2030 and hence all place units for dairy cattle have met the requirement of the 30 % ammonia reduction. In 2030, the number of dairy cattle is expected to increase to 625 000 dairy cows, which results in a replacement rate of 155 houses per year in 2020-2030, assuming that new housing on average covers 300 pieces of cattle.

155 housing = (625 000 – 160 000 dairy cattle) / 300 place units / 10 years

A replacement of 155 housing per year seems reasonable compared to the period 1995-2005, where the development include 280 new/renovated housing each year.

Table 8.10 Percentage of the production which has met the requirements of 30 % ammonia reduction.

	2011	2020	2030	2035
Dairy cattle	0	25	100	100
Heifer	0	25	100	100

Swine

The development of the pig barns follows roughly the same trend as for cattle and all sows- and fattening housing is expected to meet the 30 % ammonia reduction requirements by 2035. The current economic situation makes it difficult to finance expansion of the production by building of new housing or start major renovation of existing housing.

The assumptions regarding the establishment of ammonia reducing technology in swine housing is based on information provided by Per Tybirk employed at the Knowledge Centre for Agriculture, Department for swine. Because of the current economic situation, not much activity is expected until 2015. Only 5 % of the swine production in 2020 is assumed to have met the requirements of the 30 % ammonia reduction. The development from 2015 until 2035 depends on whether the housing is for sows, piglets or weaners.

All housing for sows in 2035 is assumed to have technology, which in average reduce the ammonia emission by 30 %. The ammonia reduction requirements are 20 % for weaners (BEK no. 291 of 06/04/2011). The current normative standard for weaners shows that the 20 % reduction is already achieved. However, a further reduction is expected as a consequence of new environmental requirements or as a consequence of economic benefits for the farmer. It is assumed that 20 % of the production has reduced the ammonia emission in housing and storage by 20 % and further 30 % of the production in 2035.

The production of fattening pigs has changes significantly towards larger farms due to structural development. For farms with more than 250 animal units higher environmental standards are required. That is why the projection works with two categories of reduction requirement – the general requirement of 30 % reduction and another category with 60 % reduction requirements. In 2035 all fattening housing has to decrease the ammonia emission by a minimum of 30 %, and 30 % of the production is assumed to reduce the ammonia emission by 60 %. The 60 % reduction is chosen because reduction technologies such as acidification in housing reduce the emissions by 70 % and air cleaning typically reduces the emission by 60 %.

Table 8.11 Percentage of production which is met by ammonia reduction requirements.

	2011	2015	2020	2030	2035
Sows					
30 % reduction requirements	0	5	-	-	100
Weaners					
20 % reduction requirements	0	5	20	-	30
Fattening pigs					
30 % reduction requirements	0	5	-	-	70
60 % extended reduction requirements	0	5	-	-	30

Fur farming

Kopenhagen Fur does not consider the general requirement of 30 % reduction of ammonia emission as a problem for a further expansion of the production (Bækggard, H.). A VERA (Verification of Environmental Technologies for Agricultural Production) verification shows a 31 % ammonia reduction by removal of slurry two times a week compared with once a week (VERA 2). A more frequent removal can take place in existing housing and with significantly lower economic cost than the introduction of technological measures. It is expected that all housing in 2025 use removal of slurry two times a week.

Poultry

A new technology in broiler housing can reduce the ammonia emissions by 41 % by establishment of a heat exchanger, which use the thermal energy of the air leaving the broiler housing to heat and dry the incoming air (VERA 3). Besides the reduction of ammonia, the heat exchange is very energy efficient and improves the air quality in housing. The heat exchanger can be established in existing housing. It is assumed that 25 % of the broiler production has heat exchanger in 2015, 50 % in 2020 and 100 % in 2030 (Jensen, 2013).

For non-caged hens establishment of a system with floor on floor system will reduce the ammonia emission by 40 % (Jensen, 2013). The front of the cage is removed and the hens are free to choose between floors and scratch space on the floor. Under each floor a belt removes the manure much more frequently compared to other systems and the manure is dried, which reduces the emission. It is assumed that all production of non-caged hens in 2025 is based on these systems.

Table 8.12 Percentage of production which is met by ammonia reduction requirements.

	2011	2015	2020	2025	2030
Broilers	0	25	50	75	100
Hens	0	-	-	100	-

8.3.3 Sulphuric acid treatment of the slurry before application to the soil

The emission factor regarding the emission from application of manure is based on a weighted emission factor, which is determined by the application practice. Different combinations of variables such as application time, application methods, length of time between application and incorporation of manure, and stage of crop growth is taken into account.

The sulphuric acid treated slurry during spreading of manure on fields is expected to expand. From 2011, slurry applied on fields with grass for feeding or fields without crop cover, has to be injected directly into the soil (BEK no. 915 of 27/06/2013). However, the injection requirements are not applicable if the slurry has been treated with sulphuric acid. Acidifications reduce the pH value and thus reduce ammonia emission, because a larger part of the nitrogen is converted to ammonium which does not evaporate as easy as ammonia.

Assumptions regarding the expansion of acidification of slurry are based on information from the Knowledge Centre for Agriculture, Department for Cattle (Westergaard, 2013). The technology is used today but to a relatively limited extend. It is assumed that this technology will increase so 30 % of the cattle slurry is acid treated in 2030 and 50 % of the pig slurry. From 2030 to 2035 no changes are expected.

Table 8.13   Assumed part of the slurry which is treated with sulphur acid.

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

A VERA verifications show that the acid treated cattle and pig slurry reduces the ammonia emission by 49 % (VERA 1, 2013) compared with use of application by trailing hoses.

The total ammonia emission from application of slurry as a result of change in application practice and use of sulphuric acid treated technology will be reduced from 2011 to 2030 by 41 % for cattle and 38 % for pigs.

8.3.4 Synthetic fertiliser

The emission factor for synthetic fertiliser is not only dependent on the amount of fertiliser, but also depends on the distribution of the different types of fertilisers. This distribution has in the last six reported years been similar and the average emission factor have varied between 1.4 and 1.6 kg NH_3-N per kg N. It is assumed that no significant changes in the distribution of fertiliser types will happen.

Emission factor for synthetic fertiliser used in the projection is based on an average for the last three reported years (2009-2011), which gives an average of 1.55 kg NH_3-N per kg N applied. This value is used for all projected years (2012-2035).

It should be noted, that when the new EMEP guidebook (EMEP, 2013) is applied next year, the emissions from fertiliser is expected to increase. In the current guidebook a temperature correction is used, but new results based on a literature study cannot confirm the correlation between lower emissions and use of fertiliser in areas with lower temperatures as e.g. in the Northern Europe. This indicates that variables other than temperature have an importance for ammonia emission from fertiliser. Thus, the emission is expected to increase, but this has not yet been quantified.

8.4 Emissions

This projection covers the latest official Danish reporting, which includes emission until 2011. Thus, the projection comprises an assessment of the emissions from the agricultural sector from 2012 to 2035.

8.4.1 NH_3 emission

Table 8.14 shows the projected emission of NH_3.

Table 8.14 Historic and projected NH_3 emissions, Gg NH_3.

	1990	2005	2010	2011	2012	2015	2020	2025	2030	2035
Manure management	87.68	68.05	60.72	59.74	59.47	57.79	56.81	53.73	50.99	49.73
Synthetic fertiliser	6.59	3.12	3.47	3.94	3.70	3.67	3.48	3.39	3.24	3.16
Pasture	2.92	2.21	1.87	1.81	1.86	1.84	1.94	1.97	2.00	2.01
Growing crops	5.92	5.34	5.41	5.42	5.34	5.28	5.18	5.13	5.08	5.03
Sewage sludge	0.07	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Field burning	0.08	0.13	0.09	0.09	0.12	0.12	0.12	0.12	0.12	0.12
NH_3 treated straw	10.19	0.26	0.24	0.24	NO	NO	NO	NO	NO	NO
Total	113.45	79.16	71.85	71.30	70.56	68.76	67.59	64.41	61.49	60.11
Total included in NEC	97.26	73.44	66.12	65.55	65.09	63.35	62.29	59.16	56.29	54.96

Note: NEC = National Emission Ceiling.

The projection shows an expected decrease of NH_3 emission from 71.30 Gg in 2011 to 67.59 Gg in 2020 and further reduction is expected to 60.11 Gg NH_3 in 2035. This corresponds to a 16 % reduction from 2011-2035.

Regarding the National Emission Ceiling Directive, the NH_3 emission from growing crops and NH_3 treated straw is not taken into account.

In the projection the agricultural NH_3 emission is estimated to be reduced by 16 % from 2011 to 2035. Figure 8.5 shows the projected NH_3 emission from livestock production, which contributes 87 % of the total emission reduction. The future decrease is expected to occur in emission from animal housing as a consequence of implementation of NH_3 reducing technology. Another reason for the decrease is reduction of emissions from manure applied to soil as a result of acidification of the manure just before application.

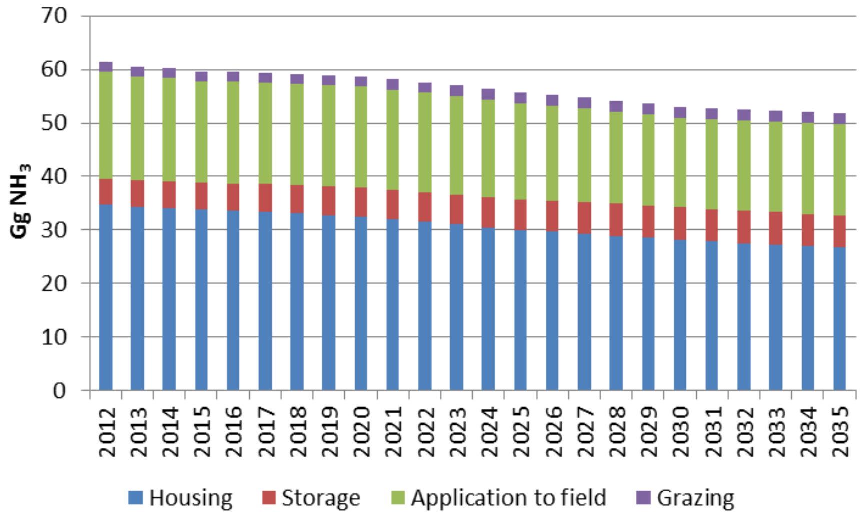


Figure 8.5 Projected NH_3 emission from manure management and grazing, 2012 to 2030.

The projected NH_3 emission from the livestock production 2012 - 2035 distributed on the main livestock categories are presented in Figure 8.6. The total emission from the livestock production is reduced by 9.59 Gg NH_3, the main part owing to reduction from the pig production. This can mainly be explained by a combination of a high emission reduction rate from NH_3 reducing technology and decreasing N-excretion.

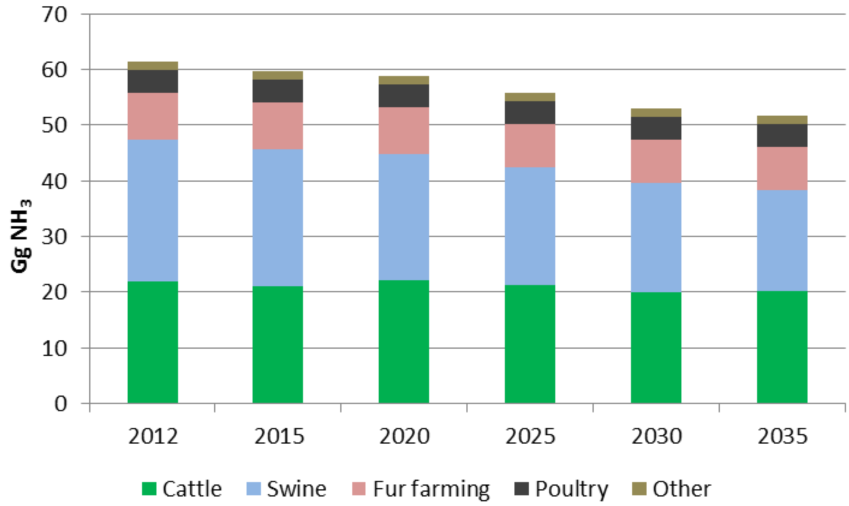


Figure 8.6 NH_3 emissions from manure management and grazing, 2012 to 2035.

8.4.2 PM emission

Emission of PM is mainly dependent on number of animals given in AAP (average annual production). Emissions from field burning of agricultural residue constitute less than 2 % of the emission of TSP. The projected emissions of PM are estimated to increase (Table 8.15) due to increase in the number of animals, mainly cattle and swine.

Table 8.15 Historic and projected total emission of TSP PM_{10} and $PM_{2.5}$, Gg.

	1990	2005	2010	2011	2012	2015	2020	2025	2030	2035
TSP	9.44	12.05	11.65	11.50	11.53	11.85	12.54	12.93	13.52	13.38
PM^{10}	4.83	6.16	5.95	5.89	5.89	6.05	6.37	6.55	6.81	6.75
$PM^{2.5}$	1.32	1.50	1.40	1.40	1.42	1.45	1.53	1.56	1.61	1.60

Around 80 % of the TSP emission originates from swine in 2011 and this trend is continued in the projected emissions, see Table 8.16. Cattle and poultry contribute with around 11 and 9 % of the emission of TSP, respectively.

Table 8.16 Historic and projected emission of TSP from animals allocated on animal category, tonnes.

	1990	2005	2010	2011	2012	2015	2020	2025	2030	2035
Dairy cattle	797	734	780	781	786	778	867	885	904	904
Non-dairy cattle	1 011	421	446	453	462	456	503	515	528	528
Swine	6 584	9 530	9 127	8 948	8 985	9 310	9 836	10 197	10 756	10 615
Poultry	832	1 020	1 044	1 069	1 012	1 027	1 052	1 052	1 052	1 052
Horses, sheep and goats	30	39	37	34	35	35	35	35	35	35
Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

8.4.3 NMVOC, SO_2 and NO_x emission

Table 8.17 shows emissions of NMVOC, SO_2 and NO_x. The projected emissions for these pollutants are estimated on the basis of the projected area of agricultural land.

Table 8.17 Historic and projected emission of NMVOC, SO_2 and NO_x from crops and field burning, tonnes.

	1990	2005	2010	2011	2012	2015	2020	2025	2030	2035
NMVOC[a+b]	2 103	2 099	2 160	2 150	2 173	2 151	2 114	2 096	2 078	2 059
SO_2[a]	10	16	11	11	13	13	13	13	13	13
NO_x[b]	77	127	89	88	102	102	102	102	102	102

[a] Field burning of agricultural residues.

[b] Crops.

8.5 Changes since previous projection

A range of changes have been made in this projection compared to the latest provided version, Nielsen et al, 2012. As shown in Figure 8.7 these changes have led to a projection with the same trend, decreasing NH_3 emission, but in a more protracted decrease. The projected emission in 2020 is higher compared with the previous projection, but in the years after 2020 is seen a significant decrease and the two projections are nearly at the same level in 2030. This projection estimates an emission of 61.5 Gg NH_3 in 2030, while previous projection has estimated the 59.7 Gg NH_3, which correspond to a 3 % difference.

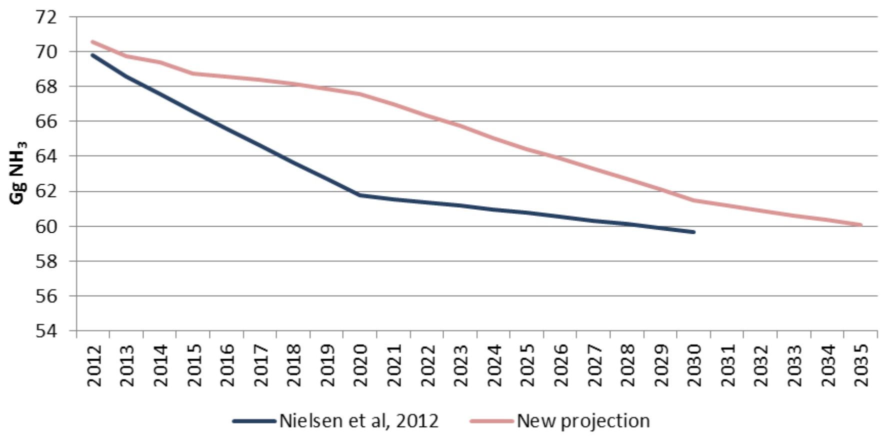


Figure 8.7 Projection of NH_3 emission given in Nielsen et al. (2012) and as a new projection.

8.5.1 Manure management

The major part of the NH_3 emission is related to the manure management and comparison between the new and previous projection for manure management shows the same trend as for the total NH_3 emission, higher emission in 2020 and same level in 2030, see Figure 8.8. The difference between the two projections is mainly due to change in number of animals and change of housings with establishment of NH_3 reducing technology.

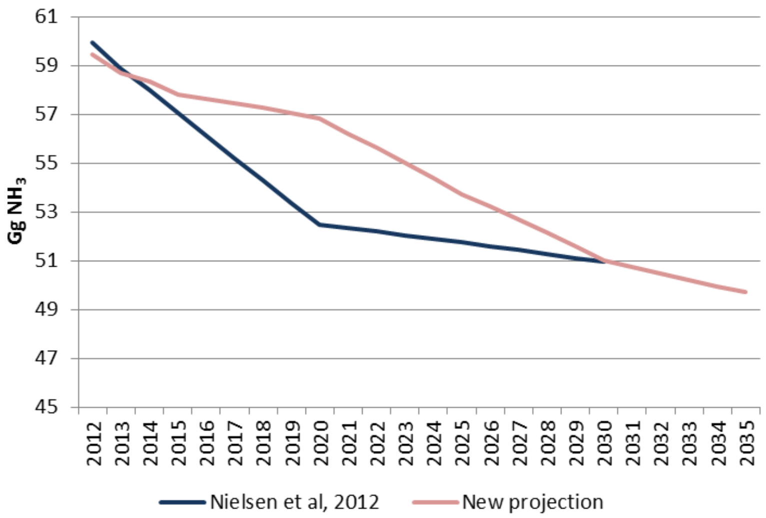
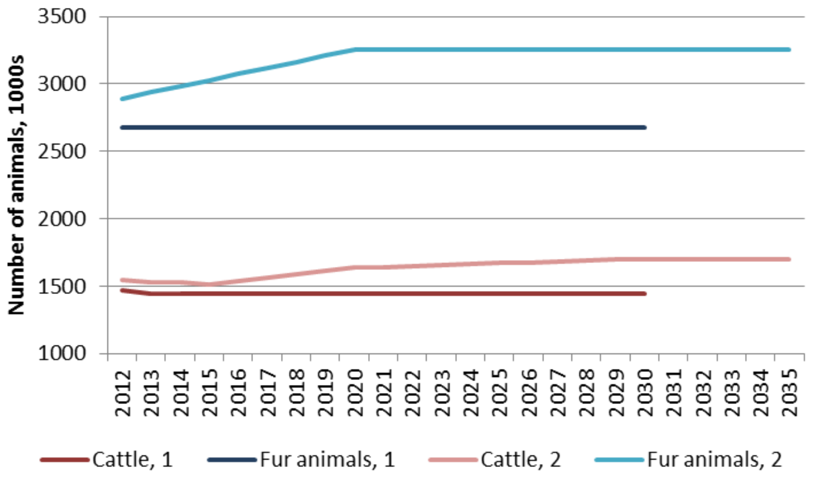


Figure 8.8 Projection of NH_3 emission from manure management given in Nielsen et al. (2012) and as a new projection.

8.5.2 Livestock production and ammonia reducing technology

New estimations for number of animals and expectations to establishment of NH_3 reducing technology in housings are based on information and assumptions from the agricultural sector (Tybirk, 2013; Aaes, 2013; Clausen, 2013; Bækgaard, 2013; Jensen, 2013). Compared to the previous projection, the agricultural sector has a more optimistic estimation of the number of animals, but a more pessimistic estimation for implementation of NH_3 reducing technic. Implementation of NH_3 reduction technology is driven by the environmental requirements to the expansion of livestock production and the construction of new housing. This requires capital, which is difficult to obtain due to the economic crises. It is expected that the economy will increase again and thereby the farmers will be able to implement NH_3 technology.

Number of animals has been changed for cattle, swine, poultry and fur animals, see Figure 8.9. For these categories the number of animals has increased compared to Nielsen et al. (2012). For the category Other (horses, sheep, goats and deer) number of animals are at the same level as in Nielsen et al. (2012).



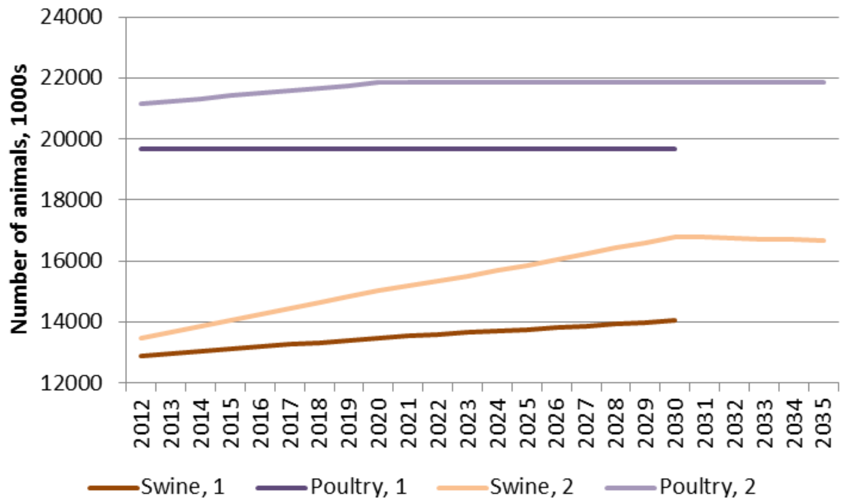


Figure 8.9 Projection of number of animals given in (1) Nielsen et al. (2012) and as a (2) new projection.

The increase of pig production compared with previous projection is due to a higher production level in 2011 and increase of production efficiency for sows. Thus the number of weaners increases with 0.5 weaners per sow in 2012-2025 and with 0.4 weaners per sow in 2025-2035 (Tybirk, 2013). The increase in productivity was in Nielsen et al. (2012) 0.3 piglet per sow for all years 2009-2030. This increase in productivity, affects the number of weaners and fattening pigs by increasing the number of animals, while the number of sows is almost unaltered in 2012 to 2035.

Table 8.18 Number of produced pigs, million.

Projected number of produced pigs	2011	2020	2030
Weaners, new	30.0	34.4	39.1
Weaners, previous	28.9	31.8	32.9
Fattening pigs, new	21.9	23.4	25.6
Fattening pigs, previous	20.2	19.8	20.9

Number of dairy cattle is estimated by Knowledge Centre for Agriculture, Department for Cattle (Clausen, 2013). From 2012 to 2015 is the production of milk regulated by milk quota an due to this the number of dairy cattle are almost unaltered compared to Nielsen et al. (2012). In Nielsen et al. (2012) the number of dairy cattle were estimated to stay at the same level after expiry of the milk quota, but Clausen (2013) estimates that the number of dairy cattle will increase from 2015 to 2030. The number of non-dairy cattle is based on development in the number of dairy cattle.

The increase in number of cattle increases the emission of NH_3 from pasture, range and paddock. Number of days on grass and EF for grazing is unaltered.

In Nielsen et al. (2012) the number of poultry and fur farming was unaltered, but estimations estimated by Danish Poultry Meat Association (Jensen, 2013) and DCA and Kopenhagen Fur (Møller, 2013; Bækgaard, 2013) show an increase in the number of animals. The increase for poultry is mainly due to expectation of increase in export of chicken meat and therefore increases in number of broilers. Increase in production of fur farming is due to expected increased demand for Danish fur, which is competitive in quality and price.

8.5.3 Synthetic fertiliser and the agricultural land

The projected NH_3 emission from synthetic fertiliser is compared to the previous projection (Nielsen et al., 2012), see Figure 8.10. This projection estimates a lower emission from synthetic fertiliser mainly due to an adjustment of the emission factor provided in the national emission inventory. New information from the Danish AgriFish Agency in 2011 regarding the distribution of fertiliser types result in a lower emission factor. The average emission factor has been changed from 1.93 % in Nielsen et al. (2012) to 1.55 % in this projection.

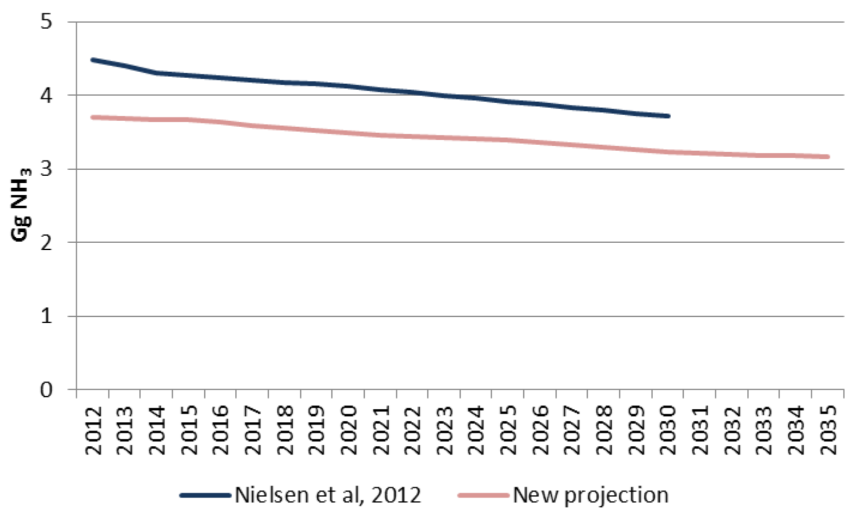


Figure 8.10 Projection of NH_3 emission from synthetic fertiliser given in Nielsen et al. (2012) and as a new projection.

Changes in amount of N in manure applied to soil and agricultural area also affect the difference in emission from synthetic fertiliser between the two projections, but for both with an opposite effect. The amount of N in manure applied to soil is lower in this projection mainly due to two things; lower N excretion from fattening pigs and less implemented NH_3 reducing technology, which prompt a lower content of N in the manure in stock.

Projection of the agricultural area has been estimated by newest knowledge and this indicates a larger area than estimated in Nielsen et al. (2012). Emissions from crops and field burning are based on agricultural area, thus a change in area prompt changes in emissions from these categorise.

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9 Waste and other

This chapter covers the 2012-2035 projection of NEC gases and particle emissions from waste handling. This includes 6.C Waste Incineration (without energy recovery) and 6.D Waste Other.

During the years 2012-2035, the waste categories are projected to emit 4-5 % of the national SO_2 emission and 1-2 % of the NH_3 and $PM_{2.5}$ emission. NMVOC, NOx, TSP and PM_{10} are all under 1 % of the national emission.

9.1 Methodology

The following sections deals with the methodology for every source category included in the waste sector.

9.1.1 Human cremation

The incineration of human corpses is a common practice that historically has been performed on an increasing part of the deceased. All Danish crematoria use optimised and controlled incinerations, with secondary combustion chambers, controlled combustion air flow, regulations for coffin materials and flue gas cleaning (bag filters with activated carbon).

9.1.2 Animal cremation

The incineration of animal carcasses in animal crematoria follows much the same procedure as human cremation. Animal crematoria use similar two chambered furnaces and controlled incineration. However, animal carcasses are incinerated in special designed plastic (PE) bags rather than coffins. Animal cremations are performed in two ways, individually where the owner often pays for receiving the ashes in an urn or collectively, which is most often the case with animal carcasses that are left at the veterinarian.

Open burning of animal carcasses is illegal in Denmark and is not occurring, and small-scale incinerators are not known to be used at Danish farms. Livestock that is diseased or in other ways unfit for consumption is disposed of through rendering plants. Incineration of livestock carcasses is illegal and these carcasses are therefore commonly used in the production of fat and soap at Daka Bio-industries.

The only animal carcasses that are approved for cremation in Denmark are deceased pets and animals used for experimental purposes, where the incineration must take place at a specialised animal crematorium.

9.1.3 Sludge spreading

Sludge from wastewater treatment plants is only spread out in the open with the purpose of fertilising crop fields. Emissions that derive from this activity are covered in Chapter 5 (NFR Sector 4).

9.1.4 Biogas production

Emissions from the combustion of biogas regardless of the origin are included in the energy sector and are allocated to the appropriate subsector in the Danish energy statistics.

9.1.5 Accidental building fires

Emissions from building fires are calculated by multiplying the number of building fires with selected emission factors. Six types of buildings are distinguished with different emission factors: detached houses, undetached houses, apartment buildings, industrial buildings, additional buildings and containers.

9.1.6 Accidental vehicle fires

Emissions from vehicle fires are calculated by multiplying the mass of vehicle fires with selected emission factors. Emission factors are not available for different vehicle types, whereas it is assumed that all the different vehicle types leads to similar emissions.

9.1.7 Compost production

Emissions from composting have been calculated according to a country specific Tier 1 method. In Denmark, composting of solid biological waste includes composting of:

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

Historically, composting is performed with simple technology in Denmark; this implies that temperature, moisture and aeration are not automatically controlled or regulated (Petersen & Hansen, 2003). There is at the present time nothing that indicates that this will change in the future.

9.1.8 Other combustion

Other combustion sources include open burning of yard waste and bonfires.

Due to the cold and wet climatic conditions in Denmark wild fires very seldom occur. Controlled field burnings are included in Chapter 8 Agriculture.

In Denmark, the open burning of private yard waste is under different restrictions according to the respective municipality. These restrictions involve what can be burned but also the quantity, and how, when and where, or in some cases a complete ban is imposed. The burning of yard waste is not allowed within urban areas (DEPA, 2011). There is no registration of private waste burning and the activity data on this subject are very difficult to estimate. Citizens are generally encouraged to compost their yard waste or to dispose of it through one of the many waste disposal/recycling sites.

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

Therefore, emissions from open burning of yard waste and bonfires have not been projected nor are they part of the historic emission inventory.

9.2 Activity data

The following sections deals with the activity data for every contributing source category in the waste sector.

9.2.1 Human cremation

It is assumed that no drastic changes will take place with regards to human cremation that will influence the emissions.

The projection of NEC gas and particle 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 9.1 for 1990-2011.

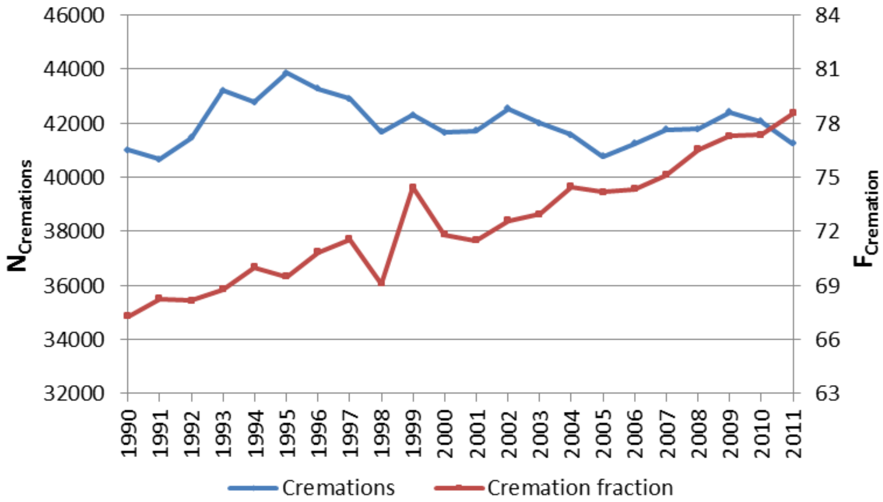

Figure 9.1 The historical development in the number of human cremations.

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 1990-2011 data. By comparing data for population with the number of deceased for the years 1901-2011, the fraction of deaths is found to be 1 %.

Table 9.1 Data on population, number of deaths and number on cremations.

	1990	2005	2010	2011	2012	2015	2020	2025	2030	2035
Population	5 135 409	5 411 405	5 534 738	5 560 628	5 580 516	5 640 666	5 725 171	5 820 464	5 919 881	6 002 435
Deaths	60 926	54 962	54 368	52 516	52 325	54 793	55 613	56 539	57 505	58 307
Cremation fraction	67,3 %	74,2 %	77,3 %	78,6 %	78,1 %	79,6 %	82,0 %	84,4 %	86,9 %	89,3 %
Cremations	40 991	40 758	42 050	41 248	40 861	43 590	45 602	47 742	49 961	52 082

9.2.1 Animal cremation

As can be seen in Figure 9.2, the historical development in the amount of cremated animal carcasses does not follow a clear trend. It is therefore also difficult to predict the future development. It is assumed that the 2012-2035 projection of activity data for animal cremation can be described by the constant average of the years 2008-2011.

Table 9.2 Amount of incinerated carcasses.

	2008	2009	2010	2011	Average
Cremated carcasses, Mg	1338.3	1338.9	1448.7	1218.6	1336.1

Figure 9.2 shows both historical and projected data for animal cremation.

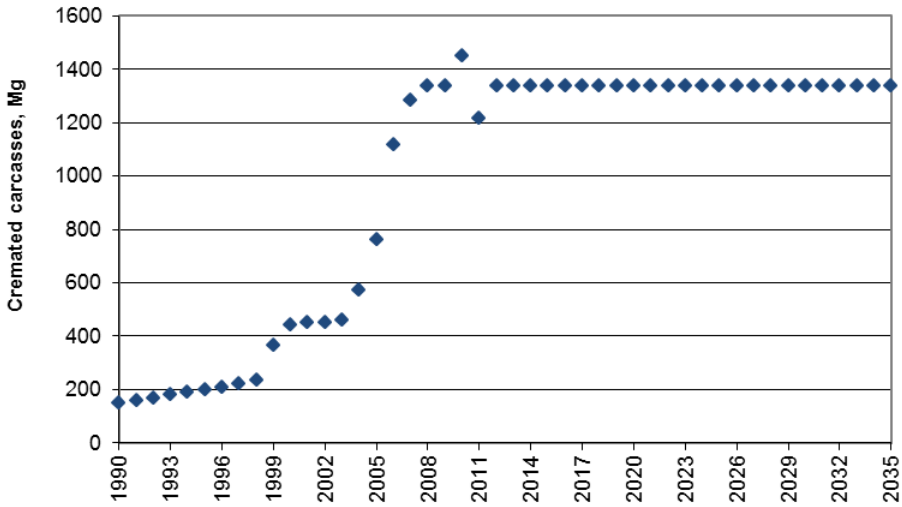

Figure 9.2 Cremated amount of carcasses, 1990-2035.

9.2.2 Accidental building fires

Activity data for building fires are classified in four categories: full, large, medium and small fires. 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 large, medium and a small scale fire makes up 75 %, 30 % and 5 % of a FSE respectively. Table 9.3 presents the average fractions of the different fires in 2007-2011.

Table 9.3 Average registered occurrence of building fires, 2007-2011, in per cent.

Size	Detached	Undetached	Apartment	Industry	Additional	Container	All building fires
Full, %	2.3	0.5	0.3	0.8	0.5	0.2	4.6
Large, %	4.0	1.1	1.1	1.7	2.7	2.0	12.6
Medium, %	5.2	2.2	6.0	2.8	5.2	17.8	39.1
Small, &	11.9	4.0	12.0	4.9	6.8	4.1	43.7
All, &	23.4	7.9	19.4	10.2	15.1	24.1	100.0

Calculations of emissions for 1990-2006 are based on surrogate data and on detailed information for 2007-2011 given by the Danish Emergency Management Agency (DEMA), but no such surrogate data are available for the projection. 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 2007-2011 data.

Table 9.4 Full Scale Equivalent (FSE) accidental building fires for 2007-2011.

	2007	2008	2009	2010	2011	Average
FSE container fires	958	962	799	594	729	808
FSE of detached house fires	757	886	876	833	818	834
FSE of undetached house fires	343	278	208	194	206	246
FSE of apartment building fires	405	433	413	348	362	392
FSE of industrial building fires	435	346	344	281	334	348
FSE additional buildings	282	523	466	429	740	488
All FSE building fires	3 179	3 428	3 106	2 678	3 189	3 116

Full scale equivalents (FSE) are calculated based on the assumption that a full, large, medium and a small scale fire makes up 100 %, 75 %, 30 % and 5 % of a FSE, respectively.

9.2.3 Accidental vehicle fires

The Danish Emergency Management Agency (DEMA) provides data for the total number of accidental vehicle fires 2007-2011 divided into the 14 categories; passenger cars, buses, light duty vehicles, heavy duty vehicles, motorcycles/mopeds, caravan, train, ship, airplane, bicycle, tractor, other transport and machine.

DTU Transport (Jensen, 2012) provides a projection of the national population of vehicles in the seven categories; passenger cars, buses, light duty vehicles, heavy duty vehicles, motorcycles/mopeds, tractors and combined harvesters.

Projections of the population of the remaining seven vehicle categories are handled in three different ways. Projections of the population of caravans and airplanes are calculated from a linear regression of the historical data (1990-2010) from Statistics Denmark (2013). The vehicle categories of train and ship are a calculated average of the populations in 2007-2011. And for the categories of bicycle, other transport and machines historical data was not sufficient enough to project, instead the average number of registered fires from 2007-2011 is used for 2012-2035; 3, 76 and 105, respectively.

Activity data for 2007-2011 for vehicle fires are classified in four categories: full, large, medium and small fires. The activity data is recalculated to full scale equivalent (FSE) fires. Here, as with building fires, it is assumed that a full, large, medium and a small scale fire makes up 100 %, 75 %, 30 % and 5 % of a FSE, respectively. By comparing the number of FSE vehicles fires with the population of vehicles in each category for 2007-2011, the following fractions are calculated.

Table 9.5 Average fraction of FSE vehicle fires in relation to total vehicle population, 2007-2011.

Category	Fraction, %
Passenger cars	0.03
Buses	0.13
Light duty vehicles	0.01
Heavy duty vehicles	0.13
Motorcycles/Mopeds	0.03
Caravan	0.03
Train	0.11
Ship	1.12
Airplane	0.06
Tractor	0.06
Combined harvester	0.15

The number of FSE accidental vehicle fires can now be calculated by multiplying the population data with the average fractions of FSE from Table 9.5.

It is assumed that no significant changes in the current average vehicle weight will occur within 2012-2035 and the activity data for vehicle fires is calculated from the projected number of FSE fires and the average vehicle weight, Table 9.6.

Table 9.6 Projection of activity data for accidental vehicle fires, Mg.

	Burnt mass of vehicles
1990	2 866
2005	2 883
2010	2 960
2011	2 526
2012	2 656
2015	2 584
2020	2 628
2025	2 706
2030	2 801
2035	2 847

9.2.4 Compost production

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

- Garden and park waste (GPW)
- Organic waste from households and other sources
- Sludge
- Home composting of garden and vegetable food waste.

The future activity of each category has been projected individually.

The three categories; garden and park waste, organic waste from households and other sources and sludge, are for the historical years 1995-2009 based on data from the Danish waste statistics (Affaldsstatistik 2009, and earlier years).

The projection of composting of garden and park waste is prepared from the linear regression of the 2002-2009 activity data. The activity of organic waste from households and other sources has been fairly constant over the last decade and is therefore projected as the constant value calculated from the average activity from 2002-2011. The historical data does not provide sufficient information for the projection of composting of sludge; this activity has therefore been estimated by an expert judgement.

Home composting of garden and vegetable food waste is for 1990-2011 determined based on data from Statistics Denmark and on Petersen & Kielland (2003). The 1990-2011 data is used in a linear regression to project home composting to 2012-2035.

Table 9.7 Projected activity data for compost production, Gg.

	1990	2005	2010	2011	2012	2015	2020	2025	2030	2035
Garden and park waste	288	737	877	901	929	1 004	1 130	1 256	1 383	1 509
Organic waste	16	45	58	59	55	55	55	55	55	55
Sludge	NO	50	120	132	135	150	175	200	225	250
Home composting	20	22	23	23	23	23	24	25	25	26
Total	324	854	1 078	1 114	1 142	1 233	1 385	1 536	1 688	1 840

9.3 Emission factors

The following sections deals with the emission factors for every contributing source category in the waste sector.

9.3.1 Human cremation

The projection of emissions from human cremation shown in Table 9.13 is calculated by multiplying the estimated activity data from Table 9.1 with the emission factors. Nielsen et al. (2013) provides the emission factors for SO_2, NO_x, NMVOC and particles. From 2011 new demands for emission limits have enquired the Danish crematoria to invest in flue gas cleaning equipment. The best suitable cleaning equipment for Danish crematoria is bag filters (Schleicher et al., 2008) and the emission factors for particles are therefore lowered by 99% for the years 2011-2035 according to standard bag filter efficiency (de Nevers, 2000) and conferential measurements performed at Danish crematoria.

Table 9.8 Emission factors for human cremation, g per body.

	1990-2011	2012-2035
SO_2	112.8	112.8
NO_x	825.0	825.0
NMVOC	13.0	13.0
TSP	38.6	0.39
PM_{10}	34.7	0.35
$PM_{2.5}$	30.8	0.31

9.3.2 Animal cremation

The projection of emissions from animal cremation shown in Table 9.13 is calculated by multiplying the estimated activity data from Table 9.2 with the emission factors known from the Nielsen et al. (2013).

Table 9.9 Emission factors for animal cremation, kg per Mg.

	Value
SO_2	0.84
NO_x	4.75
NMVOC	2.00
TSP	2.18
PM_{10}	1.53
$PM_{2.5}$	1.31

9.3.3 Accidental building fires

By assuming that building compositions and sizes will not significantly change from 2012-2035, the emission factors from Nielsen et al. (2013) are used for this projection.

Table 9.10 Emission factors for accidental building fires, kg per FSE fire.

	Detached houses	Undetached houses	Apartment buildings	Industrial buildings
SO_2	263.9	212.5	123.65	802.92
NO_x	19.7	15.9	8.04	45.00
NMVOC	98.6	79.4	40.18	225.00
NH_3	NAV	NAV	NAV	NAV
TSP	143.8	61.6	43.78	27.23
PM_{10}	143.8	61.6	43.78	27.23
$PM_{2.5}$	143.8	61.6	43.78	27.23

Emissions from accidental building fires in 2012-2035 are shown in Table 9.13.

9.3.4 Accidental vehicle fires

By assuming that vehicle compositions will not significantly change from 2012-2035, the emission factors known from Nielsen et al. (2013) are used for this projection.

Table 9.11 Emission factors for accidental vehicle fires, kg per Mg.

	Value
SO_2	5
NO_x	2
NMVOC	8.5
NH_3	NAV
TSP	2.1
PM_{10}	2.1
$PM_{2.5}$	2.1

Calculated emissions are shown in Table 9.13.

9.3.5 Compost production

By assuming that the process of compost production will not significantly change over the next two decades, the emission factors known from Nielsen et al. (2013) are used for this projection.

Table 9.12 Emission factors for compost production.

		Garden and Park waste	Organic waste	Sludge	Home composting
NH_3	Mg per Gg	0.66	0.31	0.02	0.63

Calculated emissions are shown in Table 9.13.

9.4 Emissions

The projection of the waste source category includes emissions from cremation of human bodies, cremation of animal carcasses, accidental building fires, accidental vehicle fires and composting.

Incineration of municipal, industrial, clinical and hazardous waste takes place with energy recovery, therefore the emissions are included in the relevant subsectors under NFR sector 1A. For documentation please refer to Chapter 3. Flaring off-shore and in refineries are included under NFR sector 1B2c, for documentation please refer to Chapter 5. No flaring in chemical industry occurs in Denmark.

Table 9.13 gives an overview of the projections of the national emissions from the waste source category.

Table 9.13 Projection of the overall emissions of NEC gases and particles from the waste sector.

		Unit	1990	2005	2010	2011	2012	2015	2020	2025	2030	2035
SO_2 emission from	Human cremation	Mg	4.6	4.6	4.7	4.7	4.6	4.9	5.1	5.4	5.6	5.9
	Animal cremation	Mg	0.3	1.3	2.5	2.1	2.3	2.3	2.3	2.3	2.3	2.3
	Building fires	Mg	559.3	552.4	543.0	598.2	618.1	618.1	618.1	618.1	618.1	618.1
	Vehicle fires	Mg	14.3	14.4	14.8	12.6	13.3	12.9	13.1	13.5	14.0	14.2
	Total	Mg	578.5	572.7	565.0	617.6	638.3	638.3	638.7	639.4	640.1	640.5
NO_x emission from	Human cremation	Mg	33.8	33.6	34.7	34.0	33.7	36.0	37.6	39.4	41.2	43.0
	Animal cremation	Mg	1.9	9.7	18.4	15.5	17.0	17.0	17.0	17.0	17.0	17.0
	Building fires	Mg	31.8	31.5	31.5	33.7	35.2	35.2	35.2	35.2	35.2	35.2
	Vehicle fires	Mg	5.7	5.8	5.9	5.1	5.3	5.2	5.3	5.4	5.6	5.7
	Total	Mg	73.2	80.6	90.5	88.2	91.2	93.3	95.1	97.0	99.0	100.9
NMVOC emission from	Human cremation	Mg	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.7
	Animal cremation	Mg	0.3	1.5	2.9	2.4	2.7	2.7	2.7	2.7	2.7	2.7
	Building fires	Mg	148.0	147.2	149.1	158.0	164.6	164.6	164.6	164.6	164.6	164.6
	Vehicle fires	Mg	24.4	24.5	25.2	21.5	22.6	22.0	22.3	23.0	23.8	24.2
	Total	Mg	173.2	173.7	177.7	182.4	190.4	189.8	190.2	190.9	191.8	192.2
NH_3 emission from	Animal cremation	Mg	0.3	1.4	2.8	2.3	2.5	2.5	2.5	2.5	2.5	2.5
	Compost production	Mg	207.7	515.5	614.2	630.6	647.6	698.1	782.3	866.5	950.8	1035.0
	Total	Mg	208.0	517.0	616.9	632.9	650.1	700.6	784.9	869.1	953.3	1037.5
TSP emission from	Human cremation	Mg	1.6	1.6	1.6	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	Animal cremation	Mg	0.3	1.7	3.2	2.7	2.9	2.9	2.9	2.9	2.9	2.9
	Building fires	Mg	168.6	163.9	168.8	173.0	181.0	181.0	181.0	181.0	181.0	181.0
	Vehicle fires	Mg	5.9	5.9	6.1	5.2	5.4	5.3	5.4	5.5	5.7	5.8
	Total	Mg	176.4	173.0	179.6	180.9	189.4	189.2	189.3	189.5	189.7	189.8
PM_{10} emission from	Human cremation	Mg	1.4	1.4	1.5	0.01	0.01	0.02	0.02	0.02	0.02	0.02
	Animal cremation	Mg	0.2	1.2	2.2	1.9	2.0	2.0	2.0	2.0	2.0	2.0
	Building fires	Mg	168.6	163.9	168.8	173.0	181.0	181.0	181.0	181.0	181.0	181.0
	Vehicle fires	Mg	5.9	5.9	6.1	5.2	5.4	5.3	5.4	5.5	5.7	5.8
	Total	Mg	176.1	172.4	178.5	180.1	188.5	188.4	188.4	188.6	188.8	188.9
$PM_{2.5}$ emission from	Human cremation	Mg	1.4	1.4	1.5	0.01	0.01	0.01	0.01	0.01	0.02	0.02
	Animal cremation	Mg	0.2	1.0	1.9	1.6	1.8	1.8	1.8	1.8	1.8	1.8
	Building fires	Mg	168.6	163.9	168.8	173.0	181.0	181.0	181.0	181.0	181.0	181.0
	Vehicle fires	Mg	5.9	5.9	6.1	5.2	5.4	5.3	5.4	5.5	5.7	5.8
	Total	Mg	176.1	172.2	178.2	179.8	188.2	188.1	188.1	188.3	188.5	188.6

9.5 Changes since previous projection

The following sections deals with the recalculations performed for every contributing source category in the waste sector.

9.5.1 Human cremation

The number of human bodies expected to undergo cremation has decreased in this projection compared with the last projection of NEC pollutants; Nielsen et al. (2012). This decrease is based on the projection of population provided by Statistics Denmark (2013). The decrease spans from a total of 540 cremations (1 %) in 2030 to 2467 (6 %) in 2012.

Furthermore the emission factors have been updated since last submission, causing increases in the SO_2 and NO_x emissions of 107 % and 167 % respectively and a decrease in TSP, PM_{10} and $PM_{2.5}$ emissions of 11 %, 11 % and 21 % respectively.

The joint effects of these recalculations are displayed in Table 9.14.

Table 9.14 Recalculations for human cremation.

		2012	2015	2020	2025	2030
2011 submission	SO_2, Mg	2.36	2.42	2.53	2.64	2.75
	NO_x, Mg	13.37	13.72	14.32	14.95	15.58
	NMVOC, Mg	0.56	0.58	0.60	0.63	0.66
	TSP, kg	18.85	19.35	20.19	21.08	21.97
	PM_{10}, kg	16.97	17.41	18.17	18.97	19.78
	$PM_{2.5}$, kg	16.97	17.41	18.17	18.97	19.78
2013 submission	SO_2, Mg	4.61	4.91	5.14	5.38	5.63
	NO_x, Mg	33.71	35.96	37.62	39.39	41.22
	NMVOC, Mg	0.53	0.57	0.59	0.62	0.65
	TSP, kg	15.77	16.83	17.60	18.43	19.29
	PM_{10}, kg	14.18	15.13	15.82	16.57	17.34
	$PM_{2.5}$, kg	12.60	13.45	14.07	14.73	15.41
Difference	SO_2, Mg	2.2	2.5	2.6	2.7	2.9
		95 %	103 %	104 %	104 %	105 %
	NO_x, Mg	20.3	22.2	23.3	24.4	25.6
		152 %	162 %	163 %	163 %	165 %
	NMVOC, Mg	-0.03	-0.01	-0.01	-0.01	-0.01
		-6 %	-2 %	-2 %	-1 %	-1 %
	TSP, kg	-3.1	-2.5	-2.6	-2.7	-2.7
		-16 %	-13 %	-13 %	-13 %	-12 %
	PM_{10}, kg	-2.8	-2.3	-2.3	-2.4	-2.4
		-16 %	-13 %	-13 %	-13 %	-12 %
	$PM_{2.5}$, kg	-4.4	-4.0	-4.1	-4.2	-4.4
		-26 %	-23 %	-23 %	-22 %	-22 %

9.5.2 Animal cremation

Two new datasets are available for this submission; years 2010 and 2011. Since activity data for animal cremation is calculated as an average of the previous four data years, the activity data has changed since last projection; in this case an increase of 16 Mg corresponding to 1.2 %.

Emission factors for SO_2 and NO_x are really emission factors for human cremation, since these have been updated since last projection, so has the ones for animal cremation. The effect of this update is an increase in emissions in SO_2 and NO_x emissions of 107 % and 167 % respectively.

The joint effects of these recalculations are displayed in Table 9.15, only a few chosen years are displayed since the recalculations are constant for all years.

Table 9.15 Recalculations for animal cremation.

		2012	2015	2020	2025	2030
2011 submission	SO_2, Mg	1.1	1.1	1.1	1.1	1.1
	NO_x, Mg	6.3	6.3	6.3	6.3	6.3
	NMVOC, Mg	2.6	2.6	2.6	2.6	2.6
	NH_3, Mg	2.5	2.5	2.5	2.5	2.5
	TSP, Mg	2.9	2.9	2.9	2.9	2.9
	PM_{10}, Mg	2.0	2.0	2.0	2.0	2.0
	$PM_{2.5}$, Mg	1.7	1.7	1.7	1.7	1.7
2013 submission	SO_2, Mg	2.3	2.3	2.3	2.3	2.3
	NO_x, Mg	17.0	17.0	17.0	17.0	17.0
	NMVOC, Mg	2.7	2.7	2.7	2.7	2.7
	NH_3, Mg	2.5	2.5	2.5	2.5	2.5
	TSP, Mg	2.9	2.9	2.9	2.9	2.9
	PM_{10}, Mg	2.0	2.0	2.0	2.0	2.0
	$PM_{2.5}$, Mg	1.8	1.8	1.8	1.8	1.8
Difference	SO_2, Mg	1.21 110 %	1.21 110 %	1.21 110 %	1.21 110 %	1.21 110 %
	NO_x, Mg	10.69 171 %	10.69 171 %	10.69 171 %	10.69 171 %	10.69 171 %
	NMVOC, Mg	0.03 1 %	0.03 1 %	0.03 1 %	0.03 1 %	0.03 1 %
	NH_3, Mg	0.03 1 %	0.03 1 %	0.03 1 %	0.03 1 %	0.03 1 %
	TSP, Mg	0.03 1 %	0.03 1 %	0.03 1 %	0.03 1 %	0.03 1 %
	PM_{10}, Mg	0.02 1 %	0.02 1 %	0.02 1 %	0.02 1 %	0.02 1 %
	$PM_{2.5}$, Mg	0.02 1 %	0.02 1 %	0.02 1 %	0.02 1 %	0.02 1 %

9.5.1 Accidental building fires

It is difficult to compare the activity data for building fires from this report with those of the previous report because of substantial methodological changes. The last projection only contained four building types and three sizes (large, medium and small scale fires), but this year all fires for historical years have been reclassified in six building types and four sizes causing the projected activity data to change quite substantially. Detached house- undetached house-, apartment building- and industrial building fires have decreased with between 33 – 52 % while container- and additional building fires are new categories.

Emission factors have also been significantly updated since the last projection. SO_2, NO_x and NMVOC emission factors have gone 2 % up for detached house fires, 0.4 % down for undetached house fires, 16 % up for apartment building fires (however only 1 % for SO_2) and 47 % down for industrial building fires (however no change for SO_2). The emission factors used for calculating emissions of particles (TSP, PM_{10} and $PM_{2.5}$) have for all four building categories been increased with a factor 1000 due to a previously undetected error in the source.

The joint effects of these recalculations are displayed in Table 9.16, only a few chosen years are displayed since the recalculations are constant for all years.

Table 9.16 Recalculations for accidental building fires.

Mg		2012	2015	2020	2025	2030
2011 submission	SO_2, Mg	929.3	929.3	929.3	929.3	929.3
	NO_x, Mg	62.4	62.4	62.4	62.4	62.4
	NMVOC, Mg	312.2	312.2	312.2	312.2	312.2
	TSP, Mg	0.3	0.3	0.3	0.3	0.3
	PM_{10}, Mg	0.3	0.3	0.3	0.3	0.3
	$PM_{2.5}$, Mg	0.3	0.3	0.3	0.3	0.3
2013 submission	SO_2, Mg	618.1	618.1	618.1	618.1	618.1
	NO_x, Mg	35.2	35.2	35.2	35.2	35.2
	NMVOC, Mg	164.6	164.6	164.6	164.6	164.6
	TSP, Mg	181.0	181.0	181.0	181.0	181.0
	PM_{10}, Mg	181.0	181.0	181.0	181.0	181.0
	$PM_{2.5}$, Mg	181.0	181.0	181.0	181.0	181.0
Difference	SO_2, Mg	-311.2 -33 %	-311.2 -33 %	-311.2 -33 %	-311.2 -33 %	-311.2 -33 %
	NO_x, Mg	-27.2 -44 %	-27.2 -44 %	-27.2 -44 %	-27.2 -44 %	-27.2 -44 %
	NMVOC, Mg	-147.5 -47 %	-147.5 -47 %	-147.5 -47 %	-147.5 -47 %	-147.5 -47 %
	TSP, Mg	180.7 59066 %	180.7 59066 %	180.7 59066 %	180.7 59066 %	180.7 59066 %
	PM_{10}, Mg	180.7 59066 %	180.7 59066 %	180.7 59066 %	180.7 59066 %	180.7 59066 %
	$PM_{2.5}$, Mg	180.7 59066 %	180.7 59066 %	180.7 59066 %	180.7 59066 %	180.7 59066 %

9.5.1 Accidental vehicle fires

As with accidental building fires, it is difficult to compare activity data for vehicle fires from this report with those of the previous report because of substantial methodological changes. The last projection only contained five vehicle types and assumed a burn rate of 70 % for all fires, but this year, all fires for historical years have been reclassified in 14 vehicle types and four sizes (full, large, medium and small scale fires). Furthermore the last projection was a simple linear regression of the total amount of historically burnt mass of vehicle, but this year all vehicle types have been projected individually. This causes the projected activity data to change quite substantially. There are no changes in the emission factors. The recalculations are shown in Table 9.17.

Table 9.17 Recalculations for accidental vehicle fires.

		2012	2015	2020	2025	2030
2011 submission	SO_2, Mg	21.5	22.4	23.9	25.5	27.0
	NO_x, Mg	8.6	9.0	9.6	10.2	10.8
	NMVOC, Mg	36.5	38.0	40.7	43.3	45.9
	TSP, kg	8.8	9.2	9.8	10.4	11.1
	PM_{10}, kg	8.8	9.2	9.8	10.4	11.1
	$PM_{2.5}$, kg	8.8	9.2	9.8	10.4	11.1
2013 submission	SO_2, Mg	13.3	12.9	13.1	13.5	14.0
	NO_x, Mg	5.3	5.2	5.3	5.4	5.6
	NMVOC, Mg	22.6	22.0	22.3	23.0	23.8
	TSP, kg	5.4	5.3	5.4	5.5	5.7
	PM_{10}, kg	5.4	5.3	5.4	5.5	5.7
	$PM_{2.5}$, kg	5.4	5.3	5.4	5.5	5.7
Difference	SO_2, Mg	-8.2 -38 %	-9.5 -42 %	-10.8 -45 %	-11.9 -47 %	-13.0 -48 %
	NO_x, Mg	-3.3 -38 %	-3.8 -42 %	-4.3 -45 %	-4.8 -47 %	-5.2 -48 %
	NMVOC, Mg	-13.9 -38 %	-16.1 -42 %	-18.3 -45 %	-20.3 -47 %	-22.1 -48 %
	TSP, kg	-3.4 -38 %	-3.9 -42 %	-4.4 -45 %	-4.9 -47 %	-5.3 -48 %
	PM_{10}, kg	-3.4 -38 %	-3.9 -42 %	-4.4 -45 %	-4.9 -47 %	-5.3 -48 %
	$PM_{2.5}$, kg	-3.4 -38 %	-3.9 -42 %	-4.4 -45 %	-4.9 -47 %	-5.3 -48 %

9.5.2 Compost production

Activity data for composting is projected and therefore also recalculated individually for the four waste types.

For garden and park waste, this year's projection include wood chipping which together with the new available dataset for 2009 has caused the activity data to increase with between 75.1 Mg (9 %) in 2012 and 195.4 Mg (16 %) in 2030.

For organic waste from households and other sources the projected activity data is a calculated average of the 2002-2009 data, where last projection it was the average of 1995-2008, this has caused an increase of 6.5 Mg (13 %) for all years of the projection.

For sludge, the new dataset for 2009 has proven to be higher than anticipated. The trend of the projected data is unchanged but the starting point is higher causing an increase in activity data of 25 Mg for all years (between 13 % in 2030 and 23 % in 2012).

For home composting, the extra historical data years of 2011-2012 has only resulted in minor recalculations; a decrease of between 0.1 Mg (-0.5 %) in 2012 and 0.3 Mg (-1.3 %) in 2030.

The overall recalculation in activity data for composting is an increase of between 106 Mg (10 %) in 2012 and 227 Mg (16 %) in 2030.

There are no changes in the emission factors from last projection. The joint effects of the recalculations on the emissions are displayed in Table 9.18.

Table 9.18 Recalculations for composting.

		2012	2015	2020	2025	2030
2011 submission	NH_3, Mg	595.5	595.5	595.5	595.5	595.5
2013 submission	NH_3, Mg	647.6	698.1	782.3	866.5	950.8
Difference	NH_3, Mg	52.1 9 %	102.6 17 %	186.8 31 %	271.0 46 %	355.2 60 %

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10 Uncertainty

In a projection the activity data are naturally associated with some uncertainty. To the extent possible, this projection has been based on official projections, e.g. the fuel consumption projection made by the Danish Energy Agency.

Generally, the most uncertain pollutant is particulate matter. There are still several sources of PM that is not included in the emission inventory and therefore also not part of the projection, e.g. PM emissions from agricultural field operations, quarrying, construction and demolition.

For the other pollutants the largest uncertainty relates to NMVOC, due to the wide variety of sources and the larger uncertainties associated with e.g. solvent use. NMVOC emissions from animal husbandry and manure management are currently not included in the emission inventory and hence neither in the projection. Information suggests that this source is very significant and the inclusion would significantly impact the total emissions both in the inventory and in the projection.

There are also uncertainties involved with the future EFs for road transport as history has shown that the EFs in real life do not always meet the expectations based on the legislative emission limit values.

Other uncertainties include emission factors for biomass fired plants, which are not subject to continuous monitoring. The projected increased use of biomass underlines the importance of establishing better emission factors for these installations.

10.1 Examples of sensitivity analysis

The four examples chosen below are just a small selection of the possible scenarios that can be envisaged. Many scenarios will have effects on a cross-sectoral level and hence it is difficult to quantify the impacts without a thorough analysis.

10.1.1 One PJ more biomass in residential combustion

Residential wood combustion is the main source of PM emissions in Denmark. Hence a small change in the wood consumption can result in significant emission changes. Residential wood combustion is also an important source of NMVOC and to a lesser extent NO_x. Table 10.1 shows the impact of an increase in fuel wood consumption of one PJ for selected years. The increase of one PJ equates to an increase of 4-4.5 % through the time series.

Table 10.1 Increase in emissions resulting from one PJ extra wood in residential plants.

Tonnes	2015	2020	2025	2030	2035
NO_x	84	87	89	90	92
NMVOC	337	286	241	196	150
$PM_{2.5}$	476	414	364	314	264

Due to the technological development, the emission increase for NMVOC and $PM_{2.5}$ is most pronounced in the early years of the projection and the effect lessens as more modern stoves and boilers are phased in. More information on the assumptions to project emissions from residential wood combustion is provided in Chapter 3.3.6.

10.1.2 Stable development in fuel consumption in manufacturing industries

In the official energy projection a significant decrease in the fuel consumption for manufacturing industries is envisaged. This means that the projected fuel consumption does not cover the fuel consumption for a steady trend in production at Aalborg Portland. Aalborg Portland is a large emission source for NOx and to test the sensitivity a calculation has been made where the fuel consumption by Aalborg Portland has been kept constant at the 2011 level. The result is shown in Table 10.2.

Table 10.2 Increase in emissions resulting from stable fuel consumption by Aalborg Portland.

Tonnes	2015	2020	2025	2030	2035
NO_x	74	182	264	356	431

10.1.3 Ten per cent decrease in the number of cattle

In this projection the number of cattle has been increased compared to the previous projection based on information received from the agriculture, see Chapter 8.2 for more information.

The total NH_3 emission is very dependent on the development in animal numbers of the main animal types. Hence, a change in the trend of the number of animals would have a significant impact on the NH_3 emission. Table 10.3 shows the emission reduction, if the number of cattle in a given year is 10 % lower than expected in this projection.

Table 10.3 Decrease in emissions resulting from 10 % fewer cattle.

Tonnes	2015	2020	2025	2030	2035
NH_3	2 291	2 440	2 395	2 290	2 338

As seen in Table 10.3 the emission decreases significantly when reducing the number of cattle. In 2020 the decrease corresponds to approximately 3.5 % of the projected national emission.

10.1.4 Ten per cent decrease in the number of swine

In this projection the number of swine has been increased compared to the previous projection based on information received from the agriculture, see Chapter 8.2 for more information.

The total NH_3 emission is very dependent on the development in animal numbers of the main animal types. Hence, a change in the trend of the number of animals would have a significant impact on the NH_3 emission. Table 10.4 shows the emission reduction, if the number of swine in a given year is 10 % lower than expected in this projection.

Table 10.4 Decrease in emissions resulting from 10 % fewer swine.

Tonnes	2015	2020	2025	2030	2035
NH_3	1 787	1 667	1 558	1 467	1 322

As seen in Table 10.4 the emission decreases significantly when reducing the number of swine. In 2020 the decrease corresponds to approximately 2.4 % of the projected national emission.

11 Conclusion

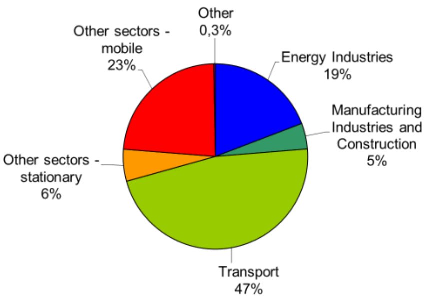
The chapters below contain a discussion on the emission projection of the seven pollutants considered. The category "other sectors stationary" mentioned is comprised of stationary plants in agriculture/forestry/aquaculture, residential & commercial/institutional sectors and the category "other sectors mobile" is comprised of machinery in household/gardening & agriculture/forestry/-fishing.

Historic and projected emissions are available in Appendix 1-7.

11.1 NO_x

Historical and projected emissions of NO_x are shown in Figure 11.1 and Figure 11.2. The total NO_x emission shows a decrease over the time-series 1990 to 2035. The most pronounced decrease occur in the historical years, and only a slight decrease is expected from 2025-2035. The main reasons are decreasing emissions from road transport due to increasing use of catalyst cars, and decreasing emissions from the energy industry sector due to decreasing coal consumption and installation of low-NOx burners and denitrifying units in power plants and district heating plants. The decreasing emissions from the energy industry sector is most pronounced in the early years, while the decreasing emissions from the transport sector continue for the whole time-series, due to stricter EU norms. As noted in Chapter 4, the legislation does not always result in the expected reductions when real-life measurements exceeds the limit values achieved during the vehicle testing and approval.

The major sources in 2035 are energy industries, transport (mainly road transport) and other mobile sources. The sectors account for 37 %, 34 % and 13 % of the total projected NO_x emission in 2035, respectively. Corresponding shares for the year 2011 and 2020 is shown in Figure 11.1.



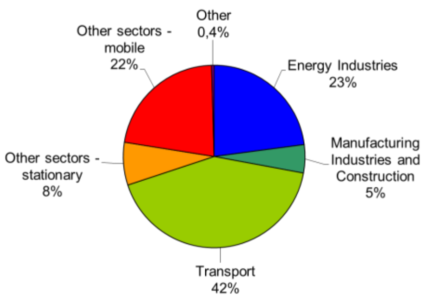


Figure 11.1 Historic and projected NOx emissions. Distribution by main sectors in 2011 (left) and 2020 (right).

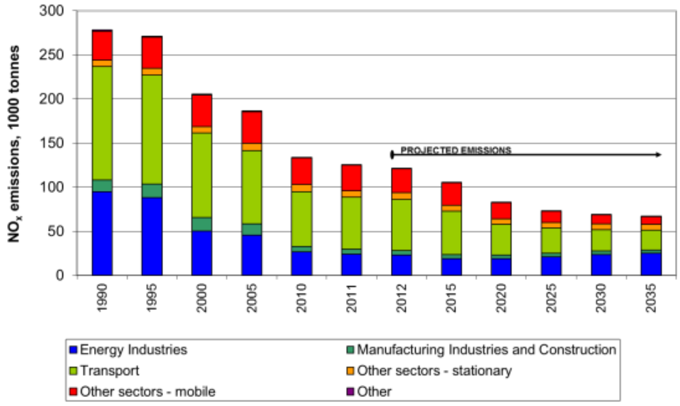


Figure 11.2 Historic and projected NO_x emissions. Time-series for selected years in the period 1990 to 2035.

11.2 SO_2

Historical and projected emissions of SO_2 are shown in Figure 11.3 and Figure 11.4. The total SO_2 emission shows a decrease over the time-series 1990 to 2035. By far the largest decrease is seen for the years 1990 to 2000, where the total SO_2 emission decreased by 83 %. The energy industry sector accounted for the major part of this decrease (90 %) due to installation of desulphurisation plant and use of fuels with lower content of sulphur in public power and district heating plants. For the years 2011 to 2035 the emissions only show minor changes.

The projected emission in 2035 is at the same level as the emission in the latest historical year 2011. The major sources in 2035 are energy industries, other sectors stationary and industrial processes. These sectors account for 36 %, 18 % and 10 % of the total projected SO_2 emission in 2035, respectively. Corresponding shares for the year 2011 and 2020 is shown in Figure 11.3.

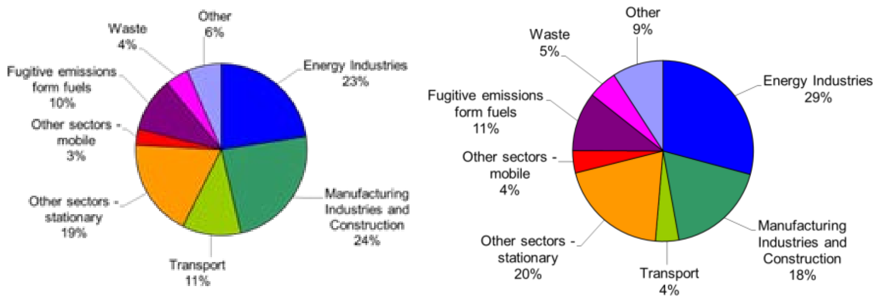


Figure 11.3 Historic and projected SO_2 emissions. Distribution by main sectors in 2011 (left) and 2020 (right).

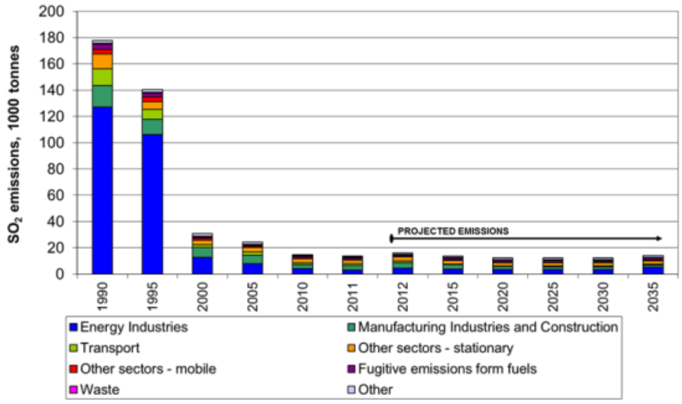


Figure 11.4 Historic and projected SO_2 emissions. Time-series for selected years in the period 1990 to 2035.

11.3 NMVOC

Historical and projected emissions of NMVOC are shown in Figure 11.5 and Figure 11.6. The total NMVOC emission shows a decrease over the time-series 1990 to 2035, (61 %) with the major part of the decrease in the years 1996 to 2011 (51 %). The decrease from 1996 to 2011 mainly owe to decreasing emissions from the transport sector (81 %), but also the sectors 'solvents and other product use' and 'fugitive emissions from fuels' contribute to the decreasing trend (45 % and 35 %, respectively). The projected emissions show a slight decrease in the first part of the projection period, and following a steady state for the last ten projection years. The major reason for the decreasing trend for transport in the historical years is the introduction of catalyst cars in 1990.

The major source to the projected emission in 2035 is the solvent and other product use sector contributing 36 %. Industrial processes contribute 13 %, and transport, fugitive emissions from fuels and other mobile sources each contribute 12 % to the total projected NMVOC emission in 2035. Corresponding shares for the year 2011 and 2020 is shown in Figure 11.5.

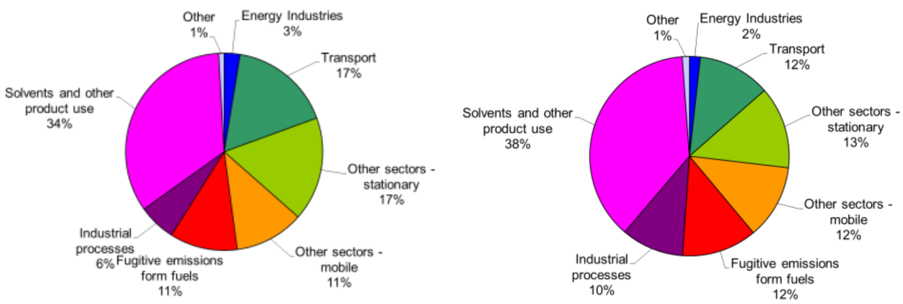


Figure 11.5 Historic and projected NMVOC emissions. Distribution by main sectors in 2011 (left) and 2020 (right).

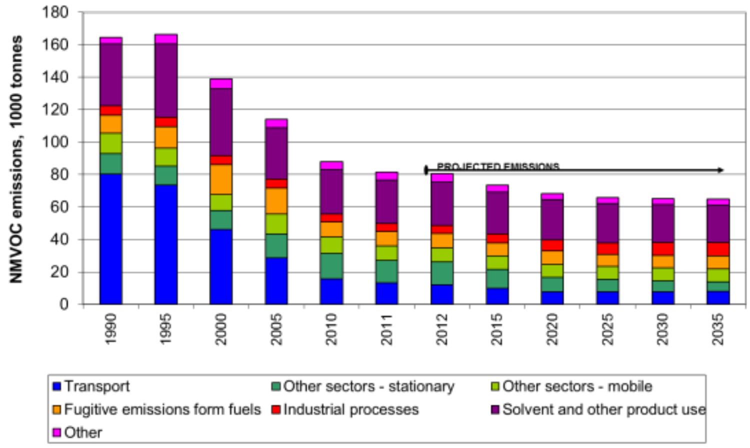


Figure 11.6 Historic and projected NMVOC emissions. Time-series for selected years in the period 1990 to 2035.

11.4 NH_3

Historical and projected emissions of NH_3 are shown in Figure 11.4. The total NH_3 emission shows a decrease over the time-series 1990 to 2035, (44 %) witht the major part of the decrease in the years 1990 to 2009 (35 %). Agriculture is by far the major sector contributing to NH_3 emissions, and manure management is the major agricultural source. Emissions from manure management decrease by 43 % from 1990 to 2035, and by 31 % from 1990 to 2009.

In 2035 manure management and the remaining agricultural sources are still the major sources, contributing 78 % and 16 % to the total projected NH_3 emission, respectively. Corresponding shares for the year 2011 and 2020 is shown in Figure 11.7.

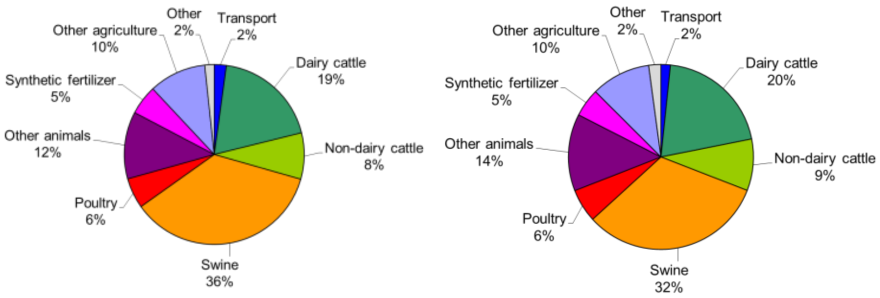


Figure 11.7 Historic and projected NH_3 emissions. Distribution by main sectors in 2011 (left) and 2020 (right).

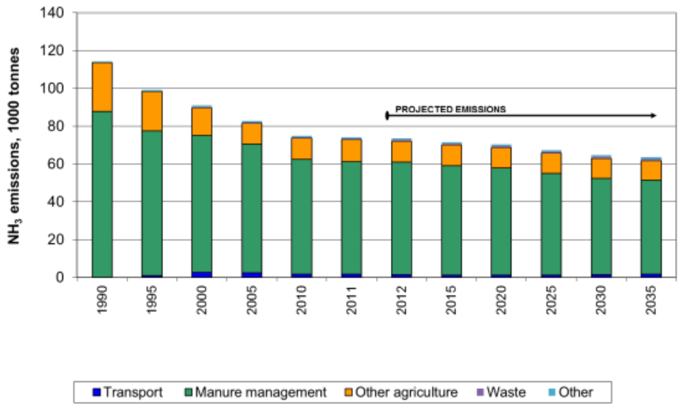


Figure 11.8 Historic and projected NH_3 emissions. Time-series for selected years in the period 1990 to 2035.

11.5 PM

Historical and projected emissions of particulate matter (PM) are shown in Figure 11.5, 11.6 and 11.7. The total PM emission shows a decrease over the time-series 2000 to 2035 (TSP: 21 %, PM_{10}: 30 %, $PM_{2.5}$: 41 %). From year 2000 to 2007 the total PM emission increases (*TSP: 21 %, PM_{10}: 30 %, $PM_{2.5}$: 41 %*), mainly due to increasing emissions in other sectors – stationary because of increasing wood consumption in the residential sector. In the following period from 2007-2035, the total PM emission decreases (*TSP: 37 %, PM_{10}: 45 %, $PM_{2.5}$: 56 %*). This mainly owes to replacement of older installation with new and more efficient installations, and to a less degree to a decreasing wood consumption in residential plants from 2007 and onwards.

The major sources to PM emissions in the latest historical year 2011 are other sectors – stationary (*TSP: 46 %, PM_{10}: 56 %, $PM_{2.5}$: 70 %*), agriculture (*TSP: 31 %, PM_{10}: 20 %, $PM_{2.5}$: 6 %*) and transport (*TSP: 12 %, PM_{10}: 12 %, $PM_{2.5}$: 12 %*). The major sources to projected PM emission in 2035 are the agricultural sector (*TSP: 46 %, PM_{10}: 33 %, $PM_{2.5}$:12 %*), other sectors – stationary (*TSP: 27 %, PM_{10}: 38 %, $PM_{2.5}$:56 %*) and transport (*TSP: 16 %, PM_{10}: 15 %, $PM_{2.5}$: 15 %*). Corresponding shares for the year 2011 and 2020 is shown in Figure 11.9, Figure 11.11 and Figure 11.13.

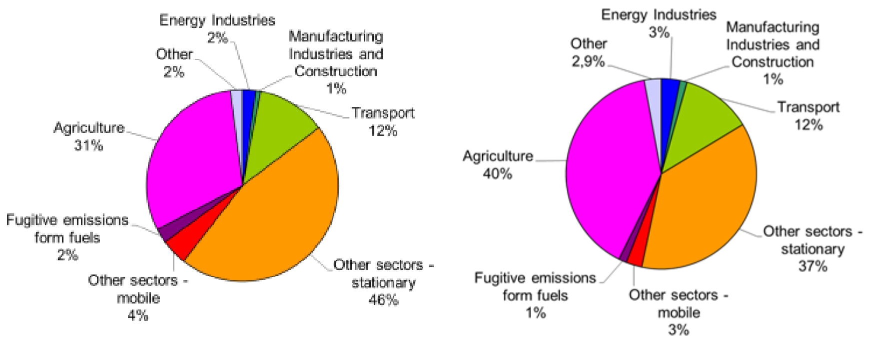


Figure 11.9 Historic and projected TSP emissions. Distribution by main sectors in 2011 (left) and 2020 (right).

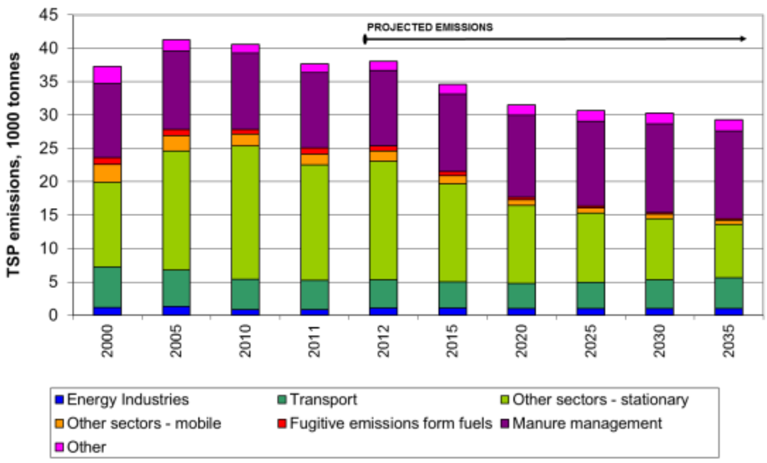


Figure 11.10 Historic and projected TSP emissions. Time-series for selected years in the period 1990 to 2035.

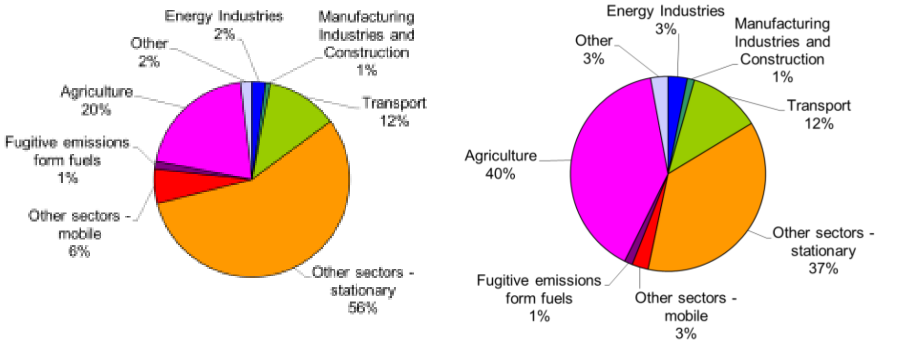


Figure 11.11 Historic and projected PM_{10} emissions. Distribution by main sectors in 2011 (left) and 2020 (right).

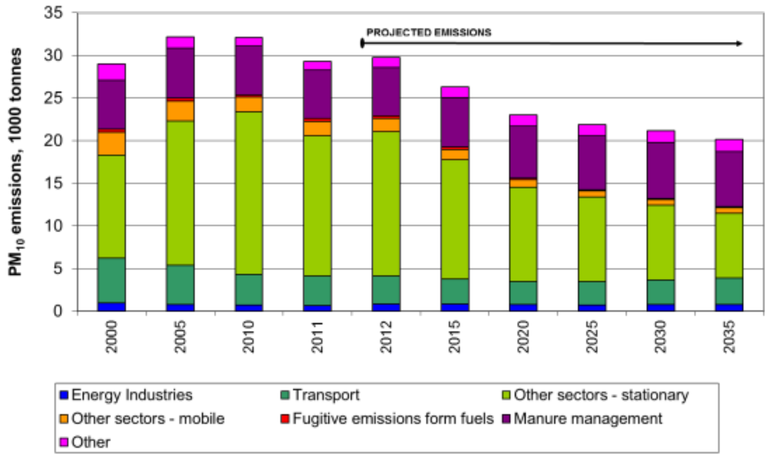


Figure 11.12 Historic and projected PM_{10}emissions. Time-series for selected years in the period 1990 to 2035.

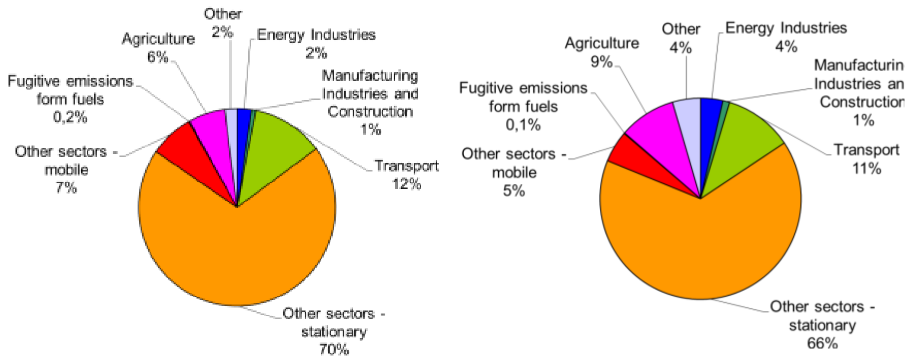


Figure 11.13 Historic and projected $PM_{2.5}$ emissions. Distribution by main sectors in 2011 (left) and 2020 (right).

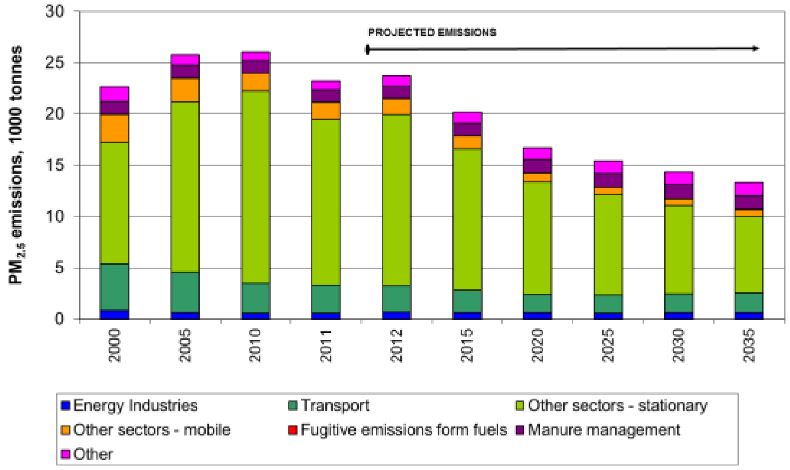


Figure 11.14 Historic and projected $PM_{2.5}$ emissions. Time-series for selected years in the period 1990 to 2035.

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Appendix 6: Historic and projected emissions of PM_{10}

Appendix 7: Historic and projected emissions of $PM_{2.5}$

Appendix 1 Historic and projected emissions of SO_2, tonnes.

NFR	Sector	1990	1995	2000	2005	2010	2011	2012	2015	2020	2025	2030	2035
1A1a	Public electricity and heat production	126 188	104 281	12 092	7 785	3 759	2 807	4 031	3 353	3 252	3 095	3 243	4 759
1A1b	Petroleum refining	1 059	2 050	598	224	231	321	321	321	321	321	321	321
1A1c	Other energy industries	3	4	8	8	8	8	8	7	7	10	11	11
1A2a-f i	Manufacturing industries and construction (Stationary)	16 155	11 652	7 448	6 240	3 163	3 297	4 179	3 441	2 208	2 096	1 966	1 863
1A2f ii	Manufacturing industries and construction (Mobile)	952	968	253	28	31	6	6	6	6	5	5	4
1A3a	Civil Aviation (LTO)	74	80	92	81	80	83	85	89	100	103	97	97
1A3b	Road transport	5 767	1 682	352	77	76	74	73	74	73	75	80	86
1A3c	Railways	376	96	7	1	2	2	2	2	2	2	2	2
1A3d	Navigation (National)	6 429	5 588	1 844	2 339	1 439	1 385	1 395	339	339	339	332	332
1A4a i	Commercial and institutional (Stationary)	1 878	779	348	273	131	107	110	105	102	100	98	95
1A4a ii	Commercial and institutional (Mobile)	2	2	3	1	1	1	1	1	1	1	1	1
1A4b i	Residential plants (Stationary)	6 415	2 324	1 522	1 653	1 670	1 452	1 520	1 380	1 142	1 155	1 172	1 194
1A4b ii	Residential plants (Mobile)	1	1	1	0	0	0	0	0	0	0	0	0
1A4c i	Agriculture, forestry and fishing (Stationary)	3 192	2 790	1 568	1 590	1 089	1 010	1 166	1 202	1 177	1 201	1 229	1 246
1A4c ii	Agriculture and forestry (Mobile)	1 561	1 451	326	34	40	8	8	8	8	8	7	6
1A4c iii	Fishing (Mobile)	742	668	695	817	364	365	343	387	446	504	580	663
1A5	Military transport	48	80	27	57	20	37	28	28	28	28	28	28
1B2a-b	Fugitive emissions from fuels	3 335	3 022	981	390	1 019	1 179	919	919	919	919	919	919
1B2c	Venting and flaring	945	205	55	299	290	243	379	379	379	379	379	379
2A-G	Industrial processes	2 043	1 937	1 937	1 896	774	849	866	918	1 062	1 166	1 263	1 351
3A-D	Solvent and other product use	29	34	55	58	41	39	39	47	48	49	51	52
4B1	Manure Management (Cattle)												
4B8	Manure Management (Swine)												
4B	Manure Management (Other)												
4D-G	Other agriculture	10	11	14	16	11	11	13	13	13	13	13	13
6C	Waste incineration	5	5	5	6	7	7	7	7	7	8	8	8
6D	Other waste	574	655	581	567	558	611	631	631	631	632	632	632
	Total UNECE	177 781	140 366	30 813	24 442	14 803	13 901	16 128	13 656	12 270	12 207	12 435	14 061
	Total NECD	177 781	140 366	30 813	24 442	14 803	13 901	16 128	13 656	12 270	12 207	12 435	14 061
1A3d	Navigation (International)	41 317	65 049	55 367	34 283	8 200	8 853	8 892	1 323	1 323	1 323	1 323	1 323
1A3a	Civil Aviation (Cruise)	558	580	708	784	743	759	793	834	949	982	921	921

Appendix 2 Historic and projected emissions of NO_x, tonnes.

NFR	Sector	1990	1995	2000	2005	2010	2011	2012	2015	2020	2025	2030	2035
1A1a	Public electricity and heat production	90 685	83 199	42 688	37 612	18 788	16 295	15 339	12 054	11 604	11 796	12 905	14 290
1A1b	Petroleum refining	1 616	1 816	1 530	1 284	1 544	1 571	1 404	1 404	1 404	1 404	1 404	1 404
1A1c	Other energy industries	2 371	3 248	6 304	6 999	6 490	6 259	6 330	5 454	6 007	8 039	9 555	9 452
1A2a-f i	Manufacturing industries and construction (Stationary)	13 299	15 061	15 303	12 624	5 898	5 636	5 181	4 843	4 150	3 965	3 782	3 647
1A2f ii	Manufacturing industries and construction (Mobile)	11 081	11 882	12 096	10 664	8 540	7 947	7 547	6 646	4 942	3 843	3 549	3 312
1A3a	Civil Aviation (LTO)	1 095	1 201	1 334	1 205	1 166	1 212	1 206	1 263	1 428	1 475	1 388	1 388
1A3b	Road transport	109 036	103 610	82 295	69 430	48 538	46 175	45 380	36 636	23 803	18 121	15 667	15 397
1A3c	Railways	4 913	5 015	3 727	3 724	2 818	2 501	2 293	1 935	1 338	1 338	1 338	1 338
1A3d	Navigation (National)	13 649	13 679	8 087	8 634	9 581	9 086	9 106	9 053	8 311	7 535	5 871	4 412
1A4a i	Commercial and institutional (Stationary)	1 330	1 510	1 293	1 047	878	716	739	699	667	647	625	602
1A4a ii	Commercial and institutional (Mobile)	70	93	104	177	217	215	219	219	219	219	219	219
1A4b i	Residential plants (Stationary)	4 954	5 211	4 743	5 830	6 617	5 658	5 990	5 519	4 726	4 751	4 796	4 859
1A4b ii	Residential plants (Mobile)	34	43	50	72	87	89	92	92	93	93	93	93
1A4c i	Agriculture, forestry and fishing (Stationary)	1 181	1 375	1 363	1 164	705	613	643	747	892	1 056	1 220	1 292
1A4c ii	Agriculture and forestry (Mobile)	12 679	13 178	13 324	12 233	10 145	9 833	9 168	7 114	4 263	2 457	1 335	860
1A4c iii	Fishing (Mobile)	8 387	8 264	9 483	11 776	10 670	10 586	9 838	10 646	8 333	5 745	4 741	3 775
1A5	Military transport	485	1 637	526	1 292	448	778	625	552	450	411	389	382
1B2a-b	Fugitive emissions from fuels												
1B2c	Venting and flaring	174	201	320	256	173	121	110	97	103	96	96	93
2A-G	Industrial processes	842	648	447	30	21	26	26	28	31	33	35	37
3A-D	Solvent and other product use	42	42	61	63	42	40	40	47	46	45	44	43
4B1	Manure Management (Cattle)												
4B8	Manure Management (Swine)												
4B	Manure Management (Other)												
4D-G	Other agriculture	77	91	114	127	89	88	102	102	102	102	102	102
6C	Waste incineration	36	39	40	43	53	49	51	53	55	56	58	60
6D	Other waste	37	42	41	39	37	39	41	40	40	41	41	41
	Total UNECE	278 074	271 087	205 271	186 327	133 545	125 532	121 469	105 244	83 006	73 265	69 251	67 095
	Total NECD	278 074	271 087	205 271	186 327	133 545	125 532	121 469	105 244	83 006	73 265	69 251	67 095
1A3d	Navigation (International)	60 639	105 113	94 441	56 540	51 065	52 516	52 782	52 746	46 112	38 406	30 459	23 283
1A3a	Civil Aviation (Cruise)	7 043	7 274	8 835	10 404	9 567	9 832	10 276	10 799	12 296	12 723	11 932	11 932

Appendix 3 Historic and projected emissions of NH_3, tonnes.

NFR	Sector	1990	1995	2000	2005	2010	2011	2012	2015	2020	2025	2030	2035
1A1a	Public electricity and heat production	0	3	8	9	10	14	11	11	12	12	13	14
1A1b	Petroleum refining	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
1A1c	Other energy industries	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
1A2a-f i	Manufacturing industries and construction (Stationary)	NE	NE	NE	NE	NE	NE	0	0	0	0	0	0
1A2f ii	Manufacturing industries and construction (Mobile)	2	2	2	2	3	2	2	2	2	2	2	2
1A3a	Civil Aviation (LTO)	0	0	0	0	0	0	NA	NA	NA	NA	NA	NA
1A3b	Road transport	72	1 096	2 544	2 404	1 731	1 601	1 549	1 322	1 150	1 265	1 461	1 640
1A3c	Railways	1	1	1	1	1	1	1	1	1	1	1	1
1A3d	Navigation (National)	0	0	0	0	0	0	0	0	0	0	0	0
1A4a i	Commercial and institutional (Stationary)	NE	NE	NE	NE	NE	NE	0	0	0	0	0	0
1A4a ii	Commercial and institutional (Mobile)	0	0	0	0	0	0	0	0	0	0	0	0
1A4b i	Residential plants (Stationary)	67	76	85	143	196	176	188	183	169	172	175	179
1A4b ii	Residential plants (Mobile)	0	0	0	0	0	0	0	0	0	0	0	0
1A4c i	Agriculture, forestry and fishing (Stationary)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
1A4c ii	Agriculture and forestry (Mobile)	3	3	3	3	4	4	4	4	4	4	3	3
1A4c iii	Fishing (Mobile)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
1A5	Military transport	0	1	0	1	0	0	0	0	0	1	1	1
1B2a-b	Fugitive emissions from fuels												
1B2c	Venting and flaring												
2A-G	Industrial processes	538	596	558	546	523	401	408	432	493	535	575	614
3A-D	Solvent and other product use	48	43	47	43	38	33	33	37	34	32	30	27
4B1	Manure Management (Cattle)	35 597	29 531	25 788	19 314	20 548	20 231	20 436	19 552	20 546	19 742	18 347	18 673
4B8	Manure Management (Swine)	41 251	36 453	35 284	35 153	26 720	26 491	25 602	24 727	22 712	21 104	19 709	18 117
4B	Manure Management (Other)	10 837	10 462	11 391	13 581	13 450	13 023	13 433	13 509	13 552	12 888	12 937	12 937
4D-G	Other agriculture	25 770	20 695	14 645	11 111	11 136	11 554	11 075	10 960	10 774	10 667	10 487	10 372
6C	Waste incineration	0	0	1	1	3	2	3	3	3	3	3	3
6D	Other waste	208	274	480	516	614	631	648	698	782	867	951	1 035
	Total UNECE	114 393	99 235	90 837	82 828	74 977	74 164	73 394	71 442	70 236	67 294	64 696	63 617
	Total NECD	98 279	87 318	83 159	77 243	69 333	68 508	68 059	66 169	65 064	62 173	59 625	58 598
1A3d	Navigation (International)												
1A3a	Civil Aviation (Cruise)												

Appendix 4 Historic and projected emissions of NMVOC, tonnes.

NFR	Sector	1990	1995	2000	2005	2010	2011	2012	2015	2020	2025	2030	2035
1A1a	Public electricity and heat production	451	2 891	3 531	2 587	2 381	1 998	2 650	1 455	1 111	933	1 024	1 120
1A1b	Petroleum refining	23	35	25	23	21	22	22	22	22	22	22	22
1A1c	Other energy industries	13	18	36	45	42	40	41	35	38	51	61	60
1A2a-f i	Manufacturing industries and construction (Stationary)	1 100	666	530	425	298	305	340	327	313	298	284	274
1A2f ii	Manufacturing industries and construction (Mobile)	2 266	2 088	1 926	1 620	1 173	1 115	1 071	955	790	714	672	641
1A3a	Civil Aviation (LTO)	274	300	260	252	183	179	108	113	128	133	125	125
1A3b	Road transport	78 131	71 087	43 901	26 780	14 456	12 201	10 973	8 903	7 002	6 734	6 923	7 233
1A3c	Railways	321	327	253	235	189	175	151	98	10	10	10	10
1A3d	Navigation (National)	1 686	1 879	1 731	1 423	937	842	791	713	707	709	704	704
1A4a i	Commercial and institutional (Stationary)	131	217	303	262	262	242	234	216	198	190	183	176
1A4a ii	Commercial and institutional (Mobile)	2 303	2 367	2 845	5 775	4 423	3 636	3 636	3 598	3 598	3 598	3 598	3 598
1A4b i	Residential plants (Stationary)	11 407	10 704	10 392	13 599	14 869	12 830	13 274	11 019	8 140	7 131	6 127	5 117
1A4b ii	Residential plants (Mobile)	1 801	1 780	1 757	2 084	2 032	1 993	1 953	1 801	1 716	1 716	1 716	1 716
1A4c i	Agriculture, forestry and fishing (Stationary)	826	764	855	728	507	491	516	530	518	527	538	545
1A4c ii	Agriculture and forestry (Mobile)	5 744	4 146	3 011	2 216	1 931	1 797	1 718	1 507	1 317	1 216	1 126	1 091
1A4c iii	Fishing (Mobile)	405	370	402	496	446	453	427	485	562	635	731	835
1A5	Military transport	53	143	55	106	40	59	48	45	42	42	42	42
1B2a-b	Fugitive emissions from fuels	11 257	13 264	18 238	16 148	9 171	8 782	8 654	7 787	8 056	7 340	7 699	7 846
1B2c	Venting and flaring	45	78	79	68	62	58	58	57	57	0	57	57
2A-G	Industrial processes	5 830	5 753	5 503	5 524	4 939	4 882	4 973	5 412	6 744	7 239	7 778	8 362
3A-D	Solvent and other product use	38 033	45 257	41 223	31 451	27 286	27 000	26 634	25 965	25 014	24 235	23 595	23 070
4B1	Manure Management (Cattle)												
4B8	Manure Management (Swine)												
4B	Manure Management (Other)												
4D-G	Other agriculture	2 103	1 996	1 976	2 099	2 160	2 150	2 173	2 151	2 114	2 096	2 078	2 059
6C	Waste incineration	1	1	1	2	3	3	3	3	3	3	3	3
6D	Other waste	172	194	176	172	174	179	187	187	187	188	188	189
	Total UNECE	164 376	166 325	139 009	114 120	87 985	81 432	80 636	73 384	68 386	65 760	65 283	64 894
	Total NECD	162 476	164 569	137 331	112 355	86 057	79 513	78 731	71 501	66 539	63 931	63 472	63 101
1A3d	Navigation (International)	2 060	3 501	3 045	1 792	1 628	1 668	1 685	1 718	1 763	1 793	1 803	1 803
1A3a	Civil Aviation (Cruise)	243	250	303	373	294	303	316	332	378	391	367	367

Appendix 5   Historic and projected emissions of TSP, tonnes.

NFR	Sector	2000	2005	2010	2011	2012	2015	2020	2025	2030	2035
1A1a	Public electricity and heat production	1 021	1 172	777	734	960	945	900	875	926	928
1A1b	Petroleum refining	144	111	94	100	100	100	100	100	100	100
1A1c	Other energy industries	3	3	3	3	3	2	2	3	4	4
1A2a-f i	Manufacturing industries and construction (Stationary)	776	421	283	300	357	358	375	363	351	342
1A2f ii	Manufacturing industries and construction (Mobile)	1 135	1 002	686	646	611	501	320	252	217	195
1A3a	Civil Aviation (LTO)	6	5	5	5	4	4	5	5	5	5
1A3b	Road transport	5 528	4 957	4 139	4.019	3 899	3 660	3 545	3 708	4 029	4 375
1A3c	Railways	141	124	95	78	67	42	1	1	1	1
1A3d	Navigation (National)	383	425	307	291	288	227	221	221	217	217
1A4a i	Commercial and institutional (Stationary)	164	157	160	168	162	150	138	133	129	125
1A4a ii	Commercial and institutional (Mobile)	30	65	67	67	67	67	67	67	67	67
1A4b i	Residential plants (Stationary)	11 957	17 100	19 323	16.596	17 054	13 980	10 992	9 758	8 532	7 300
1A4b ii	Residential plants (Mobile)	11	13	14	15	15	15	15	15	15	15
1A4c i	Agriculture, forestry and fishing (Stationary)	568	517	506	502	526	539	520	524	530	535
1A4c ii	Agriculture and forestry (Mobile)	1 334	1 011	793	762	693	477	240	150	93	69
1A4c iii	Fishing (Mobile)	172	203	167	168	158	178	205	232	267	305
1A5	Military transport	17	36	10	16	12	9	5	4	3	3
1B2a-b	Fugitive emissions from fuels	962	905	686	920	770	619	424	354	278	240
1B2c	Venting and flaring	11	8	5	4	3	3	3	3	3	0
2A-G	Industrial processes	861	456	222	220	224	238	271	291	311	332
3A-D	Solvent and other product use	403	370	411	356	356	418	448	477	506	535
4B1	Manure Management (Cattle)	1 487	1 155	1 225	1.235	1 247	1 234	1 370	1 401	1 432	1 432
4B8	Manure Management (Swine)	8 471	9 530	9 127	8.948	8 985	9 310	9 836	10 197	10 756	10 615
4B	Manure Management (Other)	1 219	1 059	1 081	1.103	1 047	1 062	1 087	1 087	1 087	1 087
4D-G	Other agriculture	274	307	214	212	247	246	246	246	246	245
6C	Waste incineration	3	3	5	3	3	3	3	3	3	3
6D	Other waste	176	170	175	178	186	186	186	187	187	187
	Total UNECE	37 255	41 284	40 579	37.648	38 044	34 576	31 526	30 658	30 296	29 261
	Total NECD	37 255	41 284	40 579	37.648	38 044	34 576	31 526	30 658	30 296	29 261
1A3d	Navigation (International)	8 791	5 761	934	975	978	609	609	609	609	609
1A3a	Civil Aviation (Cruise)	36	40	37	38	40	42	48	50	46	46

Appendix 6 Historic and projected emissions of PM_{10}, tonnes.

NFR	Sector	2000	2005	2010	2011	2012	2015	2020	2025	2030	2035
1A1a	Public electricity and heat production	829	676	603	571	746	722	684	654	685	686
1A1b	Petroleum refining	131	104	90	95	95	95	95	95	95	95
1A1c	Other energy industries	2	2	2	2	2	1	1	2	2	2
1A2a-f i	Manufacturing industries and construction (Stationary)	564	285	209	222	252	251	261	253	244	238
1A2f ii	Manufacturing industries and construction (Mobile)	1 135	1 002	686	646	611	501	320	252	217	195
1A3a	Civil Aviation (LTO)	6	5	5	5	4	4	5	5	5	5
1A3b	Road transport	4 710	4 064	3 234	3.097	2 961	2 675	2 456	2 489	2 673	2 892
1A3c	Railways	141	124	95	78	67	42	1	1	1	1
1A3d	Navigation (National)	381	422	305	289	286	226	219	219	216	216
1A4a i	Commercial and institutional (Stationary)	157	150	158	166	161	149	137	131	127	123
1A4a ii	Commercial and institutional (Mobile)	30	65	67	67	67	67	67	67	67	67
1A4b i	Residential plants (Stationary)	11 392	16 296	18 401	15.802	16 241	13 318	10 474	9 303	8 139	6 969
1A4b ii	Residential plants (Mobile)	11	13	14	15	15	15	15	15	15	15
1A4c i	Agriculture, forestry and fishing (Stationary)	529	479	473	471	493	504	486	488	492	496
1A4c ii	Agriculture and forestry (Mobile)	1 334	1 011	793	762	693	477	240	150	93	69
1A4c iii	Fishing (Mobile)	171	201	166	166	156	176	203	230	264	302
1A5	Military transport	17	36	10	16	12	9	5	4	3	3
1B2a-b	Fugitive emissions from fuels	385	362	274	368	308	248	170	142	111	96
1B2c	Venting and flaring	11	8	5	4	3	3	3	3	3	0
2A-G	Industrial processes	612	294	149	147	149	158	181	197	211	225
3A-D	Solvent and other product use	284	251	253	222	356	418	448	477	506	535
4B1	Manure Management (Cattle)	684	531	564	568	574	568	630	644	659	659
4B8	Manure Management (Swine)	3 812	4 289	4 107	4.027	4 043	4 190	4 426	4 589	4 840	4 777
4B	Manure Management (Other)	1 201	1 038	1 061	1.085	1 028	1 043	1 068	1 068	1 068	1 068
4D-G	Other agriculture	274	307	214	212	247	246	246	246	246	245
6C	Waste incineration	2	3	4	2	2	2	2	2	2	2
6D	Other waste	176	170	175	178	186	186	186	187	187	187
	Total UNECE	28 979	32 187	32 116	29.280	29 759	26 296	23 029	21 912	21 173	20 169
	Total NECD	28 979	32 187	32 116	29.280	29 759	26 296	23 029	21 912	21 173	20 169
1A3d	Navigation (International)	8 703	5 703	925	965	968	603	603	603	603	603
1A3a	Civil Aviation (Cruise)	36	40	37	38	40	42	48	50	46	46

Appendix 7 Historic and projected emissions of $PM_{2.5}$, tonnes.

NFR	Sector	2000	2005	2010	2011	2012	2015	2020	2025	2030	2035
1A1a	Public electricity and heat production	693	542	482	455	578	537	504	481	501	503
1A1b	Petroleum refining	124	101	87	93	93	93	93	93	93	93
1A1c	Other energy industries	1	1	1	1	1	1	1	2	2	2
1A2a-f i	Manufacturing industries and construction (Stationary)	323	159	142	156	165	168	183	178	173	169
1A2f ii	Manufacturing industries and construction (Mobile)	1 135	1 002	686	646	611	501	320	252	217	195
1A3a	Civil Aviation (LTO)	6	5	5	5	4	4	5	5	5	5
1A3b	Road transport	4 061	3 356	2 525	2.375	2 231	1 909	1 613	1 551	1 632	1 757
1A3c	Railways	141	124	95	78	67	42	1	1	1	1
1A3d	Navigation (National)	379	421	304	288	285	225	219	219	215	215
1A4a i	Commercial and institutional (Stationary)	146	140	149	157	152	140	129	124	120	116
1A4a ii	Commercial and institutional (Mobile)	30	65	67	67	67	67	67	67	67	67
1A4b i	Residential plants (Stationary)	11 181	16 025	18 148	15.572	16 050	13 199	10 381	9 211	8 048	6 879
1A4b ii	Residential plants (Mobile)	11	13	14	15	15	15	15	15	15	15
1A4c i	Agriculture, forestry and fishing (Stationary)	493	445	443	441	462	472	454	456	460	464
1A4c ii	Agriculture and forestry (Mobile)	1 334	1 011	793	762	693	477	240	150	93	69
1A4c iii	Fishing (Mobile)	170	199	165	165	155	175	202	228	263	300
1A5	Military transport	17	36	10	16	12	9	5	4	3	3
1B2a-b	Fugitive emissions from fuels	38	36	27	37	31	25	17	14	11	10
1B2c	Venting and flaring	11	8	5	4	3	3	3	3	3	0
2A-G	Industrial processes	407	180	97	96	97	103	119	130	140	150
3A-D	Solvent and other product use	255	229	221	194	356	418	448	477	506	535
4B1	Manure Management (Cattle)	438	342	363	365	369	365	406	415	424	424
4B8	Manure Management (Swine)	622	699	670	657	659	683	722	748	789	779
4B	Manure Management (Other)	184	167	168	173	162	164	167	167	167	167
4D-G	Other agriculture	260	291	203	201	234	234	233	233	233	233
6C	Waste incineration	2	2	3	2	2	2	2	2	2	2
6D	Other waste	176	170	175	178	186	186	186	187	187	187
	Total UNECE	22 638	25 768	26 048	23.196	23 740	20 218	16 734	15 411	14 371	13 340
	Total NECD	22 638	25 768	26 048	23.196	23 740	20 218	16 734	15 411	14 371	13 340
1A3d	Navigation (International)	8 659	5 675	920	960	964	600	600	600	600	600
1A3a	Civil Aviation (Cruise)	36	40	37	38	40	42	48	50	46	46

PROJECTION OF SO_2, NO_X, NMVOC, NH_3 AND PARTICLE EMISSIONS – 2012-2035

This report contains a description of models and background data for projection of SO_2, NO_X, NH_3, NMVOC, TSP, PM_{10} and $PM_{2.5}$ for Denmark. The emissions are projected to 2035 using basic scenarios together with the expected results of a few individual policy measures. Official Danish projections of activity rates are used in the models for those sectors, for which the projections are available, i.e. the latest official projection from the Danish Energy Agency. The emission factors refer either 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 plants. The emission projection models are based on the same structure and method as the Danish emission inventories in order to ensure consistency.

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