PROJECTION OF SO_2, NO_X, NMVOC, PARTICULATE MATTER AND BLACK CARBON EMISSIONS – 2015-2030

Scientific Report from DCE – Danish Centre for Environment and Energy No. 219 2017

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Data sheet

Series title and no.: Scientific Report from DCE – Danish Centre for Environment and Energy No. 219

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Publisher: Aarhus University, DCE – Danish Centre for Environment and Energy ©
URL: http://dce.au.dk/en

Year of publication: February 2017
Editing completed: January 2017

Referee(s): Stine S. Justesen, Danish Environmental Protection Agency
Quality assurance, DCE: Vibeke Vestergaard Nielsen

Financial support: Work funded by the Danish Environmental Protection Agency

Please cite as: Nielsen, O.-K., Plejdrup, M., Hjelgaard, K., Nielsen, M., Winter, M., Mikkelsen, M.H., Albrektsen, R., Fauser, P. & Gyldenkærne, S. 2017. Projection of SO_2, NO_x, NMVOC, particulate matter and black carbon emissions - 2015-2030. Aarhus University, DCE – Danish Centre for Environment and Energy, 145 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 219
http://dce2.au.dk/pub/SR219.pdf

Abstract: This report contains a description of models and background data for projection of SO_2, NO_X, NMVOC, $PM_{2.5}$ and black carbon for Denmark. The emissions are projected to 2030 using basic scenarios together with the expected results of a few individual policy measures. Official Danish forecasts of activity rates are used in the models for those sectors for which the forecasts are available, i.e. the latest official forecast 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 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, black carbon, SO_2, NO_X, NMVOC, TSP, PM_{10} and $PM_{2.5}$

Layout: Ann-Katrine Holme Christoffersen
Front page photo: Ann-Katrine Holme Christoffersen

ISBN: 978-87-7156-252-1
ISSN (electronic): 2245-0203

Number of pages: 145

Internet version: The report is available in electronic format (pdf) at
http://dce2.au.dk/pub/SR219.pdf

Contents

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
RDE	Real Driving Emission
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), particulate matter with an aerodynamic diameter below 2.5 µm ($PM_{2.5}$) and black carbon (BC) for Denmark. The emissions are projected to 2030 using basic scenarios, which include the estimated effects at implementation on Denmark's emissions of policies and measures agreed upon or implemented until January 2016 ('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).

The authors would like to thank:

The Danish Energy Agency (DEA) – especially Jakob Stenby Lundsager – for providing the energy consumption forecast and for valuable discussions during the project.

DTU Transport for providing information used in the road transport section.

G & O Trading ApS – especially Anders Weirup, for providing the information of swept volume per cylinder for new diesel engines in recreational craft.

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), particulate matter with diameter less than 2.5 µm ($PM_{2.5}$) and black carbon (BC) for Denmark. The emissions are projected to 2030 using basic scenarios which include the estimated effects at implementation on emissions of policies and measures implemented until January 2016 ('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[1]	Tonnes	55 000	127 000	85 000	69 000	
Emission reduction commitment	%	35	56	35	24	33
Emission level – 2005[2]	Tonnes	23 000	181 000	110 000	83 000	25 000
Emission ceiling – 2020[1]	Tonnes	14 950	79 640	71 500	63 080	16 750
Emission – 2014	Tonnes	11 419	113 356	105 785	73 318	18 349
Projected emission – 2020	Tonnes	9 665	88 890	103 031		15 919

[1] The NH_3 emission ceiling excludes the emission from straw treatment and growing crops, the NMVOC emission ceiling excludes the emission from growing crops.

[2] As inscribed in the revised Gothenburg Protocol.

Trend by Pollutant

The historical emissions in the latest historical year, 2014, are shown in Table S.2 together with the projected emissions for 2020, 2025 and 2030. The results of the projection indicate that emissions of SO_2, NO_x, NMVOC, $PM_{2.5}$ and BC decrease from the latest historical inventory year (2014) to the projection year 2020. From 2020 to 2030 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 2014 and projected emissions for 2020, 2025 and 2030.

Tonnes	SO_2	NO_x	NO_x ex. agriculture	NMVOC	NMVOC ex. agriculture	$PM_{2.5}$	BC
2014	11 419	113 356	99 296	105 785	68 105	18 349	3 983
2020	10 037	88 831	74 681	102 713	64 516	16 083	2 867
2025	10 197	76 883	62 871	100 545	61 326	14 301	2 441
2030	10 242	68 354	54 525	99 799	59 787	12 771	2 143

Nitrogen oxides, NO_X

The largest sources are road transport, other mobile sources, and energy industries, accounting for 44 %, 20 % and 15 % of the NO_x emission in 2014, respectively.

The NO_x emission is expected to decrease 22 % (40 %) from 2014 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).

It is not possible to quantify the effect of the change in NO_x tax. In the 2013 projection the possible effect of the increased tax was not estimated and likewise in this projection the effect of the lowering of the tax has not been estimated.

NO_x emissions from manure management and agricultural soils will not be part of the reduction commitment for 2030. This is due to the fact that methodologies were only recently included in the EMEP/EEA Guidebook, that the emissions from mineral fertiliser are very high and that this source was not included at the time when the reduction commitments were established.

Sulphur dioxide, SO_2

The largest sources of SO_2 emissions are manufacturing industries and energy industries both accounting for 24 % of the national SO_2 emission in 2014.

The SO_2 emission is expected to decrease 12 % (10 %) from 2014 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 due to increasing fuel consumption in this sector.

Non methane volatile organic compounds, NMVOC

The largest sources of emissions of NMVOC are agriculture followed by industrial processes, residential plants, extraction/storage/refining of oil and gas, and road transport. These sources account for 36 %, 26 %, 10 %, 9 % and 8 %, respectively, of the total NMVOC emission in 2014.

The NMVOC emission is expected to decrease 3 % (6 %) from 2014 to 2020 (2030). The largest decrease is expected for residential plants but pronounced decreases are also expected for road transport and other mobile sources.

NMVOC emissions from manure management and agricultural soils will not be part of the reduction commitment for 2030. This is due to the fact that methodologies were only recently included in the EMEP/EEA Guidebook, that the emissions from mineral fertiliser are very high and that this source was not included at the time when the reduction commitments were established.

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 62 % of the national $PM_{2.5}$ emission in 2014. 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 12 % (30 %) from 2014 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.

Black carbon, BC

The single major source of the BC emission is non-industrial combustion, mainly wood combustion in residential plants, which accounted for 43 % of the national BC emission in 2014. Other important sources are transport, other mobile sources and fugitive emissions from fuels with 23 %, 21 % and 11 %, respectively.

The BC emission is expected to decrease by 28 % (46 %) from 2014 to 2020 (2030) mainly due to a decreasing emissions from transport and other mobile sources, due to lower emission limit values for particulate matter.

Trend by sector

Stationary combustion

The trend in emissions from stationary combustion is mainly a result of the trend in the use of different fuels. The consumption of wood in heat and electricity production is expected to increase. Due to higher emission factors, this means that emissions from this sector are expected to show a slight increase. Also, the consumption of coal is projected to be at the same level in 2030 as in 2015. However, the time-series shows a dip around 2020 that can also be seen in the emission trends.

Since the latest official energy projection only covered the years until 2025, the same fuel consumption has been assumed from 2025 to 2030. This means that emissions for the most part are constant in this period. The exception being when there are changes in emission factors, which is the case for residential wood combustion due to the assumption of replacement of older appliances.

The total NO_x emission increases from 2015 to 2025 due to increasing wood consumption. The emission factor for wood is larger than for both natural gas and coal, which are the other largest fuel categories. Also, the increasing use of biogas leads to an increase in emissions due to the high emission factors for biogas. NO_x emissions from gas turbines used in the offshore sector are projected to increase significantly. From 2015 to 2025 the emission increases by 15 % due to increasing fuel consumption.

The total SO_2 emission decreases slightly from 2015 to 2025 due to a decrease in oil consumption. This mainly occurs in the industrial plants, while the emissions from the other sectors remain relatively constant.

From 2015 to 2030 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 68 % and 81 % of the total NMVOC emission from stationary combustion plants, with the higher share being in the early part of the projection period.

The $PM_{2.5}$ emission has increased in the historic years due to increasing wood combustion in residential plants. However, from 2015 to 2030 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 81 % and 89 % of the total $PM_{2.5}$ emission from stationary combustion plants in the period 2015-2030 with the share being highest in the beginning of the period.

The BC emission has increased in the historic years due to increasing wood combustion in residential plants. However, from 2015 to 2030 the BC 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 83 % and 87 % of the total BC emission from stationary combustion plants in the period 2015-2030 with the share being highest in the beginning of the period.

Road transport

Total fuel consumption and SO_2 emissions for road traffic are kept at a constant level during the 2015-2030 period. Passenger cars 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 development relies on the fuel consumption in the forecast period given that road transport fuel has a sulphur content of 10 ppm.

The NMVOC emissions from road transport are expected to decrease by 27 % from 2015 to 2030. The majority of the NMVOC emissions comes from gasoline passenger cars, and for this vehicle category the projected emissions decrease by 28 % from 2015 to 2024, explained by the gradually phasing out of less efficient catalytic converters. From 2024 onwards the emissions increase proportionally with the total mileage for gasoline cars.

In terms of $PM_{2.5}$ and BC the total emission is expected to decline by 81 % and 94 %, respectively, from 2015 to 2030, in particular due to the introduction of diesel particulate filters (DPF) for Euro 5 cars/vans, and Euro VI trucks/buses. The largest emission source is passenger cars, followed by light duty vehicles, heavy duty vehicles and buses. Emission reductions are generally higher for BC than for $PM_{2.5}$ due to the very efficient removal of BC by the DPF technology.

The NO_X emission for road transport declines by 72 % from 2015 to 2030. For trucks and buses high relative emission declines of 83 % and 86 %, respectively, are expected during the forecast period, due to the fleet turnover towards newer EU emission standards that in practice reduce the emission factors from Euro III onwards. For cars and vans the emission reductions (64 % and 72 %, respectively) are less favourable mainly due to the well-known problems for diesel cars (and vans) to comply with the EU emission legislation standards.

The fact that diesel cars and vans emit more NO_x in real driving than during type approval tests, is accounted for in the present forecast based on COPERT IV baseline factors. However, recently published measurements of high NO_x emissions from Euro 6 diesel cars foster the need for assessing the emission consequences in two cases where NO_x emission factors for the present Euro 6 diesel vehicles are even higher than suggested by COPERT IV.

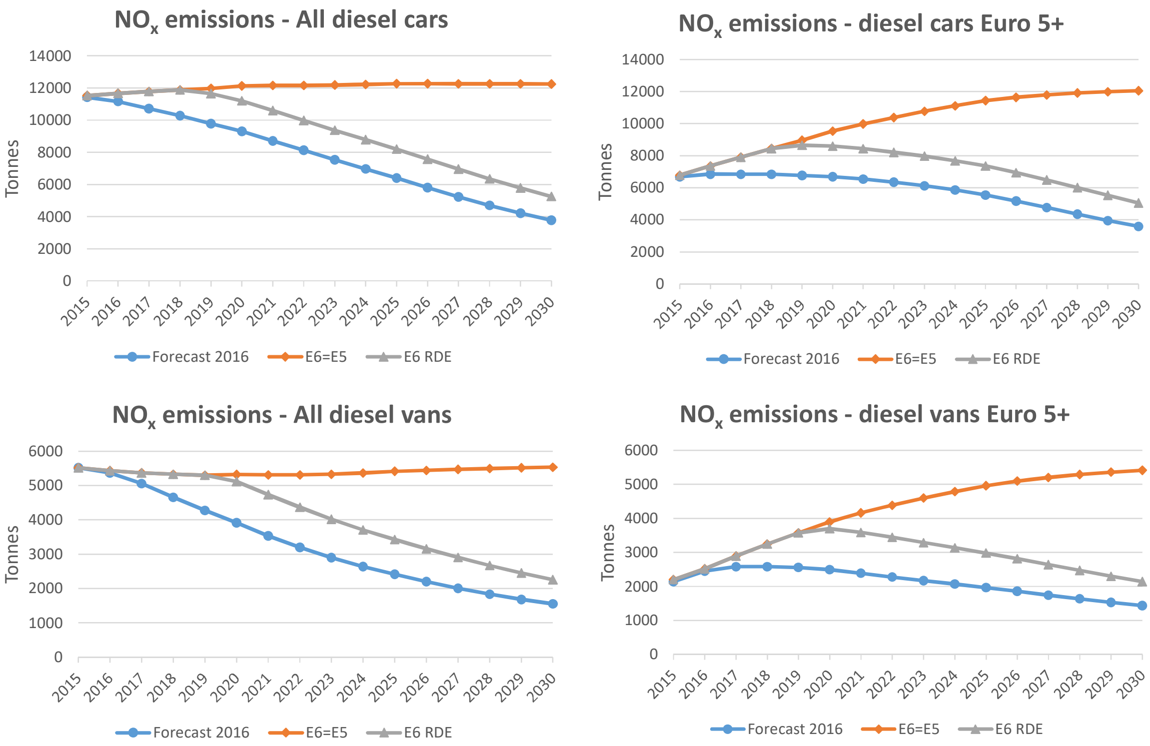


Figure ES1 Blue line: NO_X emissions from the present forecast, Orange line: No Euro 6 emission factor improvements (E6 = E5) and Grey line: Euro 6 emission factors expected from RDE (Real Driving Emission) legislation

Figure ES1 show the NO_x emission results of the following three calculation situations for diesel cars and vans:

- 2016 forecast: The present forecast using baseline emission factors from the COPERT IV model.
- Euro 6 = Euro 5: This scenario describes the situation if no emission factor improvements are gained with the introduction of the Euro 6 emission standard.
- Euro 6 RDE (Real Driving Emission): In this scenario Euro 6 emission factors are kept at Euro 5 levels until the emission factors are step wise reduced for diesel cars (in 2018/2020) and diesel vans (in 2019/2021) to comply with the RDE emission legislation limits (Euro 6 RDE).

In the Euro 6 = Euro 5 scenario the NO_x emission increases for diesel cars*[diesel vans]* become 31 %*[36 %]* in 2020 and 224 %*[256 %]* in 2030 compared with the present forecast. In total, the road transport emissions increase by 20 % and 131 %, respectively, in 2020 and 2030. In the Euro 6 RDE model case the calculated NO_x emissions for diesel cars*[diesel vans]* increase by 20 %*[31 %]* in 2020 and 39 %*[45 %]* in 2030 compared with the present forecast. In total the road transport emissions increase by 15 % and 23 %, respectively, in 2020 and 2030.

Other mobile sources

Other mobile sources are divided into the sub-sectors: National navigation, fishery, domestic air traffic, railways, working machinery and equipment in the sectors agriculture/forestry, industry, commercial/institutional and residential, and other (military activities and recreational craft).

From 2015-2030 the total fuel consumption decrease by 5 % for other mobile sources. The emissions of SO_2 increase by 8 %, due to an increase in fuel consumption for fishery, which uses marine diesel with relatively high sulphur content. For other mobile sources the emissions of NO_x, NMVOC, $PM_{2.5}$ and BC decrease by 55 %, 16 %, 64 % and 79 %, respectively.

The SO_2 emissions for other mobile sources are insignificant except for seagoing vessels. However, for navigation, the reduction of the sulphur content in heavy fuel oil used in the Baltic and North Sea SO_x emission control areas (SECAs) has had a major emission impact from 2015.

By far the most of the NMVOC emission comes from gasoline gardening machinery in commercial/institutional. The same gasoline equipment types also give considerable contributions for residential. The projected NMVOC emission reductions for commercial/institutional and residential are due to the introduction of the cleaner gasoline stage II and stage V emission technology for some types of equipment. 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 $PM_{2.5}$, industrial non road machinery is the largest emission source for other mobile sources in the beginning of the forecast period followed by agriculture/forestry, fisheries and navigation. By the end of the forecast period, fisheries and navigation become the largest emission sources. 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 $PM_{2.5}$ emissions from fishing vessels increase proportional with fuel consumption throughout the forecast period, whereas the SECA reduction in the sulphur content for heavy fuel oil has significantly reduced the $PM_{2.5}$ emissions for navigation in 2015.

Being a sub part of total PM, the decline in BC emissions throughout the forecast period is driven by the general decrease in PM emissions for diesel fuelled agriculture/forestry and industry machinery and the step-wise introduction of Stage V machinery from 2019/2020. In order to meet the Stage V PM emission standards for engines >= 19 kW particulate filters are needed which in addition are very efficient removers of BC.

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.

Fugitive emissions from fuels

This sector includes emissions from exploration, extraction, refining, storage, handling, and transport of fuels, the major sources being SO_2 and NMVOC from oil and BC emissions from solid fuels.

SO_2 mainly stem from refining of oil, and fluctuates annually in the historical years due to unpredictable circumstances at the refineries, e.g. the performance of the sulphur recovery units. The mean of the latest five historical years are applied for all projection years. SO_2 from the fugitive sector contribute 7-8 % to the national SO_2 emission in the years 2015-2030.

The major NMVOC sources are refinery processes, onshore and offshore activities in oil and gas production, and service stations, refinery processes being by far the major single source in the projection years. Fugitive emissions from refineries are highly unpredictable and only very few measurements are available. As for SO_2 the average of the latest five historical years are applied for the projection years to take the annual fluctuations into account. Emissions from onshore and offshore activities and from service stations follow the prognosis for oil- and gas production and gasoline consumption for transport, respectively. NMVOC from the fugitive sector contribute 9 % to the national NMVOC emission in the years 2015-2030 (Table S3).

Table S3 NMVOC emission from the fugitive sector

	2015	2020	2025	2030
NMVOC emission, tonnes	9191	9255	8649	8974
Share of national total NMVOC emission	9 %	9 %	9 %	9 %

The major BC source is storage of coal. BC from the fugitive sector contributes 7 % to the national BC emission in 2015, increasing to 13 % in 2030 (Table S4). The increasing share of the national total owe to decreasing emissions from other sectors (mainly transport and small combustion), as BC emissions from coal storage are at the same level for the projection years, variations only depend on the coal consumption in the energy prognosis.

Table S4 BC emission from the fugitive sector

	2015	2020	2025	2030
BC emission, tonnes	276	224	275	275
Share of national total BC emission	7 %	8 %	11 %	13 %

Industrial processes and product use

The projections of emissions from the industrial processes and product use (IPPU) sector are generally based on projection of activity data for the individual source categories and implied emission factors (IEF) for 2014. Activity data can be projected in four ways all of which has been used as described in the following chapters;

- By extrapolation of representative historical years using the projected production values for glass, steel and cement/construction industries available from the DEA (Danish Energy Agency, 2015).
- By estimating an expected future activity level and the number of years for the given source category to reach this level.

- By using an average of representative historical years.
- By linear regression of a significant trend in the historical data.

Table S5 provides an overview of emissions from the IPPU sector and the largest sources to each pollutant respectively.

Table S5 Overview of emissions from the industrial processes and product use sector.

Pollutant		Unit	2015	2020	2025	2030	Change in emission 2015-2030, %
SO_2							
	Emission from IPPU	Mg	696.6	784.4	835.8	877.8	26.0
	Share of national emission, %	-	6.2	7.8	8.2	8.6	
	Largest source in IPPU: Ceramics	Mg	560.3	648.5	700.3	742.7	32.5
	Share of IPPU, %	-	80.4	82.7	83.8	84.6	
NO_x							
	Emission from IPPU	Mg	69.1	67.4	65.7	64.0	-7.4
	Share of national emission, %	-	0.1	0.1	0.1	0.1	
	Largest source in IPPU: Charcoal for BBQs	Mg	32.7	32.7	32.7	32.7	0.0
	Share of IPPU, %	-	47.3	48.4	49.7	51.0	
NMVOC							
	Emission from IPPU	Mg	28865	27942	27176	26539	-8.1
	Share of national emission, %	-	26.9	27.1	27.0	26.6	
	Largest source in IPPU: Other solvent use (NFR 2D3i)	Mg	18778	18164	17646	17209	-8.3
	Share of IPPU, %	-	65.1	65.0	64.9	64.8	
$PM_{2.5}$							
	Emission from IPPU	Mg	698.5	746.3	769.9	786.8	12.6
	Share of national emission, %	-	3.7	4.6	5.4	6.2	
	Largest source in IPPU: Quarrying/mining	Mg	213.4	246.9	266.6	282.8	32.5
	Share of IPPU, %	-	30.5	33.1	34.6	35.9	
BC							
	Emission from IPPU	Mg	2.0	2.3	2.4	2.6	30.9
	Share of national emission, %	-	0.1	0.1	0.1	0.1	
	Largest source in IPPU: Stone wool production	Mg	0.7	0.8	0.9	0.9	32.5
	Share of IPPU, %	-	36.2	36.5	36.6	36.7	

The increasing trend of the projected SO_2 emissions is caused by increasing emission from the production of ceramics (bricks, tiles and expanded clay products), see Table S5. Ceramics are projected using the projected production values from the DEA. Only the very small contribution to SO_2 emissions from the use of tobacco has a decreasing trend, the remaining four source categories are estimated as constant in the projection.

Only three small source categories in the IPPU sector lead to NO_x emissions and only the smallest of the three (use of tobacco) is expected to decrease, the remaining two source categories are projected as constant.

The predominant source of NMVOC emissions are from diffuse solvent use constituting highly diverse activities and product uses, each comprising a large number of chemicals. Emissions from industrial sectors are typically attributed relatively low emission factors. All projected solvent use categories show a decrease in NMVOC emissions, however, there is stagnation in the latest eight years of the historic emissions; i.e. the four solvent use categories show approximately constant emissions during the period (2007 to 2014).

The most realistic projection from 2015 to 2030 is assumed to represent 25 % of an exponential fit and 75 % of the, approximately constant, historic 2007 - 2014 estimates. However, if the emissions in the coming years continue the constant trend, a possible change in the coming projection will be to assign a higher weight of the constant 2007 to present emissions compared to the exponential fit of historic 1995 – present emissions. This is in agreement with new information and data on production, sale and import/export within and outside the EU supplied by the European Solvents Industry Group (ESIG), which predict a stabilized growth in Europe and probably also in Denmark.

Between 52 % (2015) and 61 % (2030) of the projected $PM_{2.5}$ emissions from IPPU are projected using the projected production values from the DEA. The largest of these sources, and the primary reason for the increasing trend in $PM_{2.5}$ emissions, is quarrying and mining of other minerals than coal. Around 25 % of the $PM_{2.5}$ emissions from IPPU are expected to remain constant, the largest of these is wood processing.

There are seven source categories emitting BC in the IPPU sector, the largest of which is stone wool production, see Table S5. The 33 % increase in BC emissions expected from 2015-2030 is calculated based on the projection values from DEA. An additional four (of the seven) source categories are projected in the same way adding up to around 95 % of the total BC emission from IPPU.

Agriculture

In 2014 agriculture contributed with 36 % of the NMVOC emission, 12 % of the NO_x emission and 11 % of the $PM_{2.5}$ emission.

The total emission of NMVOC is expected to be nearly unaltered from 2014 to 2030. The emission from manure management increases mainly due to increase in emission from swine and dairy cattle. The emission of NMVOC from cultivated crops and field burning of agricultural residue is expected to decrease due to decrease in agricultural area.

The total emission of NO_x is expected to decrease with 2 % from 2014 to 2030. The emission from manure management decrease mainly for swine and dairy cattle due to change in housings with slurry which have a lower emission of NO_x compared to solid manure. The emission of NO_x from inorganic N-fertiliser, sewage sludge and field burning decreases due to decrease in agricultural area. Emission of NO_x from manure applied to soil increase due to increase in amount of manure applied.

The total emission of $PM_{2.5}$ is expected to increase slightly from 2014 to 2030 due to increase in the emission from manure management. The increase in $PM_{2.5}$ emission from manure management is mainly due to increase in emission from swine. The emission of $PM_{2.5}$ from field operations and field burning of agricultural residue is expected to decrease due to decrease in agricultural area.

Waste

Since all municipal, industrial and hazardous waste incineration in Denmark occur with energy recovery, emissions from these activities are included in the stationary combustion part of the inventory and projection. The sources reported in the waste sector are human and animal cremations, accidental fires and composting. The pollutants covered by this projection are not applicable to composting, where e.g. NH_3 and CH_4 emissions are estimated. Therefore, composting is not mentioned further in this report.

During the years 2015-2030, the waste categories are projected to emit 5-6 % of the national SO_2 emission. For the remaining pollutants the contribution from the waste sector are all around or under 1 % of the national emission.

The emissions for all pollutants are projected to remain relatively stable during the time-series.

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), svævestøv med diameter mindre end 2,5µm ($PM_{2.5}$) og sod (Black Carbon – BC). Emissionerne er fremskrevet til 2030 som basisscenarie, som inkluderer de estimerede effekter på emissionerne af vedtaget lovgivning inden januar 2016. 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[1]	Ton	55 000	127 000	85 000	69 000	
Emissionsreduktionsforpligtigelse	%	35	56	35	24	33
Emissionsniveau – 2005[2]	Ton	23 000	181 000	110 000	83 000	25 000
"Emissionsloft – 2020[1]	Ton	14 950	79 640	71 500	63 080	16 750
Emission – 2014	Ton	11 419	113 356	105 785	73 318	18 349
Fremskrevet emission – 2020	Ton	9 665	88 890	103 031		15 919

[1] NH_3 emissionsloftet er eksklusiv emissioner fra afgrøder og ammoniakbehandlet halm; NMVOC-emissionsloftet er eksklusiv emissioner fra afgrøder.
[2] Som indskrevet i den reviderede Gøteborgprotokol

Emissionsfremskrivninger pr. stof

De historiske emissioner for det seneste historiske år, 2014, er vist i Tabel S.2 sammen med de fremskrevne emissioner for 2020, 2025 og 2030. Resultatet af fremskrivningen indikerer, at emissionerne af SO_2, NO_x, NMVOC partikler og sod falder fra det seneste historiske år (2014) til fremskrivningsåret

2020. Fra 2020 til 2030 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 2030.

Tabel S.2 Historiske emissioner for 2014 og fremskrevne emissioner for 2020, 2025 og 2030.

Ton	SO_2	NO_x	NO_x ekskl. landrug	NMVOC	NMVOC ekskl. landbrug	$PM_{2.5}$	BC
2014	11 419	113 356	99 296	105 785	68 105	18 349	3 983
2020	10 037	88 831	74 681	102 713	64 516	16 083	2 867
2025	10 197	76 883	62 871	100 545	61 326	14 301	2 441
2030	10 242	68 354	54 525	99 799	59 787	12 771	2 143

Kvælstofoxider, NO_X

De største kilder er vejtransport, andre mobile kilder og energiproduktion, der udgør hhv. 44 %, 20 % og 15 % af den samlede NO_x-emission i 2014.

NO_x-emissionen forventes at falde 22 % (40 %) fra 2014 til 2020 (2030). Faldet sker hovedsageligt for vejtransport og andre mobile kilder og skyldes de stigende lovgivningsmæssige krav.

Det er ikke muligt at kvantificere effekten af ændringen i NO_x-afgift. Der blev ikke i 2013-fremskrivningen indregnet en effekt af den højere afgift, og tilsvarende er der i nærværende fremskrivning ikke indregnet en effekt af sænkningen af NO_x-afgiften.

NO_x-emissionen fra gødningshåndtering og landbrugsjorde er ikke omfattet af reduktionsmål for 2030. Dette skyldes, at standardmetoder først for nyligt er blevet inkluderet i EMEP/EEA Guidebook, at emissionerne fra især handelsgødning er meget høje og at denne kilde ikke var inkluderet, da måltallene for NO_x blev beregnet.

Svovldioxid, SO_2

De største kilder til SO_2-emission er fremstillingsvirksomhed og energiproduktion, der begge udgør 24 % af den nationale SO_2-emission i 2014.

SO_2-emissionen forventes at falde 12 % (10 %) fra 2014 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 svagt.

Andre flygtige organiske forbindelser end metan, NMVOC

De største kilder til emissioner af NMVOC er landbrug, efterfulgt af industrielle processer, husholdninger, udvinding, lagring og raffinering af olie og gas samt vejtransport. Disse kilder udgør hhv. 36 %, 26 %, 10 %, 9 %, og 8 % af den totale NMVOC-emission i 2014.

NMVOC-emissionen forventes at falde 3 % (6 %) fra 2014 til 2020 (2030). De største fald forventes for forbrænding i husholdninger, men væsentlige fald forventes også for vejtransport samt for andre mobile kilder.

NMVOC-emissioner fra gødningshåndtering og landbrugsjorde er ikke omfattet af reduktionsmål for 2030. Dette skyldes, at standardmetoder først blev inkluderet i EMEP/EEA Guidebook i 2013-versionen, at emissionerne fra især husdyr er meget høje og at denne kilde ikke var inkluderet, da måltallene for NMVOC blev beregnet.

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 62 % af den nationale $PM_{2,5}$-emission i 2014. Andre væsentlige kilder er vejtransport, andre mobile kilder og landbrug med hhv. 10 %, 9 % og 6 %.

$PM_{2,5}$-emissionen forventes at falde med 12 % (30 %) fra 2014 til 2020 (2030) hovedsageligt på grund af faldende emissioner fra husholdninger på grund af udskiftning af gamle brændeovne og kedler samt andre mobile kilder på grund af lavere emissionsgrænseværdier.

Sod, BC

Den største kilde til emission af BC er ikke-industriel forbrænding, hvilket hovedsageligt dækker over træfyring i husholdninger, som udgjorde 43 % af den totale BC-emission i 2014. Andre vigtige kilder er transport, andre mobile kilder og flygtige emissioner, som henholdsvis udgør 23 %, 21 % og 11 %.

BC-emissionen forventes at falde med 28 % (46 %) fra 2014 til 2020 (2030) hovedsageligt på grund af faldende emissioner fra transport og andre mobile kilder, hvilket skyldes lavere partikelemissionsgrænseværdier.

Emissionsfremskrivning pr. sektor

Stationær forbrænding

Udviklingen i emissionen fra stationær forbrænding er hovedsageligt et resultat af udviklingen i forbruget af de forskellige brændsler. Forbruget af træ i produktionen af el og varme forventes at stige. På grund af højere emissionsfaktorer for træ, betyder det en svag stigning i emissionerne fra denne sektor. Forbruget af kul er fremskrevet til at være på samme niveau i 2030 som i 2015. Der er dog et dyk i det forventede forbrug omkring 2020, hvilket kan ses i emissionsudviklingen.

Da den seneste officielle energifremskrivning kun dækker perioden frem til 2025, så er der antaget et konstant brændselsforbrug for årene 2025-2030. Dette betyder, at emissionerne for det meste er konstante i denne periode. Undtagelsen er hvor der er en udvikling i emissionsfaktorer, hvilket f.eks. er tilfældet for træfyring i husholdninger fordi der antages en løbende udskiftning af gamle brændeovne og -kedler.

Den samlede NO_x-emission stiger fra 2015 til 2025 på grund af et stigende forbrug af træ i el- og varmesektoren. Emissionsfaktoren for træ er højere end for både naturgas og kul, som er de andre betydende brændsler. Den øgede mængde biogas, som hovedsageligt forbrændes i motorer, har også en højere emissionsfaktor med deraf følgende stigning i emissionen. NO_x-emissionen fra gasturbinerne på Nordsøen er fremskrevet til at stige væsentligt. Fra 2015 til 2025 stiger emissionen med 15 % på grund af et stigende energiforbrug.

SO_2-emissionen falder svagt fra 2015 til 2025 på grund af et fald i olieforbruget. Faldet finder hovedsageligt sted i fremstillingsvirksomhed, mens emissionerne fra de øvrige sektorer holder sig nogenlunde konstante.

Fra 2015 til 2030 er NMVOC-emissionen fremskrevet til at falde på grund af en faldende emissionsfaktor for træfyring i husholdninger. Dette skyldes, at gamle brændeovne og kedler antages løbende at blive udskiftet med nyere teknologier med lavere emissionsfaktorer. Husholdninger udgør mellem 68 % og 81 % af den samlede emission fra stationær forbrænding i fremskrivningsperioden, med den højeste andel i starten af perioden.

Emissionen af $PM_{2.5}$ steg i de historiske år som følge af stigende træforbrug i husholdninger. Fra 2015 til 2030 forventes $PM_{2.5}$ emissionen at falde på grund af udskiftning af gamle brændeovne og brændekedler. Husholdninger udgør mellem 81 % og 89 % af den samlede emission fra stationær forbrænding i fremskrivningsperioden, med den højeste andel i starten af perioden.

Emissionen af sod steg i de historiske år som følge af stigende træforbrug i husholdninger. Fra 2015 til 2030 forventes BC-emissionen at falde på grund af udskiftning af gamle brændeovne og brændekedler. Husholdninger udgør mellem 83 % og 87 % af den samlede emission fra stationær forbrænding i fremskrivningsperioden, med den højeste andel i starten af perioden.

Vejtransport

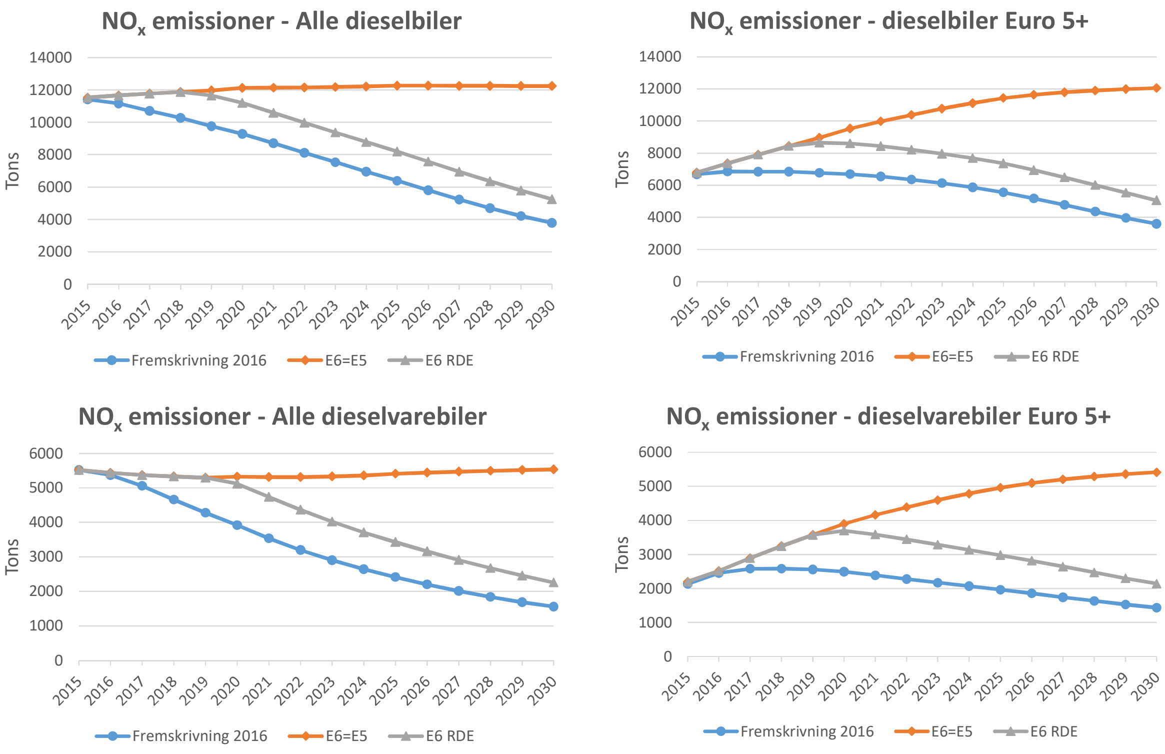
Vejtrafikkens energiforbrug og SO_2-emissioner ligger på et konstant niveau i prognoseperioden 2015-2030. Personbiler har den største andel af energiforbruget, fulgt af lastbiler, varebiler, busser og tohjulede køretøjer. Udviklingen i SO_2-emissionen afhænger af energiforbruget, da vejtrafikkens brændstof har et fast svovlindhold på 10 ppm.

Vejtrafikkens NMVOC-emissioner forventes at falde med 27 % fra 2015 til 2030. Størstedelen af NMVOC-emissionerne kommer fra benzinpersonbiler, og fra 2015-2024 beregnes et emissionsfald på 28 % fra disse køretøjer pga. udfasningen af ældre Euro-normer med mindre effektive katalysatorer. Efter 2024 stiger NMVOC-emissionen proportionalt med trafikarbejdet for benzinbiler.

For $PM_{2.5}$ og BC beregnes totale emissionsfald på hhv. 81 % og 94 % mellem 2015 og 2030 altovervejende pga. indførslen af dieselpartikelfiltre for Euro 5 personbiler og varebiler samt Euro VI lastbiler og busser. Personbiler er den største emissionskilde, fulgt af varebiler, lastbiler og busser. Emissionsreduktionen er større for BC end for $PM_{2.5}$ pga. dieselfiltrenes store rensningseffektivitet for BC.

For NO_x forventes et emissionsfald på 72 % fra 2015-2030. For lastbiler og busser bliver emissionsreduktionerne hhv. 83 % og 86 pga. indførslen af skærpede emissionskrav, der i praksis gradvist sænker emissionsfaktorerne fra Euro III og frem. For personbiler og varebiler bliver emissionsfaldene mindre (hhv. 64 % og 72 %) pga. dieselbilernes (og varebilernes) velkendte problemer med forhøjede NO_x-emissioner i den virkelige trafik i forhold til emissionerne ved typegodkendelse.

Den nuværende prognose bruger COPERT IV-modellens basisemissionsfaktorer, der tager højde for at dieselpersonbiler og –varebiler udleder mere NO_x i den virkelige trafik sammenlignet med emissionerne ved typegodkendelse. Men nye publicerede høje emissionsmålinger for Euro 6 dieselpersonbiler skaber et behov for at beregne emissionskonsekvenserne i to situationer, hvor NO_x-emissionsfaktorerne for Euro 6 dieselkøretøjerne som udgangspunkt er endnu højere end COPERT IV-modellens anviste emissionsfaktorer.



Figur DS1 Blå kurve) NO_x resultater for den nuværende fremskrivning, Orange kurve) Ingen forbedring af Euro 6-faktorerne (E6 = E5) og Grå kurve) Tidlig E6 = E5, derefter Euro 6-faktorer forventet fra den vedtagne RDE (Real Driving Emission) lovgivning.

NO_x-emissionskurverne på Figur DS1 viser resultatet af de følgende tre beregningssituationer for dieselpersonbiler og -varebiler:

- 2016 prognosen: Den nuværende prognose der bruger COPERT IV-modellens basisemissionsfaktorer.
- Euro 6 = Euro 5: Dette scenarie beskriver en situation hvor emissionsfaktorerne for nye biler ikke ændrer sig, når Euro 6-emissions-normen træder i kraft (Euro 6 = Euro 5).
- Euro 6 RDE (Real Driving Emission): I dette scenarie fastholdes Euro 6-emissionsfaktorerne på Euro 5-niveau, indtil de trinvist reduceres for dieselbiler (i 2018/2020) og dieselvarebiler (i 2019/2021) svarende til EU's RDE-lovgivningskrav (Euro 6 RDE).

I Euro 6 = Euro 5-scenariet beregnes NO_x-emissionsstigninger for diesel personbiler*[dieselvarebiler]* på 31 %*[36 %]* i 2020 og 224 %*[256 %]* i 2030 i forhold til den nuværende fremskrivning. De samlede vejtrafikemissioner forøges med hhv. 20 % og 131 % i 2020 og 2030. I Euro 6 RDE-scenariet beregnes NO_x-emissionsstigninger for dieselpersonbiler*[dieselvarebiler]* på 20 %*[31 %]* i 2020 og 39 %*[45 %]* i 2030 i forhold til den nuværende fremskrivning. Totalt set stiger vejtrafikemissionerne med hhv. 15 % og 23 % i 2020 og 2030.

Andre mobile kilder

Andre mobile kilder er opdelt i underkategorierne: National søfart, fiskeri, indenrigs flytrafik, jernbane, arbejdsredskaber og –maskiner indenfor landbrug/skovbrug, industri, handel/service og husholdninger samt øvrige kilder (militæraktiviteter og fritidsfartøjer).

For andre mobile kilder falder energiforbruget med 5 % fra 2015-2030. I samme periode stiger SO_2-emissionen med 8 % pga. en stigning i energiforbruget for fiskeri, der benytter marin diesel med et relativt højt svovlindhold. For andre mobile kilder falder de beregnede NO_x, NMVOC, $PM_{2.5}$ og BC-emissioner med hhv. 55 %, 16 %, 64 % og 79 %.

SO_2-emissionerne for andre mobile kilder er ubetydelige undtagen for skibe. Dog har de skærpede SECA (SO_x emission control areas) krav til svovlindhold for tung olie i Østersøen og Nordsøen betydet et stort fald i skibes SO_2-emissioner fra 2015.

Langt størstedelen af NMVOC-emissionerne kommer fra benzindrevne havemaskiner i handel og service. De samme typer af maskiner bidrager også med store emissioner for husholdninger. NMVOC-emissionerne forventes at falde i prognoseperioden pga. indfasningen af de mere miljøvenlige Stage II og Stage V emissionsteknologier for en vis del af de anvendte maskintyper. For landbrug/skovbrug og industri falder NMVOC-emissionerne igennem prognoseperioden pga. de gradvist skrappere emissionskrav for dieselmaskiner samt et faldende energiforbrug.

Industriens arbejdsredskaber og -maskiner er den største $PM_{2.5}$-emissionskilde for andre mobile kilder i starten af prognoseperioden, fulgt af landbrug/skovbrug, fiskeri og søfart. De to sidstnævnte kategorier er de største kilder til $PM_{2.5}$-emissionen i slutningen af prognoseperioden. $PM_{2.5}$-emissionerne fra landbrug/skovbrug og industri falder igennem prognoseperioden pga. af udbredelsen af nye motorer der opfylder de fremtidige emissionsstandarder.

$PM_{2.5}$-emissionerne fra fiskefartøjer stiger proportionalt med det stigende energiforbrug igennem prognoseperioden. For national søfart gælder, at SECA-kravene til svovlindholdet i tung olie har medført et stort fald i $PM_{2.5}$-emissionen i 2015.

BC udgør en del af de samlede partikler og faldet i BC-emissionen i prognoseperioden skyldes den generelle reduktion i PM-emissionen fra dieseldrevne maskiner indenfor landbrug/skovbrug og industri samt indførslen af Stage V-emissionsnormen fra 2019/2020. For at overholde Stage V-partikelnormen for motorstørrelser >= 19 kW er det nødvendigt at anvende partikelfiltre som i tilgift har en meget høj rensningseffektivitet for BC.

For landbrug/skovbrug, industri, national søfart, fiskeri og jernbane forventes markante NO_x-emissionsreduktioner igennem prognoseperioden pga. indfasningen af renere emissionsteknologier der opfylder de fremtidige emissionskrav.

Flygtige emissioner fra brændsler

Sektoren omfatter emissioner fra efterforskning, udvinding, raffinering, lagring, håndtering og transport af brændsler, hvoraf de vigtigste kilder er SO_2 og NMVOC fra olie og BC fra kul.

SO_2 stammer hovedsageligt fra raffinering af olie, og fluktuerer årligt pga. uforudsigelige forhold på raffinaderierne, f.eks. virkningsgraden af svovlgenindvindingsanlæg. Gennemsnittet for de seneste fem historiske år er anvendt for alle fremskrivningsår. SO_2 fra sektoren bidrager med 7-8 % til den nationale total SO_2-emission i årene 2015-2030.

De vigtigste NMVOC-kilder er processer på raffinaderierne, aktiviteter på land og til vands i forbindelse med olie- og gasproduktion samt tankstationer, hvoraf førstnævnte er den største kilde. Flygtige emissioner fra raffinaderier er uforudsigelige, og der foreligger kun få målinger. Som for SO_2, er gennemsnittet for de seneste fem historiske år anvendt for fremskrivningsårene, for at tage højde for de årlige fluktuationer. Emissioner fra aktiviteter i forbindelse med olie- og gasproduktion samt tankstationer følger prognosen for hhv. olie- og gasproduktion samt benzinforbrug til transport. NMVOC fra sektoren bidrager med 9 % til den nationale totale NMVOC-emission i årene 2015-2030 (Tabel S.3).

Tabel S.3 Flygtige NMVOC-emissioner.

	2015	2020	2025	2030
NMVOC-emission, ton	9191	9255	8649	8974
Andel af national total NMVOC-emission	9 %	9 %	9 %	9 %

Den største kilde til BC-emissioner er lagring af kul. BC fra sektoren bidrager med 7 % til den nationale totale BC-emission i 2015 stigende til 13 % i 2030 (Tabel S.4). Den stigende andel skyldes faldende emissioner i andre sektorer (hovedsageligt transport og små forbrændingsanlæg), da BC-emissionerne fra kullagring er på samme niveau i fremskrivningsårene, og alene varierer i forhold til kulforbruget.

Tabel S.4 Flygtige BC-emissioner.

	2015	2020	2025	2030
BC-emission, ton	276	224	275	275
Andel af national total BC-emission	7 %	8 %	11 %	13 %

Industrielle processer og produktanvendelse

Fremskrivningen af emissioner fra sektoren industrielle processer og produkt anvendelser (IPPU) er generelt baseret på fremskrivning af aktivitetsdata for de enkelte kildekategorier samt afledte emissionsfaktorer (IEF) for 2014. Aktivitetsdata kan fremskrives på følgende fire måder:

- Ved at ekstrapolere et gennemsnit af repræsentative historiske år vha. fremskrevne produktionsværdier for glas-, stål- og cement- og byggeriindustrierne, som er tilgængelige fra Energistyrelsen.
- Ved at estimere et forventet fremtidigt aktivitetsniveau samt det antal år den pågældende kildekategori er om at nå dette niveau.
- Ved at anvende et gennemsnit af repræsentative historiske år.
- Ved lineær regression af en signifikant udvikling i de historiske data.

Tabel S5 giver et overblik over emissionerne fra IPPU-sektoren og de største kilder til hvert stof.

Tabel S5 Overblik over emissioner fra sektoren industrielle processer og produkt anvendelser.

Stof		Enhed	2015	2020	2025	2030	Ændring i emission 2015-2030, %
SO_2							
	Emissioner fra IPPU	Mg	696,6	784,4	835,8	877,8	26,0
	Andel af national emission, %	-	6,2	7,8	8,2	8,6	
	Største kilde i IPPU: Keramik	Mg	560,3	648,5	700,3	742,7	32,5
	Andel af IPPU, %	-	80,4	82,7	83,8	84,6	
NO_x							
	Emissioner fra IPPU	Mg	69,1	67,4	65,7	64,0	-7,4
	Andel af national emission, %	-	0,1	0,1	0,1	0,1	
	Største kilde i IPPU: Grillkul	Mg	32,7	32,7	32,7	32,7	0,0
	Andel af IPPU, %	-	47,3	48,4	49,7	51,0	
NMVOC							
	Emissioner fra IPPU	Mg	28865	27942	27176	26539	-8,1
	Andel af national emission, %	-	26,9	27,1	27,0	26,6	
	Største kilde i IPPU: Opløsningsmidler (NFR 2D3i)	Mg	18778	18164	17646	17209	-8.3
	Andel af IPPU, %	-	65.1	65.0	64.9	64.8	
$PM_{2.5}$							
	Emissioner fra IPPU	Mg	698,5	746,3	769,9	786,8	12,6
	Andel af national emission, %	-	3,7	4,6	5,4	6,2	
	Største kilde til $PM_{2.5}$ i IPPU: Stenbrud/minedrift	Mg	213,4	246,9	266,6	282,8	32,5
	Andel af IPPU, %	-	30,5	33,1	34,6	35,9	
BC							
	Emissioner fra IPPU	Mg	2,0	2,3	2,4	2,6	30,9
	Andel af national emission, %	-	0,1	0,1	0,1	0,1	
	Største kilde til BC i IPPU: Stenuld	Mg	0,7	0,8	0,9	0,9	32,5
	Andel af IPPU, %	-	36,2	36,5	36,6	36,7	

Den stigende udvikling i de fremskrevne SO_2-emissioner skyldes en stigende emission fra produktionen af keramik (mursten, tegl og ekspanderede lerprodukter), se Tabel S5. Keramik er fremskrevet vha. de fremskrevne produktionsværdier fra ENS. Kun det meget lille bidrag til SO_2-emissionen fra anvendelse af tobak har en faldende udvikling, de resterende fire kildekategorier er estimeret til at være konstante i fremskrivningen.

Kun tre små kildekategorier i IPPU fører til NO_x-emissioner og kun den mindste af disse tre (anvendelse af tobak) forventes at falde; de øvrige to kildekategorier holdes konstante frem mod 2030.

Den dominerende kilde til NMVOC-emissioner er fra diffus anvendelse, hvilket omfatter mange forskellige aktiviteter og produkter samt et stort antal kemiske forbindelser (NMVOC). Emissioner fra industrielle aktiviteter er typisk relateret til relativt lave emissionsfaktorer. Alle fremskrevne kategorier viser et fald i NMVOC-emissioner. Der er dog en stagnation i de seneste otte år af den historiske opgørelse, dvs. de fire kategorier for anvendelse af opløsningsmidler viser tilnærmelsesvis konstante emissioner i perioden fra 2007 til 2014.

Den mest realistiske fremskrivning i perioden fra 2015 til 2030 er beskrevet ved en vægtning på 25 % af en eksponentiel repræsentation af historiske data fra 1995 til 2014 og 75 % af en tilnærmelsesvis konstant trend i de historiske emissioner fra 2007 til 2014. Hvis den konstante trend fortsætter i de kommende år, vil det være nødvendigt med en større vægtning af den konstante trend fra 2007 til rapporteringsåret sammenlignet med den eksponentielle tilpasning fra 1995 til rapporteringsåret. Dette er i overensstemmelse med nye informationer og data for produktion, salg og import/eksport til og fra EU fra European Solvents Industry Group (ESIG), som estimerer en stabiliseret vækst i Europa og sandsynligvis også i Danmark.

Imellem 52 % (2015) og 61 % (2030) af de fremskrevne $PM_{2.5}$-emissioner fra IPPU er fremskrevet vha. produktionsværdierne fra ENS. Den største af disse kilder, og den primære årsag til den stigende udvikling i $PM_{2.5}$-emissioner, er stenbrud og minedrift efter andre mineraler end kul. Omkring 25 % af $PM_{2.5}$-emissionerne fra IPPU forventes at forblive uændrede frem mod 2030. Den største af disse konstante kilder er bearbejdning af træ.

Der er syv kildekategorier i IPPU sektoren, som emitterer BC. Den største af disse er stenuldsproduktion, se Tabel S5. Den 33 % stigning i BC-emissionen, som forventes for 2015-2030, er beregnet baseret på produktionsværdierne fra ENS. Yderligere fire (af de syv) kildekategorier er fremskrevet på samme vis, hvilket samlet dækker omkring 95 % af de totale BC-emissioner fra IPPU.

Landbrug

I 2014 udgjorde emissionen af NMVOC fra landbrug 36 % af den totale emission, mens landbrug udgjorde 12 % af NO_x-emissionen og 11 % af $PM_{2,5}$-emissionen.

Den totale emission af NMVOC forventes at være stort set uændret fra 2014 til. Emissionen fra husdyrgødning stiger og dette især fra svin og malkekøer pga. forventet stigning i antal dyr. Emissionen af NMVOC fra afgrøder og halmafbrænding forventes at falde fordi landbrugsarealet forventes at falde.

Den totale emission af NO_x forventes at falde med ca. 2 % fra 2014 til 2030. Emissionen fra husdyrgødning falder især for svin og malkekøer, fordi der forventes en ændret opstaldning af dyrene, så der bliver en større andel af gyllebaserede systemer, og disse har en lavere emissionsfaktor end staldsystemer med fast gødning. Emissionen af NO_x fra handelsgødning, slam og halmafbrænding forventes at falde, fordi landbrugsarealet forventes at falde.

Den totale emission af $PM_{2,5}$ forventes at stige en smule fra 2014 til 2030 pga. stigning i emissionen fra husdyrgødning. Stigningen i emission fra husdyrgødning sker især for svin pga. forventet stigning i antal dyr. Emissionen af $PM_{2,5}$ for markoperationer og halmafbrænding forventes at falde pga. af forventet fald i landbrugsarealet.

Affald

Da al forbrænding af husholdningsaffald, industriaffald og farligt affald i Danmark sker med indvinding af energien i form af elektricitet og/eller varme, så er emissionen fra disse aktiviteter inkluderet under stationær forbrænding både i emissionsopgørelsen og i emissionsfremskrivningen. Kilderne rapporteret i affaldssektoren er kremeringer af dyr og mennesker, ildebrande samt kompostering. For de stoffer, der er omfattet af denne fremskrivning er kompostering ikke relevant, da emissioner af NO_x, SO_2, NMVOC, PM og BC ikke estimeres for kompostering i modsætning til f.eks. NH_3 og CH_4. Kompostering er derfor ikke beskrevet yderligere i denne rapport.

For årene 2015-2030 bidrager affald (hovedsageligt ildebrande) med 5-6 % af den samlede SO_2-emission. For de resterende stoffer er affaldssektorens bidrag omkring eller under 1 %. Emissionerne for alle stoffer er fremskrevet til at være relativt konstante gennem fremskrivningsperioden.

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. The models were updated and further developed in 2013 (Nielsen et al., 2013).

This project has updated the projection models taking into account changes in projected activity data and emission factors since the latest projection project.

Projections have been made for all anthropogenic sources of emissions included in the Danish emission inventory. The calculation methods and activity data for the individual sectors are presented in Chapter 3-8 and the results are discussed. A brief discussion on the most important general assumptions, i.e. the official projections for fuel consumption and transport is included in Chapter 2.

The results of this projection have also been published in a memorandum (in Danish)[1]. This memorandum also includes a discussion of the uncertainties. Discussion on the uncertainties is not included in this report.

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 recalculated to a "ceiling" value.

1 http://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notater_2016/DCE_notat_fremskrivning.pdf

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 – 2014	Tonnes	11 419	113 356	105 785	73 318	18 349
Projected emission – 2020	Tonnes	9 665	88 890	103 031		15 919

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

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.

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 2030 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 2030 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 some 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.

Annual emissions are available for the years until 2014, while the emissions for 2015 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.

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

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).

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).

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.

Exceedance 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.

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, power 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, 2013) 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. (2016).

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 2014, the most important acidification factor in Denmark was ammonia nitrogen and the relative contributions for SO_2, NO_x and NH_3 were 6 %, 36 % and 58 %, respectively. However, with regard to long-range transport of air pollution, SO_2 and NO_x are still the most important pollutants.

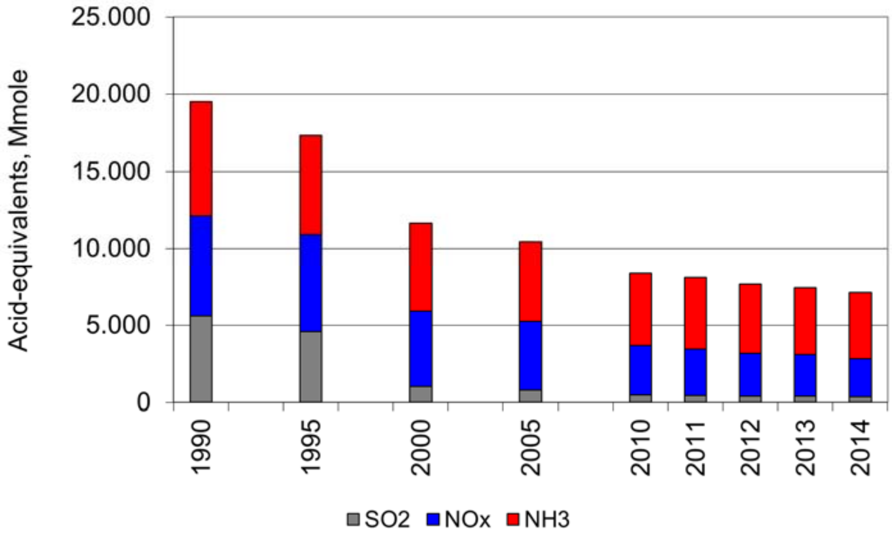


Figure 1.1 Emissions of NH_3, NO_X and SO_2 in acid equivalents.

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 2014, the total emission decreased by 93.6 %. 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 24 % 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 65 % decrease in the years 2000 to 2014.

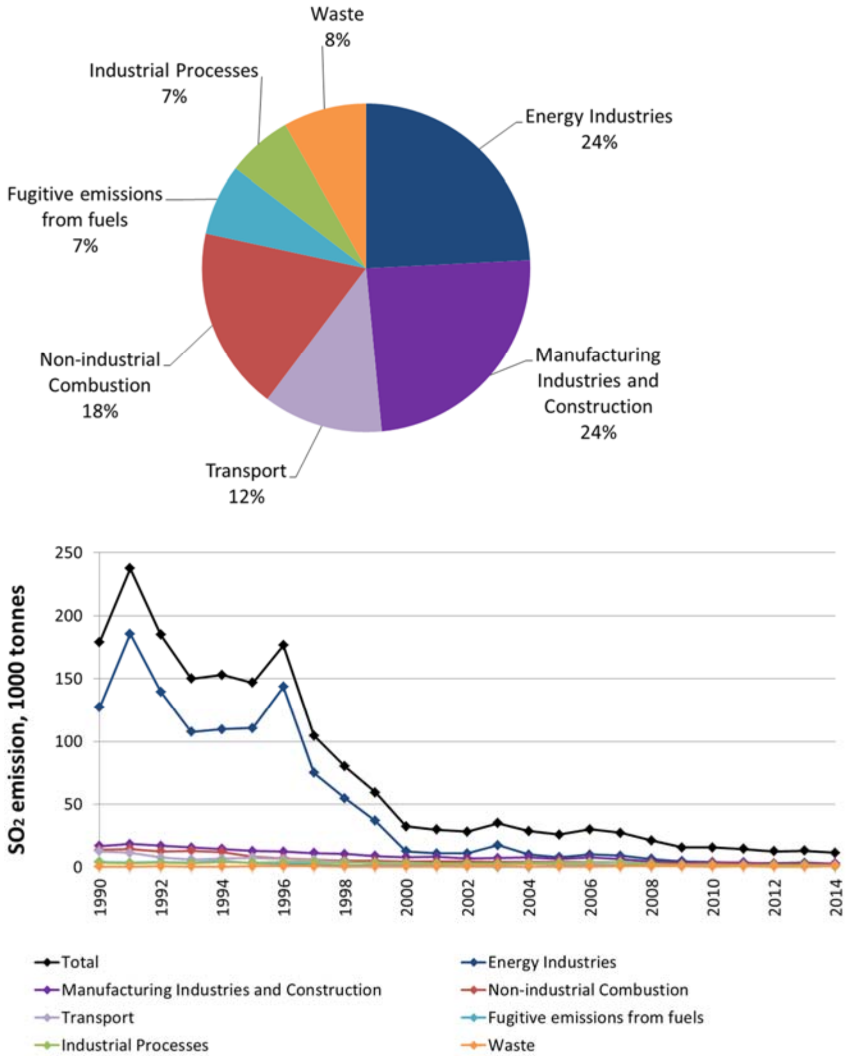


Figure 1.2 SO_2 emissions. Distribution by the main sectors (2014) and time series for 1990 to 2014.

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 2014, 44 % 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 2014. In the same period, the total emission decreased by 62 %. 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. Agriculture is accounting for a significant part of the NO_x emission, this is mainly related to emissions from the application of mineral fertiliser.

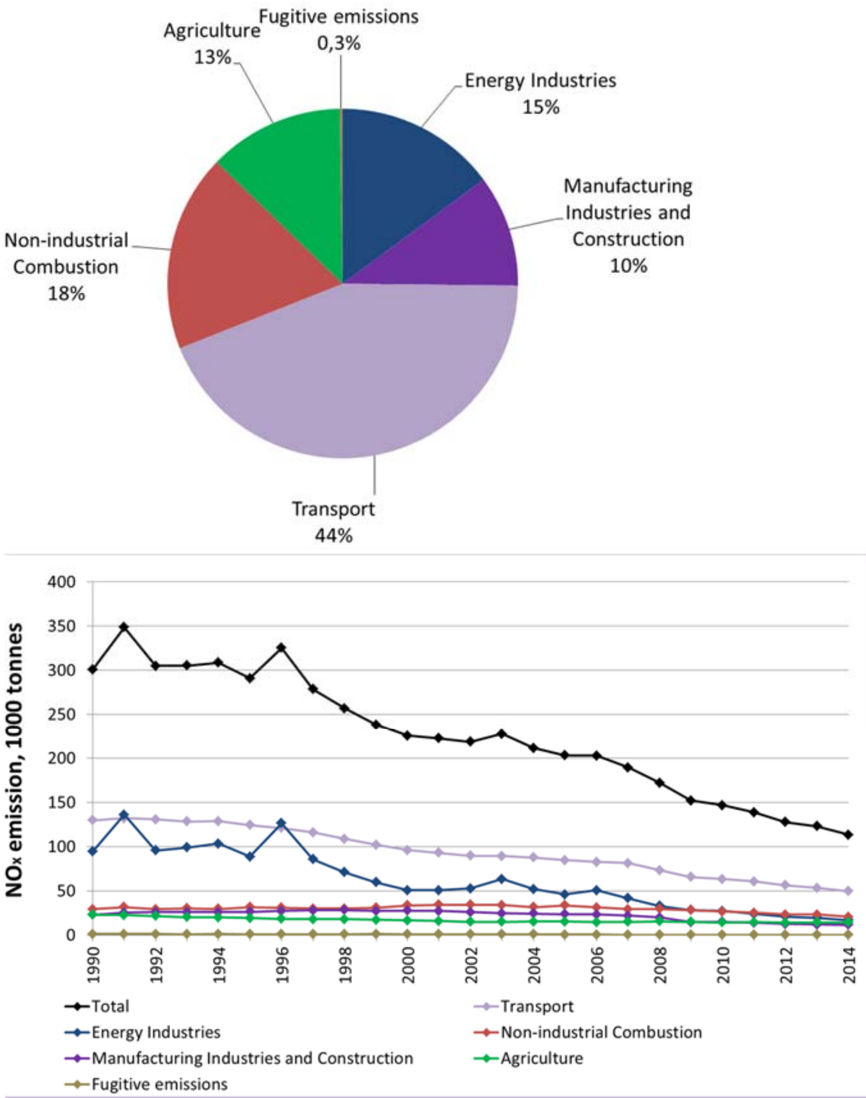
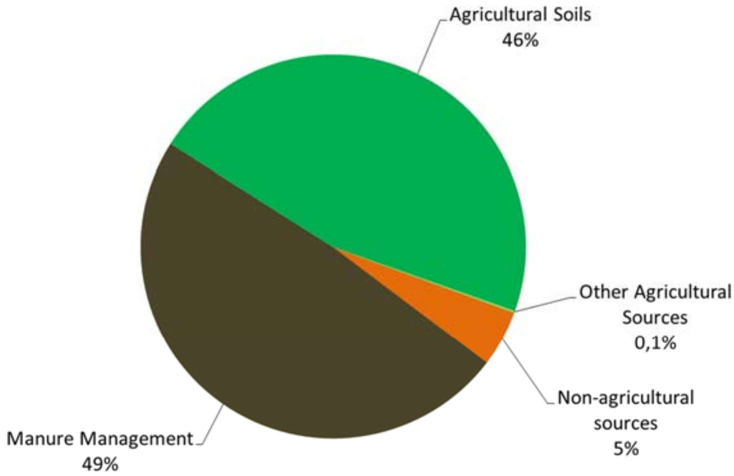


Figure 1.3 NO_X emissions. Distribution by main sectors (2014) and time series for 1990 to 2014.

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 (49 %), and the largest losses of ammonia occur during the handling of the manure in stables and in field application. For agricultural soils, which accounts for 46 %, the main sources are application of mineral and animal fertiliser on fields and emissions from growing crops. Minor agricultural NH_3 emissions come from sewage sludge used as fertiliser and field burning.

The total ammonia emission decreased by 42 % from 1990 to 2014. 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.



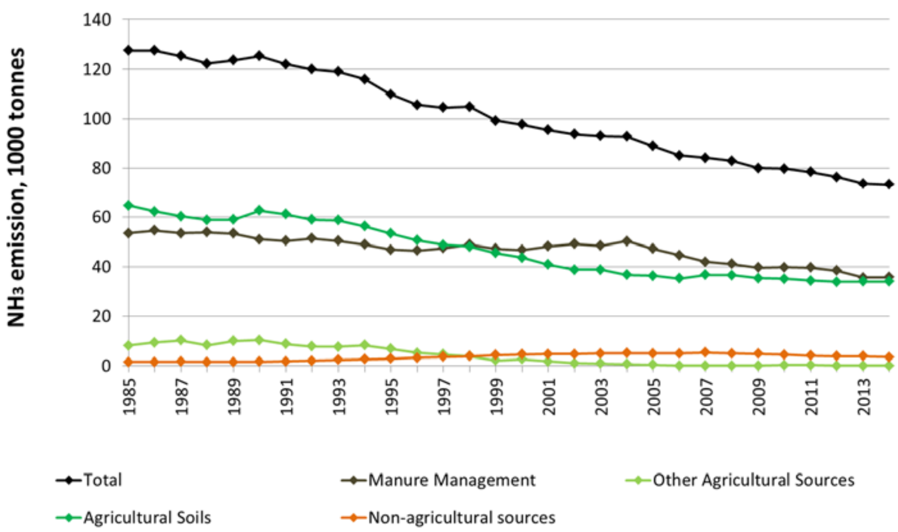


Figure1.4 NH_3 emissions. Distribution by the main sectors (2014) and time series for 1990 to 2014.

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 animal husbandry and manure management as well as 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 48 % from 1990 to 2014, largely due to the increased use of catalyst cars and reduced emissions from use of solvents.

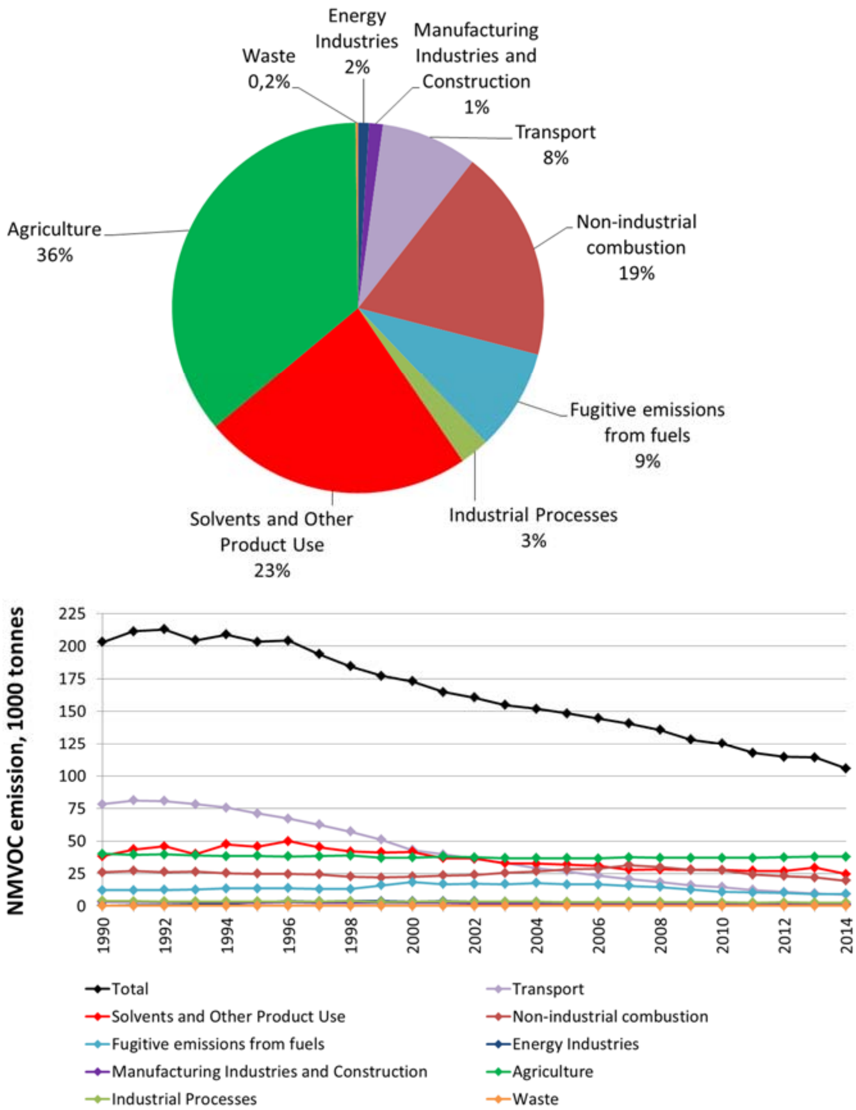


Figure 1.5 NMVOC emissions. Distribution by main sectors (2014) and time series for 1990 to 2014.

Particulate Matter

The particulate matter (PM) emission inventory has been reported for the years 2000-2014. 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 (59 %), road traffic (10 %) and other mobile sources (9 %). For the latter, the most important source is off-road vehicles and machinery in the industrial sector (34 %). For the road transport sector, exhaust emissions account for the major part (52 %) of the emissions.

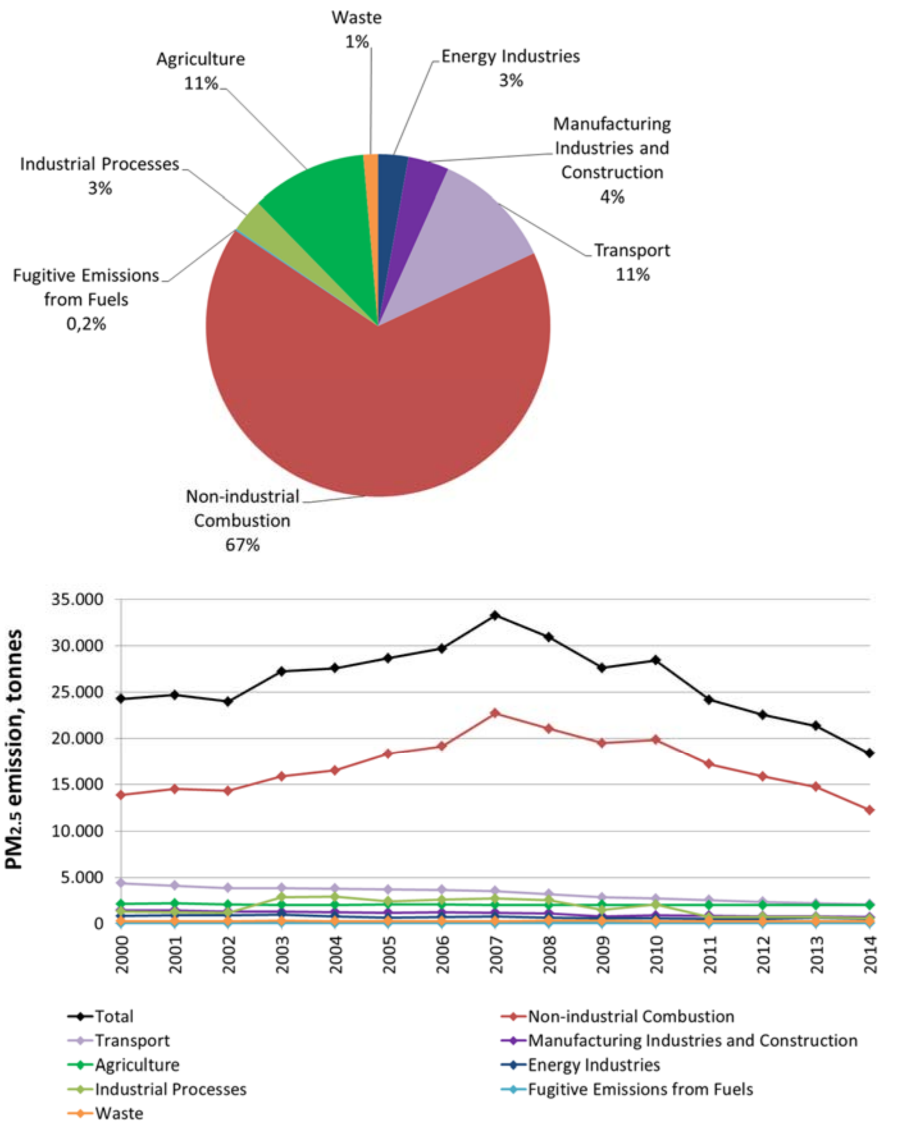


Figure 1.6 $PM_{2.5}$ emissions. Distribution by main sectors (2014) and time series for 2000 to 2014.

Black carbon

The largest black carbon (BC) emission sources are the residential sector (39 %), road traffic (21 %) and fugitive emissions from fuel (11 %). For the latter, the dominant source is coal storage and handling.

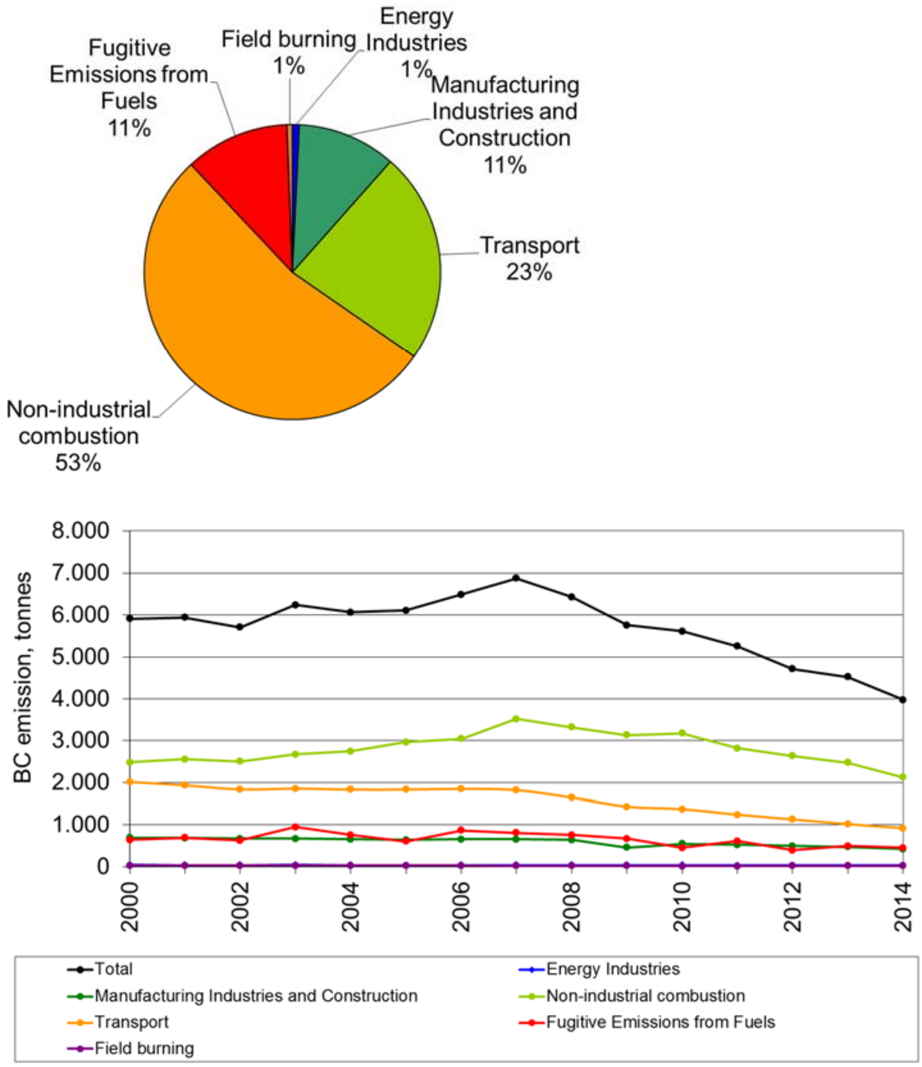


Figure 1.7 BC emissions. Distribution by main sectors (2014) and time series for 2000 to 2014.

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

In order to model the emission development as a consequence of changes in technology and legislation, the activity rates and emission factors of the emission source should be aggregated at an appropriate level, at which relevant parameters such as process type, reduction targets and installation type can be taken into account. If detailed knowledge and information of the technologies and processes are available, the aggregated emission factor for a given pollutant and sector can be estimated from the weighted emission factors for relevant technologies as given in Equation 1.3:

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, EF_s,k is the emission factor for a given technology and k is the type of technology.

Official Danish forecasts of activity rates are used in the models for those sectors for which 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, 2013), 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, 2013) and the SNAP (Selected Nomenclature for Air Pollution) sector categorisation and nomenclature are used. The detailed level makes it possible to aggregate to both the UNECE/EMEP nomenclature 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 November 2015 (DEA, 2015).

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. All elements in the Energy Agreement from 2012, the National Budgets up until the 2016 version, Growth Plan DK and the Growth agreement from 2014 including the cancelation of the supply security tax and the reduction in PSO charges for the industry have been included in the projection.

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 (2015) 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 2015 published by the International Energy Agency. The assumptions related to economic growth are based on information from the Danish Ministry of Finance, published in April 2015.

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[2].

Key points in the November 2015 projection

The projection made by the DEA includes three scenarios. The scenarios are named A, B and FM. This projection is based on the A scenario. More details on the specific assumptions made in the different scenarios are included in the report by the DEA (DEA, 2015).

The final energy consumption is projected to increase from 596 PJ in 2014 to 606 PJ in 2025. This covers a very small decrease in final energy consumption in households, while the energy consumption in the transport sector and commercial/industrial sector is projected to increase. The energy consumption for the transport sector is projected to increase from 208 PJ in 2014 to 213 PJ in 2025. The increased energy efficiency of the vehicle fleet contributes to lessen the increase in energy consumption.

[2] In Danish: http://www.ens.dk/info/tal-kort/fremskrivninger-analyser-modeller/fremskrivninger
In English (limited): http://www.ens.dk/en/info/facts-figures/scenarios-analyses-models/models

Gross energy consumption is projected to decrease with approximately 2 % 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 several large off-shore wind farms (Anholt, Horn Rev 3 & Kriegers Flak). The consumption of fossil fuels is projected to decrease significantly (109 PJ until 2020 corresponding to approximately 19 %). However, the fossil fuels are partially replaced by increased use of biogenic fuels, i.e. biomass (47 PJ), biofuels in the transport sector (6 PJ) and biogas (9 PJ). From 2020 onwards the consumption of fossil fuels is projected to remain relatively constant with an increase in the coal consumption and a slight decrease 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.

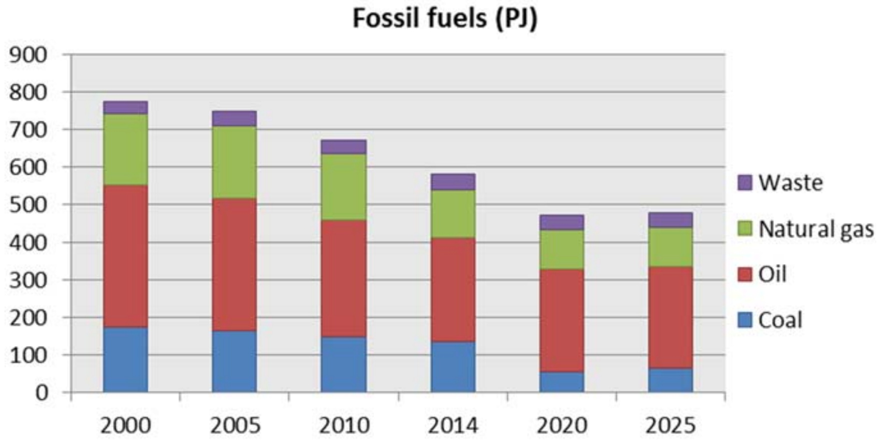

Figure 2.1 Development of fossil fuels in the gross energy consumption.

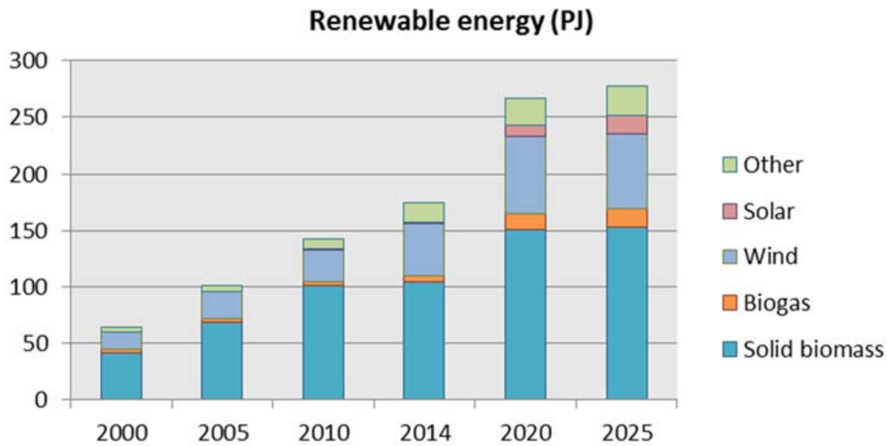

Figure 2.2 Development of renewable energy in the gross energy consumption.

The energy projections only covered the years until 2025. For the purposes of the emission projection the fuel consumption has been assumed constant between 2025 and 2030.

Overall comparison between 2012 and 2015 projection

To understand the differences between the previous emission projection and the current projection, a comparison is made below between the two energy projections underpinning the emission projections.

Table 2.1 shows the gross energy consumption (Observed energy consumption) for 2020 and 2025 as projected in the 2012 projection and 2015 projection. It can be seen that the total gross energy consumption projected in the 2015 projection is somewhat lower than the 2012 projection. The consumption of oil and natural gas are lower in the 2015 projection, while the coal consumption is lower in 2020 but higher in 2025. The consumption of solid biomass shows an increase, while estimates for biogas and other renewables have been lowered in the 2015 projection.

Table 2.1 Comparison of gross energy consumption in the 2012 energy projection (DEA, 2012) and the 2015 energy projection (DEA, 2015).

		2020	2025
2012 projection	**Total**	**757**	**772**
2012 projection	Coal	69	58
2012 projection	Oil	300	307
2012 projection	Natural gas	115	115
2012 projection	Fossil waste	20	20
2012 projection	Solid biomass	132	133
2012 projection	Biogas	17	24
2012 projection	Wind	65	72
2012 projection	Other renewables	39	43
2015 projection	**Total**	**737**	**754**
2015 projection	Coal	55	64
2015 projection	Oil	275	273
2015 projection	Natural gas	102	102
2015 projection	Fossil waste	39	37
2015 projection	Solid biomass	151	152
2015 projection	Biogas	14	17
2015 projection	Wind	68	66
2015 projection	Other renewables	24	26

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 2020 and 2025 as projected in the 2012 projection and 2015 projection. The 2015 projection for transport and industry and services shows a lower level compared to the 2012 projection, while the energy consumption in households are at a higher level compared to the 2012 projection.

Table 2.2 Comparison of final energy consumption in the 2012 energy projection (DEA, 2012) and the 2015 energy projection (DEA, 2015).

		2020	2025
2012 projection	**Total**	**620**	**629**
2012 projection	Transport	229	236
2012 projection	Industry and services	214	213
2012 projection	Households	176	179
2015 projection	**Total**	**596**	**606**
2015 projection	Transport	213	213
2015 projection	Industry and services	200	208
2015 projection	Households	184	185

2.2 Transport projection

Fleet and mileage data for the road transport projections are provided by DTU Transport. The data for the projection period 2015-2035 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 (2015).

Aggregated fleet and mileage data for passenger cars, vans, trucks and buses are forecasted for the years 2015-2030 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. 2014).

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, 2012: Danmarks Energifremskrivning 2012 (In Danish). Available at: http://www.ens.dk/sites/ens.dk/files/info/tal-kort/fremskrivninger-analyser-modeller/fremskrivninger/danmarks_energifremskrivning_2012_endelig_v1.2.pdf (27-04-2016).

DEA, 2015: Danmarks Energifremskrivning 2015 (In Danish). Available at: http://www.ens.dk/sites/ens.dk/files/info/tal-kort/fremskrivninger-analyser-modeller/fremskrivninger/danmarks_energi-_og_klimafremskrivning_2015_-_web.pdf (27-04-2016).

Jensen, T.C., O. 2015: Dokumentation af konvertering af trafiktal til emissionsopgørelser, arbejdsnotat 35187, 29 pp. DTU Transport, 2015.

3 Stationary combustion

Annual emissions are available for the years until 2014, while the presented emissions for 2015-2030 are projections.

For the years 2015-2030, emissions from stationary combustion will make up around 70 % of the national SO_2 emissions. The NO_x emission from stationary combustion is about the same in 2015 as in 2030, but the decreasing national emissions causes the contribution from stationary combustion to increase from 25 % in 2015 to 42 % in 2030.

The total NMVOC and particle emissions from stationary combustion decrease throughout the projected time series. NMVOC and $PM_{2.5}$ make up for 13 % and 68 % of the national emission in 2015, respectively, and 10 % and 63 % in 2030, 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 2014 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 2014 emission factors are included in the latest Informative Inventory Report (IIR) (Nielsen et al., 2016) 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 2014 emission data from annual environmental reports/PRTR data or projected emission factors provided by plant owners.

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.

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 'Projection 2015-2030' 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 'Projection 2015-2030' 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 'Projection 2015-2030' 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.

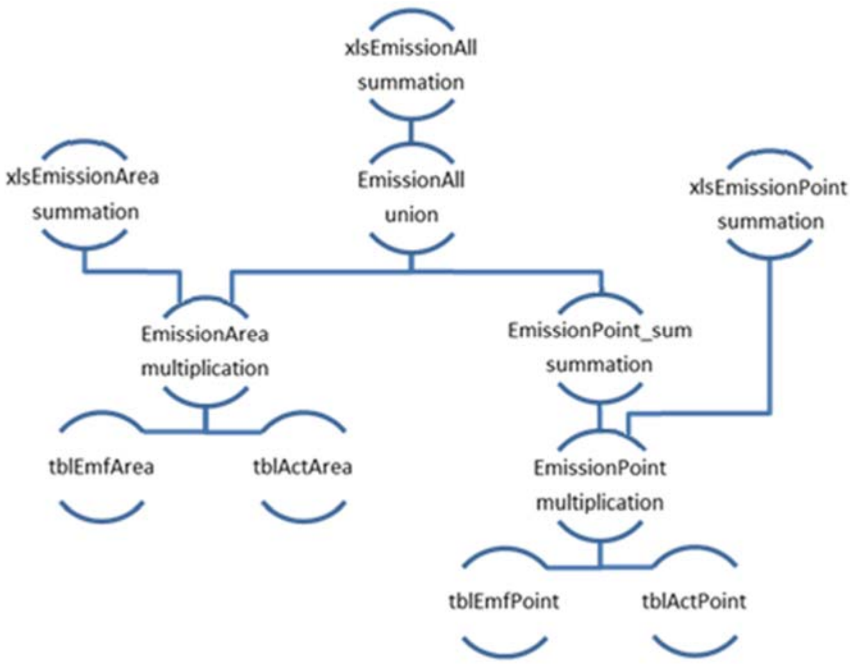

Figure 3.1 Overall construction of the database and calculation of emissions.

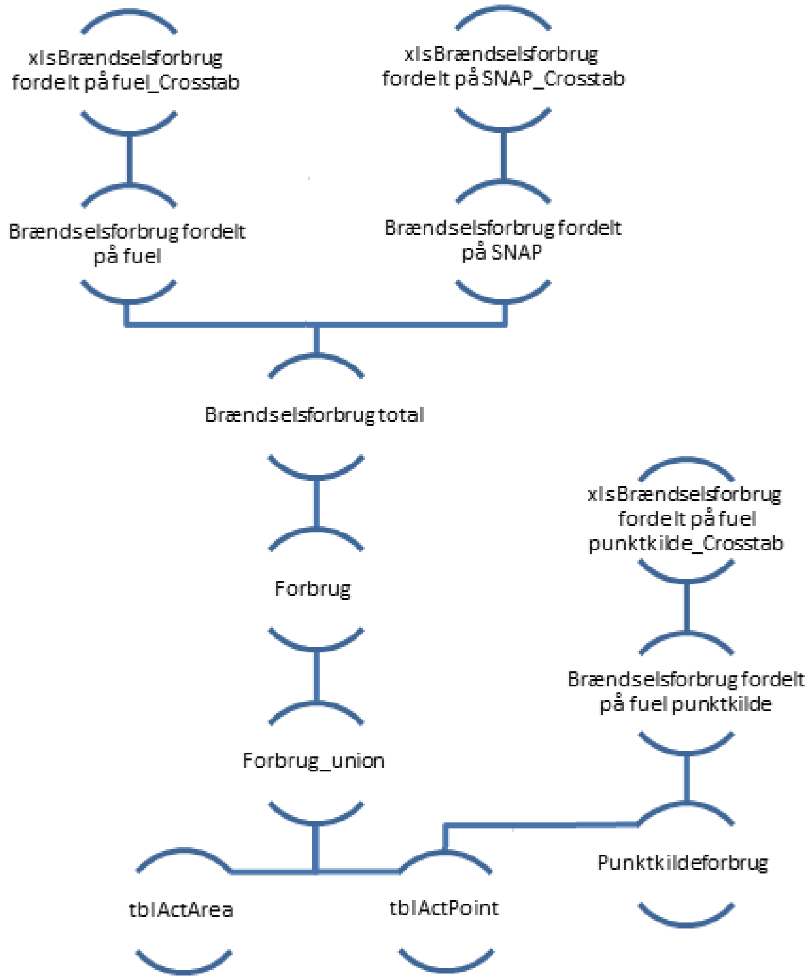

Figure 3.2 Overall construction of the database and calculation of fuel consumptions.

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, 2015a), and the projection for large combustion plants, Ramses (DEA, 2015b), from 2015 to 2025. For 2015 to 2030 there is no official energy projection. The fuel consumption has therefore been assumed constant at the 2025 level until 2030. For this report a projection from 2015 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.

At first, the most important fuel is natural gas, the second most important is wood, which then takes over as the most important fuel for the last part of the time-series. The use of coal is projected to remain relatively constant between 2015 and 2025 (and 2030), but with a dip in consumption around

2020. The largest variations are seen for renewable energy use. For wood, the projected consumption increases by 44 % from 2015 to 2020 and by 50 % from 2015 to 2030. The use of biogas is projected to increase drastically throughout the time series; 156 % from 2015 to 2025. 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.

Table 3.5 Fuel consumption for stationary combustion, TJ.

	2015	2020	2025	2030
Natural gas	121562	101907	103030	103030
Steam coal	67970	54897	67755	67755
Wood and simil.	89509	129100	134531	134531
Municipal waste	39683	38717	38094	38094
Gas oil	13439	3579	2598	2598
Agricultural waste	21294	22284	22176	22176
Refinery gas	15524	15524	15524	15524
Residual oil	5206	4488	4826	4826
Petroleum coke	6740	6838	7140	7140
Biogas	6594	13946	16861	16861
LPG	934	958	1047	1047
Coke	583	318	282	282
Kerosene	11	10	10	10
Total	389049	392566	413875	413875

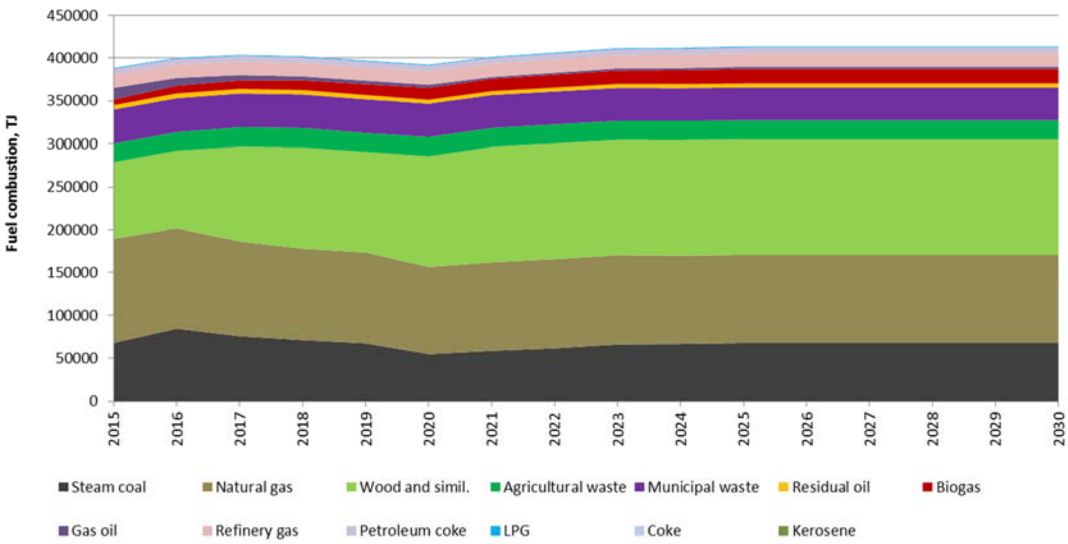

Figure 3.3 Fuel consumption distributed according to fuel type.

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 by 15 % from 2015 to 2025. 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.

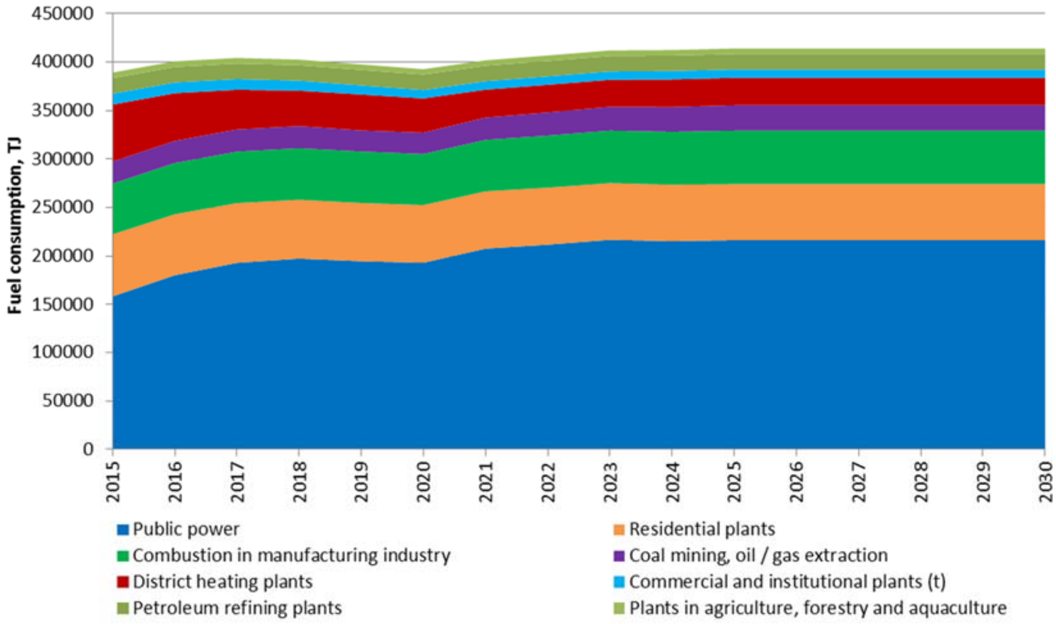

Figure 3.4 Fuel consumption distributed by sector.

Power plants larger than 25 MW_e use between 28 % and 39 % of the total fuel. The fuel consumption in these sources is expected to remain relatively constant throughout the time-series. 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. The amount of wood combusted by large point sources is expected to increase whereas the natural gas consumption decreases.

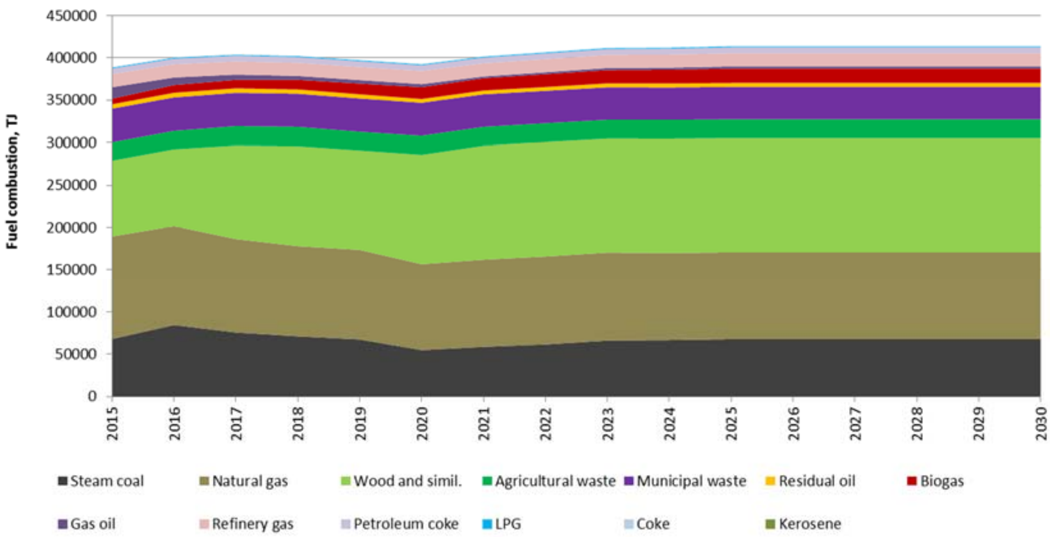

Figure 3.5 Fuel consumption for plants > 25 MW_e.

3.3 Emission factors

NO_X

In general, the applied NO_x emission factors are the emission factors used for 2014 in the latest inventory. References for the emission factors and the related assumptions are reported in the Annual Danish Informative Inventory Report to UNECE (Nielsen et al., 2016).

The disaggregation to different technologies is less detailed in the projection model than in the historic inventories. Implied emission factors based on 2014 data have been estimated for the projection source categories that include different technology specific emission factors in the historic inventories.

NO_x emission factors for centralised power plants are based on plant specific information from DONG Energy and Vattenfall (Hvidbjerg, 2013; Jørgensen, 2013) and on environmental approvals/draft environmental approvals. Implied emission factors for NO_x emission in 2014 have been applied for other large combustion plants included as point sources in the projection.

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

SO_2

In general, the applied SO_2 emission factors are the emission factors used for 2014 in the latest inventory. References for the emission factors and the related assumptions are reported in the Annual Danish Informative Inventory Report to UNECE (Nielsen et al., 2016).

In general, 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 2014.

Emission limits from the legislation for large combustion plants have been implemented (MST, 2015). A few plant specific environmental approvals/draft environmental approvals have been implemented.

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

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

NMVOC

In general, the applied NMVOC emission factors are the emission factors used for 2014 in the latest inventory. References for the emission factors and the related assumptions are reported in the Annual Danish Informative Inventory Report to UNECE (Nielsen et al., 2016).

Some of the emission factors applied in the projection model are aggregated based on emission factors for different technologies. The technology distribution in 2014 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.

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

In general, the applied emission factors for particulate matter are the emission factors used for 2014 in the latest inventory. References for the emission factors and the related assumptions are reported in the Annual Danish Informative Inventory Report to UNECE (Nielsen et al., 2016).

Some emission factors have been aggregated based on different 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.

BC

The applied BC emission factors are the emission factors for 2014. However, for residential wood combustion a time series have been estimated based on the time series for $PM_{2.5}$.

NH_3

Stationary combustion is a small source category for NH_3 emission. The emission factors for NH_3 all refer to the 2014 emission factors in the latest 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., 2016).

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; Hansen, 2015). 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 lower emission limit values entering into force in 2015 and 2017 and the new emission limit value for eco-labelled stoves from 2015 have been taken into account. 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 2014 to 2030.

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.

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

NO_x

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

The total NO_x emission increases from 2015 to 2025 due to increasing wood consumption. The emission factor for wood is larger than for both natural gas and coal which are the other largest fuels. Also, the increasing use of biogas leads to an increase in emissions due to the high emission factors for biogas.

Table 3.6 NO_X emissions from stationary combustion, Mg.

Sector	1990	1995	2000	2005	2010	2014	2015	2020	2025	2030
Public power and district heating plants	90615	83470	42788	37642	18865	10940	12934	13292	13482	13461
Petroleum refining plants	1462	1859	1593	1288	1544	1233	1692	1692	1692	1692
Oil/gas extraction	2371	3248	6304	6999	6770	4662	4463	4313	5126	5126
Commercial and institutional plants	1457	1605	1375	1175	923	671	655	562	581	581
Residential plants	4488	4617	4028	4522	4921	3244	3643	3453	3410	3427
Plants in agriculture, forestry and aquaculture	1202	1404	1381	1175	746	525	505	502	517	517
Combustion in industrial plants	11979	14260	15622	12841	6035	4511	3790	3829	3985	3939
Total	113573	110463	73090	65642	39804	25785	27683	27642	28794	28744

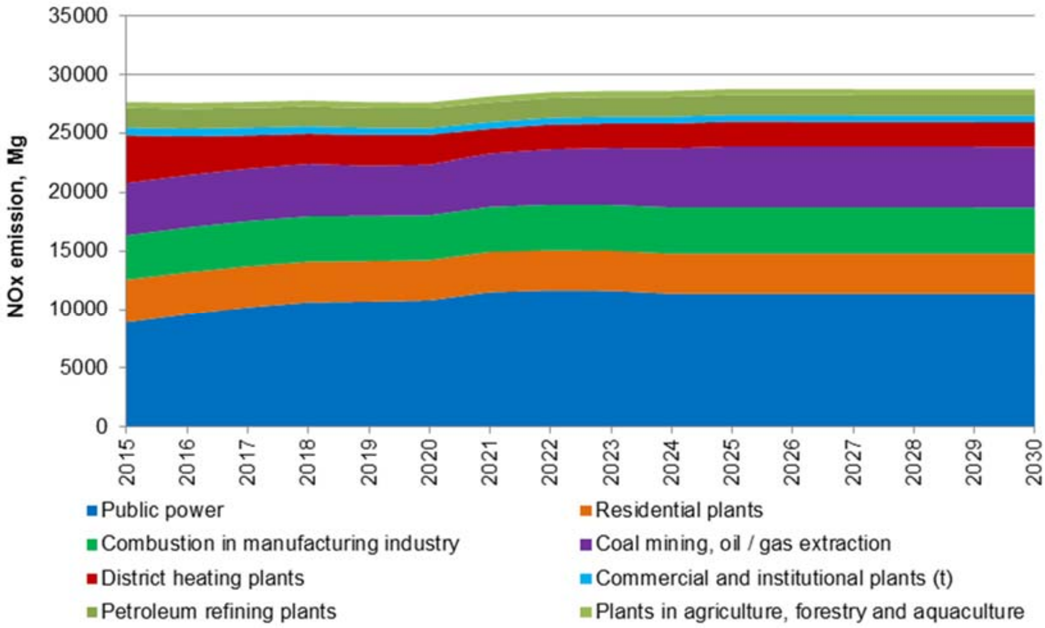

Figure 3.6 Projected NO_X emissions by sector.

NO_x emissions from gas turbines used in the offshore sector are projected to increase significantly. From 2015 to 2025 the emission increases by 15 % due to increasing fuel consumption.

SO_2

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

The total SO_2 emission decreases slightly from 2015 to 2025 due to a decrease in oil consumption. This mainly occurs in the industrial plants, while the emissions from the other sectors remain relatively constant.

Table 3.7 SO_2 emissions from stationary combustion, Mg.

Sector	1990	1995	2000	2005	2010	2014	2015	2020	2025	2030
Public power and district heating plants	126144	108560	12045	7697	3687	2589	3009	2707	2831	2831
Petroleum refining plants	1059	2050	583	267	229	165	223	223	223	223
Oil/gas extraction	4	6	11	12	12	10	10	9	11	11
Commercial and institutional plants	1877	777	348	274	120	109	143	99	102	102
Residential plants	6291	2163	1322	1288	1191	720	890	835	822	822
Plants in agriculture, forestry and aquaculture	3189	2905	1566	1588	1240	892	903	862	880	880
Combustion in industrial plants	15762	11943	7627	6582	3699	2765	2987	2050	2002	2002
Total	154327	128404	23501	17709	10177	7250	8164	6786	6871	6871

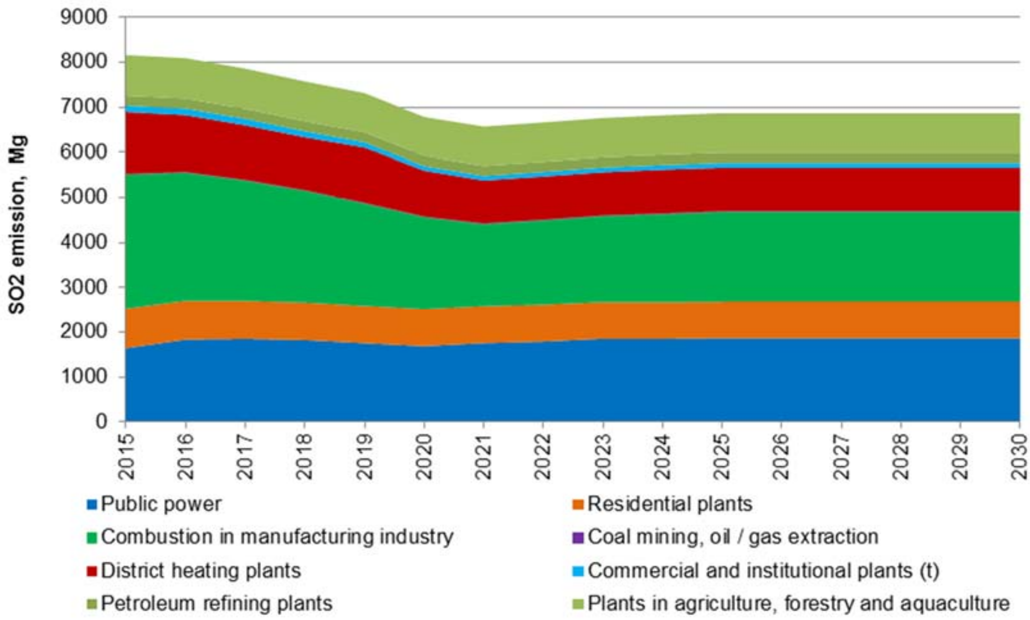

Figure 3.7 Projected SO_2 emissions by sector.

NMVOC

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

From 2015 to 2030 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 68 % and 81 % of the total NMVOC emission from stationary combustion plants, with the higher share being in the early part of the projection period.

Table 3.8 NMVOC emissions from stationary combustion, Mg.

Sector	1990	1995	2000	2005	2010	2014	2015	2020	2025	2030
Public power and district heating plants	451	2910	3556	2604	2403	940	750	1211	1372	1372
Petroleum refining plants	23	35	25	23	21	23	23	23	23	23
Oil/gas extraction	13	18	36	45	43	38	36	35	42	42
Commercial and institutional plants	132	218	304	264	262	216	216	191	190	190
Residential plants	11903	12398	11141	14648	16516	10441	11340	9333	8165	7117
Plants in agriculture, forestry and aquaculture	2366	2011	1796	1606	1416	1326	1360	1293	1317	1317
Combustion in industrial plants	1099	663	517	416	303	238	266	353	386	386
Total	15986	18253	17375	19605	20964	13221	13991	12439	11494	10447

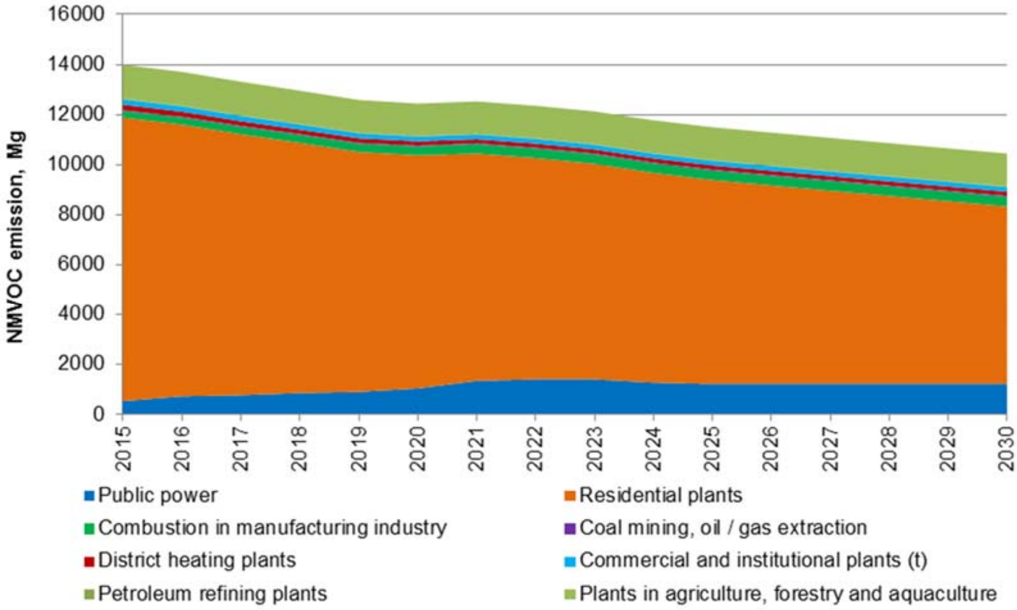

Figure 3.8 Projected NMVOC emissions by sectors.

$PM_{2.5}$

The estimated $PM_{2.5}$ emissions are shown in Table 3.9 and in Figure 3.9.

The $PM_{2.5}$ emission has increased in the historic years due to increasing wood combustion in residential plants. However, from 2015 to 2030 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 81 % and 89 % of the total $PM_{2.5}$ emission from stationary combustion plants in the period 2015-2030 with the share being highest in the beginning of the period.

Table 3.9 $PM_{2.5}$ emissions from stationary combustion, Mg.

Sector	2000	2005	2010	2014	2015	2020	2025	2030
Public power and district heating plants	693	542	483	429	593	684	702	702
Petroleum refining plants	124	101	87	90	91	91	91	91
Oil/gas extraction	1	1	1	1	1	1	1	1
Commercial and institutional plants	147	141	149	164	170	148	146	146
Residential plants	11259	16128	18102	10743	11457	9279	7808	6435
Plants in agriculture, forestry and aquaculture	493	445	451	443	455	433	442	442
Combustion in industrial plants	305	157	156	129	115	144	157	157
Total	13022	17515	19429	12000	12883	10779	9347	7974

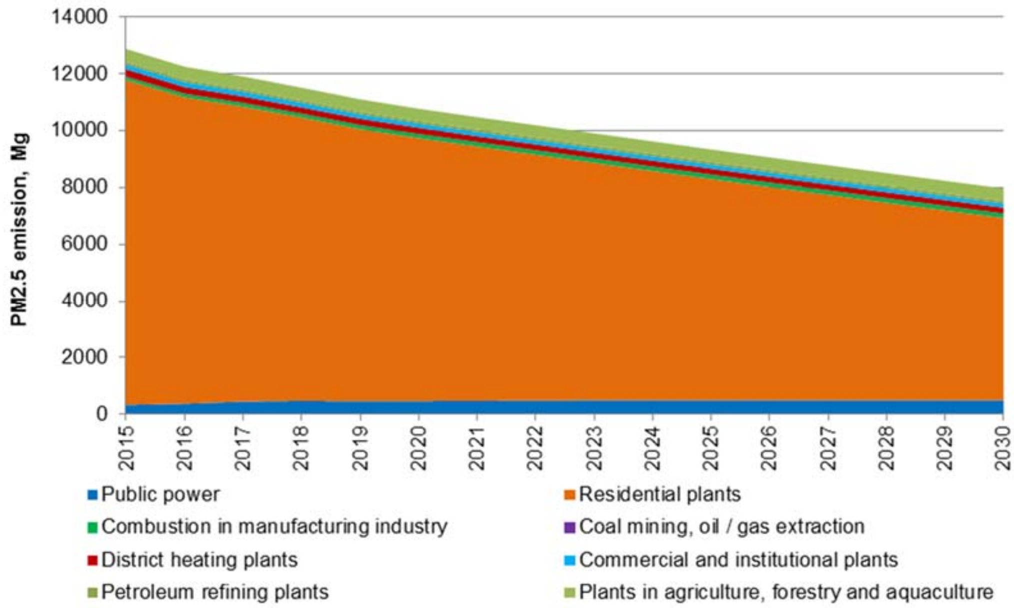

Figure 3.9 Projected $PM_{2.5}$ emissions by sector.

Black Carbon

The estimated black carbon (BC) emissions are shown in Table 3.10 and in Figure 3.10.

The BC emission has increased in the historic years due to increasing wood combustion in residential plants. However, from 2015 to 2030 the BC 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 83 % and 87 % of the total BC emission from stationary combustion plants in the period 2015-2030 with the share being highest in the beginning of the period.

Table 3.10 BC emissions from stationary combustion, Mg.

Sector	2000	2005	2010	2014	2015	2020	2025	2030
Public power and district heating plants	28	20	22	15	33	27	26	26
Petroleum refining plants	17	15	14	15	15	15	15	15
Oil/gas extraction	0	0	0	0	0	0	0	0
Commercial and institutional plants	51	45	45	49	50	41	41	41
Residential plants	1363	2027	2444	1545	1675	1468	1336	1214
Plants in agriculture, forestry and aquaculture	143	125	125	123	126	120	122	122
Combustion in industrial plants	55	32	45	19	25	33	37	37
Total	1657	2265	2696	1765	1924	1704	1577	1455

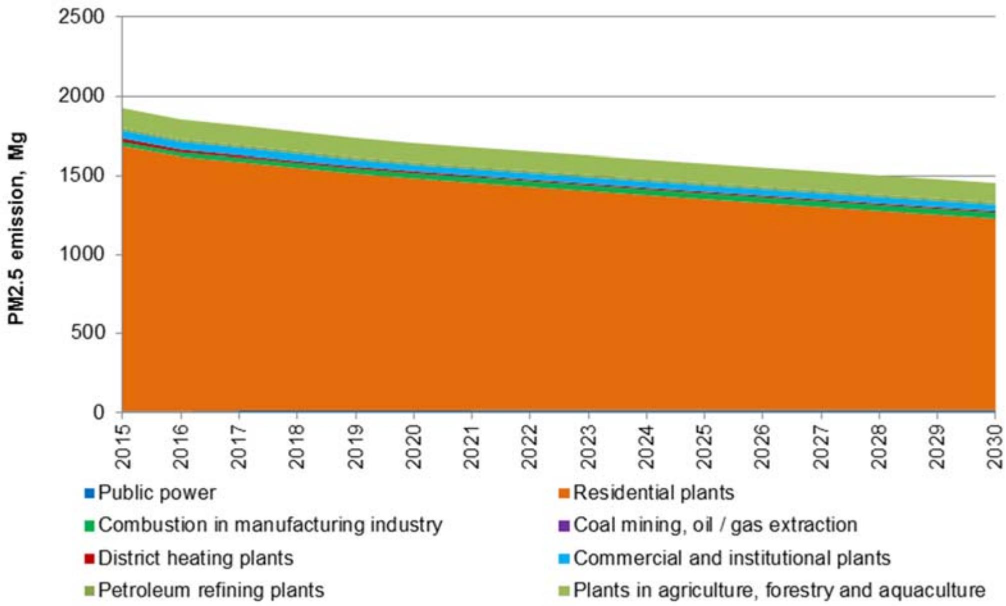

Figure 3.10 Projected BC emissions by sector.

3.5 Changes since previous projection

Activity data

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

Emission factors

The emission factors have been updated according to the emission factors applied for 2014.

Time series for residential wood combustion have been updated. Time series have been added for NO_x and NH_3 from residential wood combustion.

Time series have been added for natural gas fuelled boilers in industry/district heating and for natural gas fuelled residential boilers.

Emission factors based on 2015 legislation for large plants (DEPA, 2015) have been implemented.

BC has been added.

3.6 References

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4 Road transport and other mobile sources

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

For mobile sources, the aggregation of emission results into the formats used by the UNFCCC and UNECE Conventions is made by using the code correspondence information shown in Table 4.1. In the case of mobile sources, the CRF (Common Reporting Format) and NFR (National Format for Reporting) used by the UNFCCC and UNECE Conventions, respectively, are similar.

Table 4.1 SNAP – CRF/NFR correspondence table for mobile sources.

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

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

For aviation, LTO (Landing and Take Off)[3] refers to the part of flying which is below 1000 m. This part of the aviation emissions (SNAP codes 080501 and 080502) are included in the national emissions total as prescribed by the UNECE reporting rules. According to UNFCCC the national emissions for

[3] 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.

aviation comprise the emissions from domestic LTO (0805010) and domestic cruise (080503).

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

The description of methodologies and references for the transport part of the Danish inventory is given in two sections; one for road transport and one for the other mobile sources.

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 engines, taking into account gradually stricter emission standards and emission degradation due to catalyst wear. Furthermore, the emission effects of cold-start and evaporation are simulated.

Vehicle fleet and mileage data

Corresponding to the COPERT fleet classification, all present and future vehicles in the Danish traffic 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.

Table 4.2 Model vehicle classes and sub-classes.

Vehicle classes	Fuel type	Engine size/weight
Passenger cars	Gasoline	< 0.8 l.
Passenger cars	Gasoline	0.8 - 1.4 l.
Passenger cars	Gasoline	1.4 – 2 l.
Passenger cars	Gasoline	> 2 l.
Passenger cars	Diesel	< 1.4 l.
Passenger cars	Diesel	1.4 - 2 l.
Passenger cars	Diesel	> 2 l.
Passenger cars	LPG	
Passenger cars	2-stroke	
Vans	Gasoline	
Vans	Diesel	
Vans	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 annual mileage data are provided by DTU Transport for the vehicle categories present in COPERT IV (Jensen, 2015). The latter source also provides information of the mileage split between urban, rural and highway driving. The respective average speeds come from The Danish Road Directorate (e.g. Winther & Ekman, 1998). Additional data for the moped fleet and motorcycle fleet disaggregation is given by The National Motorcycle Association (Markamp, 2013). For information on the historical vehicle stock and annual mileage, please refer to Winther (2015).

In addition data from a survey made by the Danish Road Directorate (Hansen, 2010) has information on the total mileage driven by foreign trucks on Danish roads in 2009. This mileage contribution has been added to the total mileage for Danish trucks on Danish roads, for trucks > 16 tonnes of gross vehicle weight. The data has been further processed by DTU Transport; by using appropriate assumptions, the mileages have been back-casted to 1985 and forecasted to 2030.

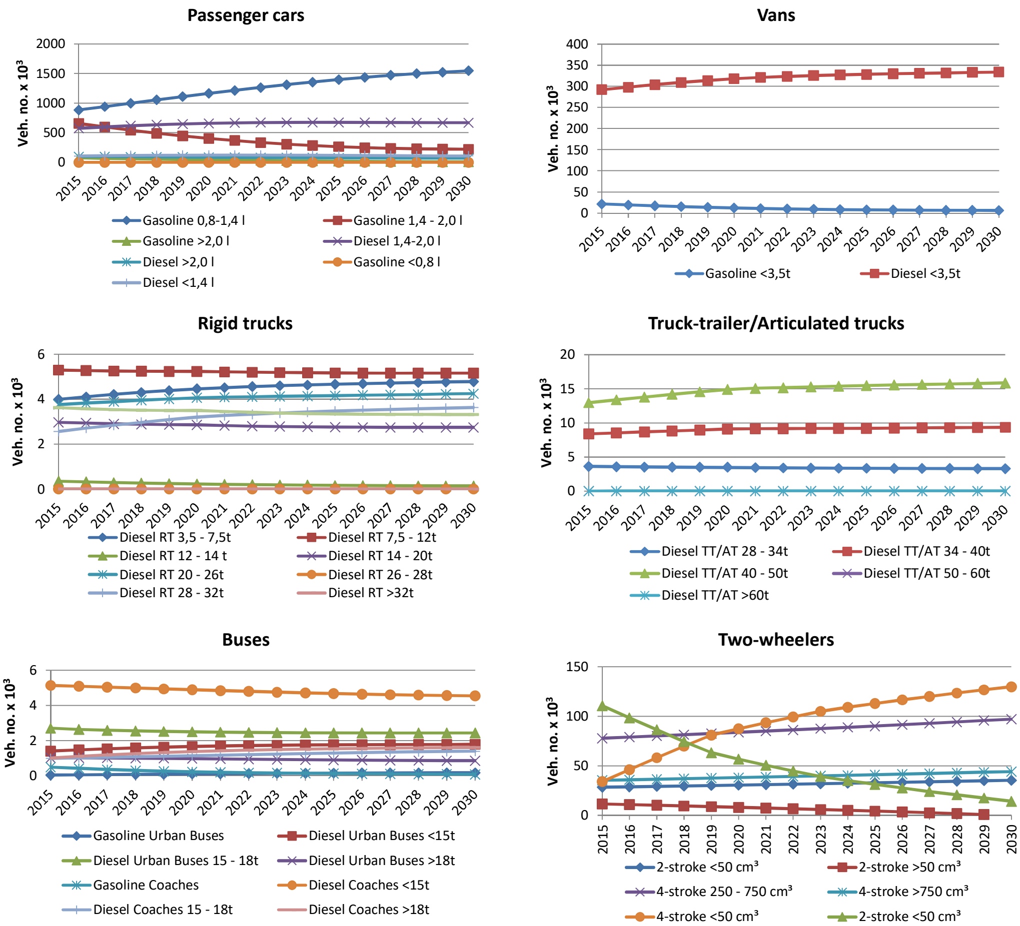

Figure 4.1 Number of vehicles in sub-classes from 2015-2030.

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:

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

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.

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

The trends in vehicle numbers and total mileages per EU layer are also shown in the Figures 4.2 and 4.3 for the 2015-2030 periods. The latter figure clearly shows how vehicles complying with the gradually stricter EU emission levels (EURO 5/V, Euro 6/VI and Euro 6c) are introduced into the Danish motor fleet in the forecast period.

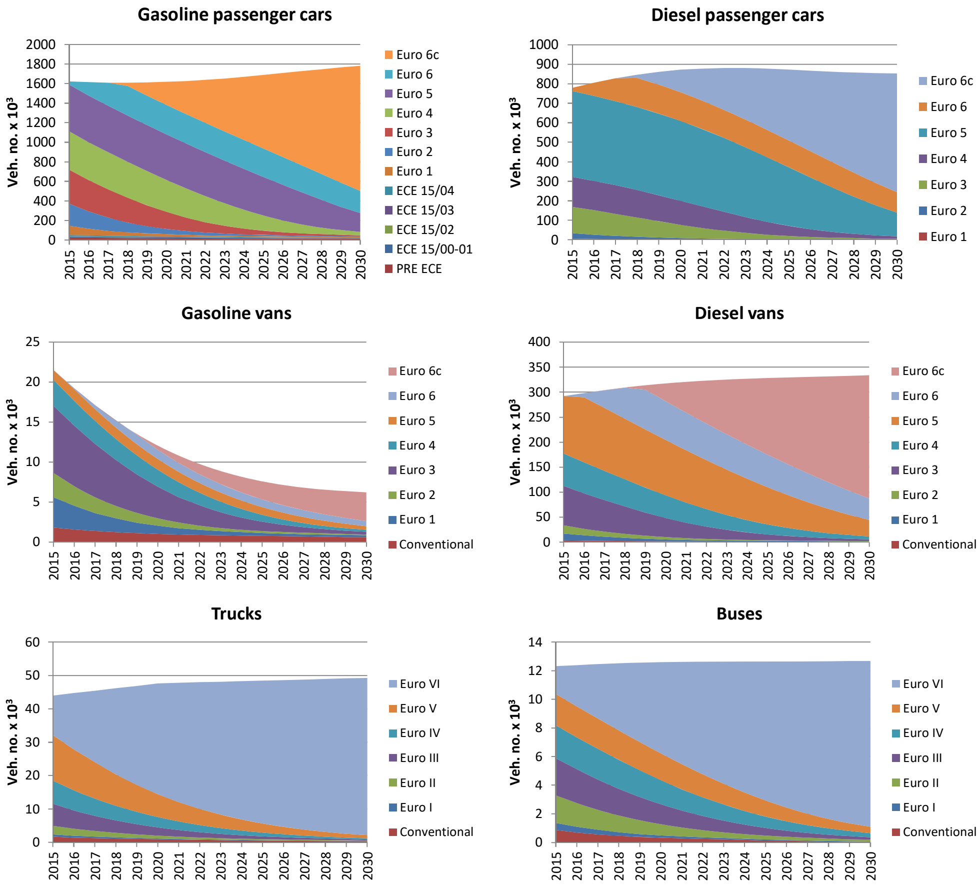

Figure 4.2 Layer distribution of vehicle numbers per vehicle type in 2015-2030.

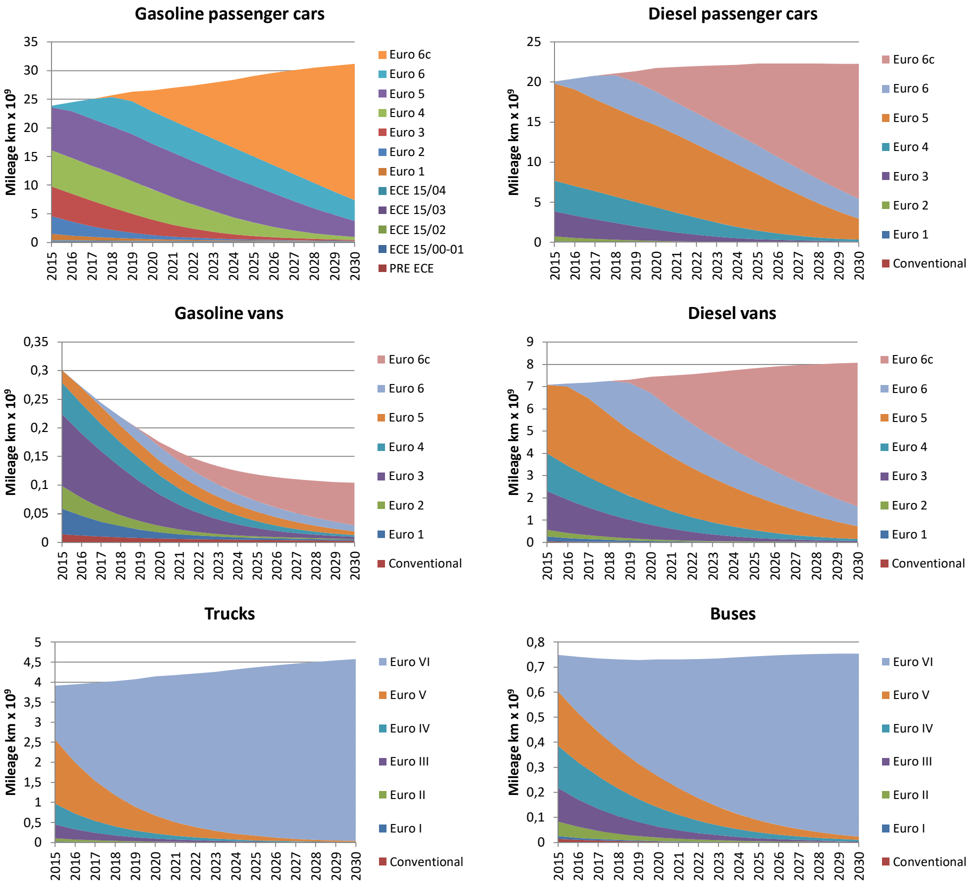

Figure 4.3 Layer distribution of total mileage per vehicle type in 2015-2030.

Fuel and emission legislation

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

The NEDC test cycle is not adequately describing real world driving behaviour, and as an effect, for diesel cars and vans, there is an increasing mismatch between the step wise lowered EU emission limits the vehicles comply with during the NEDC test cycle, and the more or less constant emissions from the same vehicles experienced during real world driving. In order to bridge this emission inconsistency gap work have been made towards developing a new test procedure for Euro 6 vehicles, the "World-Harmonized Light-Duty Vehicles Test Procedure" (WLTP), which simulates much more closely real world driving behaviour. In correspondence, the next generation

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

of “WLTP certified” Euro 6 vehicles, the so-called “Euro 6c” vehicles, must still be able to comply with the Euro 6 emission limits as they are today.

For the new Euro 6c vehicles it has been decided that emission measurements must also be made with portable emission measurement systems (PEMS) during real traffic driving conditions with random acceleration and deceleration patterns. During the new Real Driving Emission (RDE) test procedure the emissions of NO_x are not allowed to exceed the existing (NEDC based) emission limits by more than 110 % by January 2017 for all new car models and by January 2019 for all new cars[5]. From January 2020 the NO_x emission not-to-exceed levels are adjusted downwards to 50 % for all new car models and by January 2021 for all new cars[6]. Implementation dates for vans are one year later.

In the road transport emission model, the dates for implementation of the Euro 6c technology is set to 1/9 2018 and 1/9 2019, for diesel cars and vans, respectively.

For NOx, VOC (NMVOC + CH_4), CO and PM, the emissions from road transport vehicles have to comply with the different EU directives listed in Table 4.3. For cars and vans the emission directives distinguish between three vehicle classes according to vehicle reference mass[7]: Passenger cars and light duty trucks (<1305 kg), light duty trucks (1305-1760 kg) and light duty trucks (>1760 kg).The specific emission limits are shown in Winther (2015).

For heavy-duty vehicles (trucks and buses), the emission limits are given in g pr kWh and the measurements are carried out for engines in a test bench, using the ECE R-49, EU ESC (European Stationary Cycle) and ETC (European Transient Cycle) test cycles, depending on the Euro norm and exhaust gas after-treatment system installed. For Euro VI engines the WHSC (World Harmonized Stationary Cycle) and WHTC (World Harmonized Transient Cycle) test cycles are used. For a description of the test cycles see e.g. www.dieselnet.com.

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.

[5] For ambient test temperatures below 3 degrees Celcius, not-to-exceed emission limits are 60 % higher. For ambient test temperatures below minus 2 degrees Celcius the emission limits no longer apply.
[6] For ambient test temperatures below 0 degrees Celcius, not-to-exceed emission limits are 60 % higher. For ambient test temperatures below minus 7 degrees Celcius the emission limits no longer apply.
[7] 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	-	-
	ECE 15/00-01	70/220 - 74/290	1972[a]
	ECE 15/02	77/102	1981[b]
	ECE 15/03	78/665	1982[c]
	ECE 15/04	83/351	1987[d]
	Euro I	91/441	1.10.1990[e]
	Euro II	94/12	1.1.1997
	Euro III	98/69	1.1.2001
	Euro IV	98/69	1.1.2006
	Euro V	715/2007(692/2008)	1.1.2011
	Euro VI	715/2007(692/2008)	1.9.2015
	Euro VIc	459/2012	1.9.2018
Passenger cars (diesel and LPG)	Conventional	-	-
	ECE 15/04	83/351	1987[d]
	Euro I	91/441	1.10.1990[e]
	Euro II	94/12	1.1.1997
	Euro III	98/69	1.1.2001
	Euro IV	98/69	1.1.2006
	Euro V	715/2007(692/2008)	1.1.2011
	Euro VI	715/2007(692/2008)	1.9.2015
	Euro VIc	459/2012	1.9.2018
Light duty trucks (gasoline and diesel)	Conventional	-	-
	ECE 15/00-01	70/220 - 74/290	1972[a]
	ECE 15/02	77/102	1981[b]
	ECE 15/03	78/665	1982[c]
	ECE 15/04	83/351	1987[d]
	Euro I	93/59	1.10.1994
	Euro II	96/69	1.10.1998
	Euro III	98/69	1.1.2002
	Euro IV	98/69	1.1.2007
	Euro V	715/2007	1.1.2012
	Euro VI	715/2007	1.9.2016
	Euro VIc	459/2012	1.9.2019
Heavy duty vehicles	Euro 0	88/77	1.10.1990
	Euro I	91/542	1.10.1993
	Euro II	91/542	1.10.1996
	Euro III	1999/96	1.10.2001
	Euro IV	1999/96	1.10.2006
	Euro V	1999/96	1.10.2009
	Euro VI	595/2009	1.10.2013
Mopeds	Conventional	-	
	Euro I	97/24	2000
	Euro II	2002/51	2004
	Euro III	2002/51	2014[f]
	Euro IV	168/2013	2017
	Euro V	168/2013	2021
Motor cycles	Conventional	Conventional	0
	Euro I	97/24	2000
	Euro II	2002/51	2004

Continued			
	Euro I	97/24	2000
	Euro III	2002/51	2007
	Euro IV	168/2013	2017
	Euro V	168/2013	2021

a,b,c,d: Expert judgement suggest that Danish vehicles enter into the traffic before EU directive first registration dates. The effective inventory starting years are a: 1970; b: 1979; c: 1981; d: 1986.e: The directive came into force in Denmark in 1991 (EU starting year: 1993). f: Applies for new types only. Until 2017, mopeds with an existing Euro II type approval can be sold.

Fuel consumption and emission factors

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

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

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

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 by Winther (2015).

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 (2015).

Fuel consumption and emission calculations

The fuel consumption and emissions are calculated for operationally hot engines and for engines during cold start. A final fuel balance adjustment is made in order to account for the statistical fuel sold according to Danish energy statistics.

The calculation procedure for hot engines is to combine basis fuel consumption and emission factors, number of vehicles and annual mileage numbers and mileage road type shares. For additional description of the hot and cold start calculations and fuel balance approach, please refer to Winther (2015) and Nielsen et al. (2016).

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.

Activity data

Air traffic

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

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

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

Non road working machinery and recreational craft

Non-road working machinery and equipment are used in agriculture, forestry and industry, for household/gardening purposes and inland waterways (recreational craft). The specific machinery types comprised in the Danish inventory are shown in Table 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	Silvicultural tractors, harvesters, forwarders, chippers	-
Industry	Construction machinery, fork lifts, airport ground equipment, other	Fork lifts (LPG), building and construction, other
Residential and Commercial/ institutional	-	Riders, lawn movers, chain saws, cultivators, shrub clearers, hedge cutters, trimmers, other

The number of machines is forecasted by using different approaches depending on the type of machinery, historical stock data and new sales information available. The basic principles for non-road mobile fleet projections are explained by Winther et al. (2006).

For historical years, please refer to the reports by Winther et al. (2006), Winther (2015) and Nielsen et al. (2016) 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, 2015).

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 2014. For these ferry routes the following detailed traffic and technical data have been gathered: Ferry name, year of service, engine size (MCR), engine type, fuel type, average load factor, auxiliary engine size and sailing time (single trip). Please refer to Winther (2015) and Nielsen et al. (2016) for more details.

Fleet/activity projections for domestic ferries are made by assuming a constant number of return trips per ferry route in the forecast period and by assuming an engine lifetime of 30 years for the specific ferries being used.

Table 4.5 Ferry routes comprised in the Danish inventory.

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

Other sectors

The activity data for military, railways, international sea transport and fishery consists of fuel consumption information from DEA (2015). For international sea transport, the basis is expected fuel sold in Danish ports for vessels with a foreign destination, as prescribed by the IPCC guidelines.

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 emission approval of the EU Stage I, II and IIIA engine technologies, emissions (and fuel consumption) measurements are made using the steady state test cycle ISO 8178 C1, referred to as the Non-Road Steady Cycle (NRSC), see e.g. www.dieselnet.com. In addition to the NRSC test, the newer Stage IIIB and IV (and optionally Stage IIIA) engine technologies are tested under more realistic operational conditions using the new Non-Road Transient Cycle (NRTC).

For gasoline, the directive 2002/88 distinguishes between hand-held (SH) and not hand-held (NS) types of machinery (Table 3.3.11). Emissions are tested using one of the specific constant load ISO 8178 test cycles (D2, G1, G2, G3) depending on the type of machinery. The test cycles are described in more in more detail in the relevant directives.

In September 2014 the European Commission proposed a further tightening of the emission standards (Stage V) relevant for all types of non-road machinery (Commission proposal COM (2014) 581 final).

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

Engine	Engine size	CO	VOC	NO_x	$VOC+NO_x$	PM	Diesel machinery			Tractors	
category								Implement. date		EU	Implement.
	[kW]		[g pr kWh]				EU Directive	Transient	Constant	Directive	Date
Stage I											
A	130<=P<560	5	1.3	9.2	-	0.54	97/68	1/1 1999	-	2000/25	1/7 2001
B	75<=P<130	5	1.3	9.2	-	0.7		1/1 1999	-		1/7 2001
C	37<=P<75	6.5	1.3	9.2	-	0.85		1/4 1999	-		1/7 2001
Stage II											
E	130<=P<560	3.5	1	6	-	0.2	97/68	1/1 2002	1/1 2007	2000/25	1/7 2002
F	75<=P<130	5	1	6	-	0.3		1/1 2003	1/1 2007		1/7 2003
G	37<=P<75	5	1.3	7	-	0.4		1/1 2004	1/1 2007		1/1 2004
D	18<=P<37	5.5	1.5	8	-	0.8		1/1 2001	1/1 2007		1/1 2002
Stage IIIA											
H	130<=P<560	3.5	-	-	4	0.2	2004/26	1/1 2006	1/1 2011	2005/13	1/1 2006
I	75<=P<130	5	-	-	4	0.3		1/1 2007	1/1 2011		1/1 2007
J	37<=P<75	5	-	-	4.7	0.4		1/1 2008	1/1 2012		1/1 2008
K	19<=P<37	5.5	-	-	7.5	0.6		1/1 2007	1/1 2011		1/1 2007
Stage IIIB											
L	130<=P<560	3.5	0.19	2	-	0.025	2004/26	1/1 2011	-	2005/13	1/1 2011
M	75<=P<130	5	0.19	3.3	-	0.025		1/1 2012	-		1/1 2012
N	56<=P<75	5	0.19	3.3	-	0.025		1/1 2012	-		1/1 2012
P	37<=P<56	5	-	-	4.7	0.025		1/1 2013	-		1/1 2013
Stage IV											
Q	130<=P<560	3.5	0.19	0.4	-	0.025	2004/26	1/1 2014	1/1 2014	2005/13	1/1 2014
R	56<=P<130	5	0.19	0.4	-	0.025		1/10 2014	1/10 2014		1/10 2014
Stage V											
NRE-v/c-7	P>560	3.5	0.19	3.5		0.045	COM (2014) 581 final		2019		2019
NRE-v/c-6	130≤P≤560	3.5	0.19	0.4		0.015			2019		2019
NRE-v/c-5	56≤P<130	5.0	0.19	0.4		0.015			2020		2020
NRE-v/c-4	37≤P<56	5.0			4.7	0.015			2019		2019
NRE-v/c-3	19≤P<37	5.0			4.7	0.015			2019		2019
NRE-v/c-2	8≤P<19	6.6			7.5	0.4			2019		2019
NRE-v/c-1	P<8	8.0			7.5	0.4			2019		2019

Table 4.7 Overview of EU emission directives relevant 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	-	1/2 2005
	SH2	20≤S<50	805	241	5.36	-	1/2 2005
	SH3	50≤S	603	161	5.36	-	1/2 2005
Not hand held	SN3	100≤S<225	519	-	-	16.1	1/2 2005
	SN4	225≤S	519	-	-	13.4	1/2 2005
	Stage II						
Hand held	SH1	S<20	805	-	-	50	1/2 2008
	SH2	20≤S<50	805	-	-	50	1/2 2008
	SH3	50≤S	603	-	-	72	1/2 2009
Not hand held	SN1	S<66	610	-	-	50	1/2 2005
	SN2	66≤S<100	610	-	-	40	1/2 2005
	SN3	100≤S<225	610	-	-	16.1	1/2 2008
	SN4	225≤S	610	-	-	12.1	1/2 2007
	Stage V						
Hand held (<19 kW)	NRSh-v-1a	S<50	805	-	-	50	2019
	NRSh-v-1b	50≤S	805	-	-	72	2019
Not hand held (P<19 kW)	NRS-vr/vi-1a	80≤S<225	610	-	-	10	2019
	NRS-vr/vi-1b	S≥225	610	-	-	8	2019
Not hand held (19=<P<30 kW)	NRS-v-2a	S≤1000	610	-	-	8	2019
	NRS-v-2b	S>1000	4.40*	-	-	2.70*	2019
Not hand held (30=<P<56 kW)	NRS-v-3	any	4.40*	-	-	2.70*	2019

* Or any combination of values satisfying the equation $(HC+NOx) \times CO^{0.784} \leq 8.57$ and the conditions $CO \leq 20.6$ g/kWh and $(HC+NOx) \leq 2.7$ g/kWh

For recreational craft, Directive 2003/44 comprises the Stage I emission legislation limits for diesel engines, and for 2-stroke and 4-stroke gasoline engines, respectively. The CO and VOC emission limits depend on engine size (kW) and the inserted parameters presented in the calculation formulas in Table 4.8. For NO_x, a constant limit value is given for each of the three engine types. For TSP, the constant emission limit regards diesel engines only.

In Table 4.9 the Stage II emission limits given by Directive 2013/53 are shown. CO and HC+NOx limits are provided for gasoline engines depending on the rated engine power and the engine type (stern-drive vs. outboard) while CO, HC+NOx, and particulate emission limits are defined for compression ignition (CI) engines depending on the rated engine power and the swept volume.

Table 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 2013/53 for recreational craft.

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

(*) Alternatively, this engine segment shall not exceed a PM limit of 0.2 g/kWh and a combined HC + NO_x limit of 5.8 g/kWh
(**) Small and medium size manufacturers making outboard engines <= 15 kW have until 18/1 2020 to comply

Table 4.10 Overview of the EU emission directive 2004/26 for railway locomotives and motor cars.

	Engine size [kW]		CO	HC	NO_X	HC+NO_X	PM	Impl.
			[g pr kWh]	[g pr kWh]	[g pr kWh]	[g pr kWh]	[g pr kWh]	date
Locomotives	Stage IIIA							
	130<=P<560	RL A	3.5	-	-	4	0.2	1/1 2007
	560<P	RH A	3.5	0.5	6	-	0.2	1/1 2009
	2000<=P and piston displacement >= 5 l/cyl.	RH A	3.5	0.4	7.4	-	0.2	1/1 2009
	Stage IIIB	RB	3.5	-	-	4	0.025	1/1 2012
	Stage V							
	0<P	RLL-v/c-1	3.5	-	-	4	0.025	2021
Motor cars	Stage IIIA							
	130<P	RC A	3.5	-	-	4	0.2	1/1 2006
	Stage IIIB							
	130<P	RC B	3.5	0.19	2	-	0.025	1/1 2012
	Stage V							
	0<P	RLR-v/c-1	3.5	0.19	2	-	0.015	2021

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.

Marpol 73/78 Annex VI agreed by IMO (International Maritime Organisation) concerns the control of NO_x emissions (Regulation 13 plus amendments) and SO_x and particulate emissions (Regulation 14 plus amendments) from ships (DNV, 2009).

The baseline NO_x emission regulation of MARPOL Annex VI apply for diesel engines with a power output higher than 130 kW, which are installed on a ship constructed on or after 1 January 2000 and diesel engines with a power output higher than 130 kW which undergo major conversion on or after 1 January 2000.

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

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

The further amendment of MARPOL Annex VI Regulation 13 contains a three tiered approach in order to strengthen the emission standards for NO_x. The three tier approach 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 (initial regulation).
- Tier II: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2011.
- Tier III[8]: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2016.

The three tier NO_x emission limit functions are shown in Table 4.10.

Table 4.10 Tier I-III NO_x emission limits for ship engines in MARPOL Annex VI.

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

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

In relation to the sulphur content in heavy fuel and marine gas oil used by ship engines, Table 4.11 shows the EU and IMO (Regulation 14 plus amendments) legislation in force for SECA (Sulfur Emission Control Area) areas and outside SECA's.

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

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 (2008, plus amendments).

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 (2006) 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 and BC 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 (2015), 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 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, 2009) and Winther et al. (2006). The NMVOC/CH_4 split is taken from IFEU (2009).

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

The source for aviation (jet fuel) emission factors is the EMEP/EEA guidebook (EMEP/EEA, 2013). For a number of different representative aircraft types, the EMEP/EEA guidebook comprises fuel flow and NO_x, CO and VOC emission indices for the four LTO modes and distance based emission factors for cruise. For Auxiliary power units (APU), APU load specific NO_x, CO and VOC emission factors come from ICAO (2011). The APU factors are given for different APU aircraft groups to be linked with the different representative aircraft types. VOC/CH_4 splits for aviation comes from EMEP/EEA (2013).

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, NO_x, VOC and CO emission factors are provided by Kristensen (2008), originating from measurement results by Hansen et al. (2004), Wismann (1999) and PHP (1996). Kristensen (2013) has provided complimentary emission factor data for new ferries.

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

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 (2015) and Nielsen et al. (2016).

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, IV and V, transient operational effects are also taken into consideration by using average transient factors. For more details regarding the calculation procedure please refer to Winther (2015).

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, and the fuel consumption associated with the sailing activities between Denmark and Greenland/Faroe Islands are taken from DEA (2015).

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, go into a fuel transferal between national sea transport and fisheries (diesel) and industry (heavy fuel oil).

Please refer to Winther (2015) for more details regarding the calculations for national sea transport.

Other sectors

For fishing vessels, military and railways, the emissions are estimated as the product of fuel-related emission factors and total fuel consumption from the DEA.

Energy balance between DEA statistics and inventory estimates

Following convention rules, the DEA statistical fuel sales figures make up the basis for the full Danish inventory. For mobile sources, however, in some cases 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.

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 (Winther, 2015).

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, 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 gasoline and diesel are transferred to recreational craft.

Non-road machinery and recreational craft

For diesel, the non-road fuel consumption estimated by DCE exceeds the sum of statistical fuel sales in the following DEA sectors relevant for non road fuel consumption: agriculture and forestry, market gardening, and building and construction. In this case, the missing amount of diesel is taken from the sectors, “Combustion in manufacturing industry” (0301) and “Non-industrial combustion plants” (0203) in the Danish emission inventory. Reversely, the amounts of LPG in the “gap filling” statistical sectors not being used by non-road machinery is subsequently included in the “Combustion in manufacturing industry” (0301) and “Non-industrial combustion plants” (0203) inventory sectors.

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	1995	2000	2005	2010	2014	2015	2020	2025	2030
Energy	Industry - Other (1A2g)	11.6	11.7	12.1	13.0	14.4	13.9	13.9	13.7	13.6	13.5
	Civil Aviation nat. (1A3a)	4.4	5.1	5.7	5.4	4.5	4.7	4.7	4.9	5.1	5.2
	Road (1A3b) - exhaust	126.4	144.2	152.5	166.1	165.2	161.4	161.4	163.0	162.0	162.0
	Railways (1A3c)	4.0	4.1	3.1	3.1	3.3	3.4	3.3	2.9	2.3	0.8
	Navigation (1A3d)	9.9	10.4	6.7	6.4	6.6	4.8	4.7	4.6	4.6	4.6
	Comm./Inst. (1A4a)	1.0	1.1	1.2	2.2	2.4	2.3	2.3	2.3	2.3	2.3
	Residential (1A4b)	0.5	0.5	0.6	0.8	0.9	0.9	0.8	0.8	0.8	0.8
	Agriculture/forestry (1A4c)	17.7	16.2	14.4	15.1	15.9	16.0	15.8	15.0	14.8	14.6
	Fisheries (1A4c)	7.9	7.1	9.4	8.7	6.7	5.8	6.3	6.9	7.3	7.3
	Other (1A5b)	2.3	4.3	2.7	5.1	2.8	3.1	3.1	3.1	3.1	3.1
	Navigation int. (1A3d)	39.1	65.1	52.6	30.7	27.0	29.4	29.4	29.4	29.4	29.4
	Civil Aviation int. (1A3a)	23.1	23.6	29.1	32.2	31.3	34.5	34.4	36.4	37.8	38.7
SO_2	Industry - Other (1A2g)	958	973	254	28	31	6	6	6	6	6
	Civil Aviation nat. (1A3a)	101	117	131	125	104	107	108	114	118	121
	Road (1A3b) - exhaust	5767	1682	352	77	76	71	70	71	70	70
	Railways (1A3c)	376	96	7	1	2	2	2	1	1	0
	Navigation (1A3d)	6397	5536	1770	2245	1393	1169	223	222	222	221
	Comm./Inst. (1A4a)	2	2	3	1	1	1	1	1	1	1
	Residential (1A4b)	1	1	1	0	0	0	0	0	0	0
	Agriculture/forestry (1A4c)	1561	1451	326	35	36	7	7	7	7	7
	Fisheries (1A4c)	741	669	881	818	316	270	296	322	341	342
	Other (1A5b)	81	131	101	151	67	70	68	68	68	68
	Navigation int. (1A3d)	41317	65049	55182	34283	8200	8765	1414	1414	1414	1414
	Civil Aviation int. (1A3a)	531	542	669	740	719	792	790	836	868	890
NO_x	Industry - Other (1A2g)	11130	11934	12135	10715	8744	7181	6765	4949	3688	3383
	Civil Aviation nat. (1A3a)	1353	1468	1644	1663	1334	1556	1575	1659	1718	1759
	Road (1A3b) - exhaust	110310	104913	83376	71612	50765	38455	34360	20896	13708	9483
	Railways (1A3c)	4913	5015	3727	3724	2818	2232	2036	1199	943	312
	Navigation (1A3d)	13111	12898	7299	7599	8582	7441	7254	6688	6061	5084
	Comm./Inst. (1A4a)	70	93	104	177	217	219	219	199	172	169
	Residential (1A4b)	34	43	50	72	87	92	92	86	73	69
	Agriculture/forestry (1A4c)	12677	13176	13331	12275	9090	6988	6273	3815	2396	1414
	Fisheries (1A4c)	8325	8252	11992	11759	9251	7488	8107	6040	3981	2909
	Other (1A5b)	916	2283	1361	2368	1455	1449	1399	1137	968	837
	Navigation int. (1A3d)	60639	105113	91641	56540	51065	55487	55659	49022	41163	32919
	Civil Aviation int. (1A3a)	7157	7300	8996	10537	10657	13048	13014	13767	14301	14668
NMVOC	Industry - Other (1A2g)	2314	2126	1954	1641	1233	1035	996	785	666	614
	Civil Aviation nat. (1A3a)	266	310	249	206	153	129	156	160	163	165
	Road (1A3b) - exhaust	48092	45903	32275	21174	12086	6896	6480	4753	4427	4483
	Road (1A3b) - non exhaust	29132	24162	10024	4769	1817	1451	1307	1219	1190	1174
	Railways (1A3c)	321	327	253	235	189	161	132	9	7	2
	Navigation (1A3d)	509	541	347	345	366	239	232	235	238	247
	Comm./Inst. (1A4a)	2284	2334	2783	5606	4355	3587	3573	3476	3274	3255
	Residential (1A4b)	1801	1777	1755	2088	2047	1875	1826	1715	1620	1573
	Agriculture/forestry (1A4c)	5894	4300	3091	2276	1930	1459	1383	1170	1073	989
	Fisheries (1A4c)	389	364	503	489	387	335	369	407	436	439
	Other (1A5b)	1166	1410	1374	1146	553	340	311	266	235	217
	Navigation int. (1A3d)	2060	3501	2940	1792	1628	1815	1834	1893	1937	1959
	Civil Aviation int. (1A3a)	126	130	160	145	118	136	136	143	149	153
$PM_{2.5}$	Industry - Other (1A2g)	1605	1373	1149	1028	737	575	545	322	160	66
	Civil Aviation nat. (1A3a)	12	15	14	14	12	13	13	14	15	15
	Road (1A3b) - exhaust	4778	4689	3194	2408	1559	970	849	430	228	157
	Road (1A3b) - non exhaust	626	720	785	862	865	886	892	957	1011	1050
	Railways (1A3c)	202	206	141	124	95	61	50	1	1	0
	Navigation (1A3d)	793	787	235	274	193	149	101	101	101	100
	Comm./Inst. (1A4a)	24	24	30	65	67	67	67	67	67	67
	Residential (1A4b)	11	11	11	13	14	15	15	15	15	15
	Agriculture/forestry (1A4c)	2698	2183	1504	1136	781	541	467	244	154	90
	Fisheries (1A4c)	181	163	215	200	143	122	134	146	155	155
	Other (1A5b)	104	233	161	182	115	93	89	60	42	25
	Navigation int. (1A3d)	5448	9925	8614	5675	920	992	641	641	641	641

Continued											
	Civil Aviation int. (1A3a)	93	95	119	173	160	190	189	200	208	214
BC	Industry - Other (1A2g)	873	747	637	615	507	410	391	236	112	35
	Civil Aviation nat. (1A3a)	4	6	6	6	6	7	7	7	7	7
	Road (1A3b) - exhaust	2106	2233	1730	1543	1117	694	602	268	96	37
	Road (1A3b) - non exhaust	106	122	134	148	150	153	154	166	175	182
	Railways (1A3c)	131	134	91	80	62	40	32	1	0	0
	Navigation (1A3d)	120	127	52	53	40	29	23	23	23	22
	Comm./Inst. (1A4a)	1	1	2	3	3	3	3	3	3	3
	Residential (1A4b)	1	1	1	1	1	1	1	1	1	1
	Agriculture/forestry (1A4c)	1461	1186	815	635	465	329	284	142	83	44
	Fisheries (1A4c)	57	51	68	63	45	38	42	46	49	49
	Other (1A5b)	21	85	42	63	41	37	36	23	16	9
	Navigation int. (1A3d)	714	1325	1138	741	159	173	130	130	130	130

Road transport

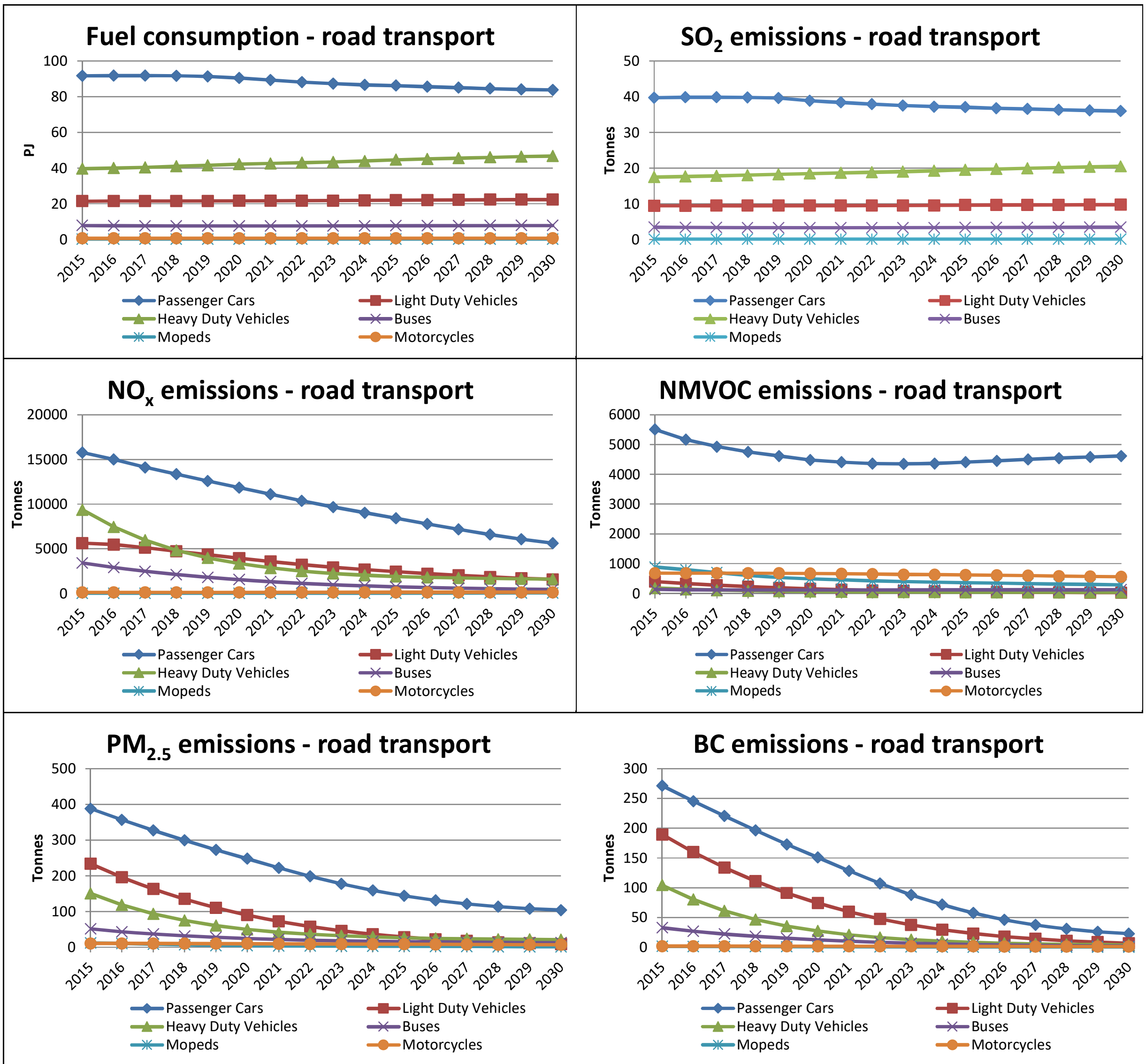

Figure 4.4 Fuel consumption, NO_X, SO_2, NMVOC, $PM_{2.5}$ and BC emissions from 2015-2030 for road traffic.

Total fuel consumption and SO_2 emissions for road traffic stays at the same level during the 2015-2030 periods. 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 majority of the NMVOC emission from road transport comes from gasoline passenger cars (Figure 4.4). The NMVOC emission is projected to decrease around 27 % from 2015 to 2027 for passenger cars, explained by the introduction of gradually more efficient catalytic converters for gasoline cars. From 2027 onwards the emissions increase proportionally with the total mileage for these vehicles.

In terms of $PM_{2.5}$ and BC the total emission is expected to decline by 81 % and 94 %, respectively, from 2015 to 2030, in particular due to the introduction of diesel particulate filters (DPF) for Euro 5 cars/vans, and Euro VI trucks/buses. The largest emission source is passenger cars, followed by light duty vehicles, heavy duty vehicles and buses. Emission reductions are generally higher for BC than for $PM_{2.5}$ due to the very efficient removal of BC by the DPF technology.

The NO_X emission for road transport declines by 72 % from 2015 to 2030. For trucks and buses the relative emission declines of 83 % and 86 %, respectively, are quite significant during the forecast period, due to the automatic fleet turnover towards newer EU emission standards that in practice reduce the emission factors from Euro III onwards. For cars and vans the emission reductions (64 % and 72 %, respectively) are less favourable mainly due to the well-known problems for diesel cars and vans to comply with the EU emission legislation standards. The NO_x emission factors for diesel vehicles are shown in Figure 4.5[9].

The fact that diesel cars and vans emit more NO_x in real driving than during type approval test, is accounted for in the present forecast based on COPERT IV baseline factors. However, recent measurements of high NO_x emissions from Euro 6 diesel cars (ICCT, 2014) makes it important to examine the total emission consequences, if NO_x emission factors for the present Euro 6 cars are in reality even higher than suggested by COPERT IV. Hence, for diesel cars and vans NO_x emissions sensitivity estimates are made for two additional situations in the present project.

The first (worst case) scenario investigates the situation if no emission factor improvements are gained with the introduction of the Euro 6 emission standard (Euro 6 = Euro 5). This scenario assumption corresponds with recent NO_x emission measurements made on Euro 6 cars reported by ICCT (2014). The latter study found measured emission factors to be on average approximately seven times higher than the EU Euro 6 emission certification levels (see also EEA (2016)).

In the second model run Euro 6 emission factors are kept at Euro 5 levels until the emission factors are step wise reduced for diesel cars (in 2018/2020) and diesel vans (in 2019/2021) in order to comply with the RDE emission legislation limits explained in section 4.1.2.

[9] Since the previous national emission projections published by Nielsen et al. (2013) a few changes have been made in NO_x emission factor by the developers of the COPERT IV emission model. For diesel cars Euro 5/6 the NO_x emission factors have changed from 0.64/0.22 g/km to 0.55/0.19 g/km. For diesel vans the Euro 5 emission factor has changed from 0.53 g/km to 0.68 g/km. Additionally, emission factors for a new model layer of Euro 6c vehicles covered by the updated EU emission legislation, have been included in the emission model by the COPERT IV developers. Since the previous national emission projections published by Nielsen et al. (2013) the diesel share of passenger cars in 2020*[2030]* has changed from 42*[47]* % to 35*[32]* %.

The NO_x emission results are shown in Table 4.13 for total road (present forecast) together with present forecast, E6=E5 and E6 RDE model results for diesel cars and diesel vans.

Table 4.13 NO_x emissions for total road transport (present forecast), and present forecast, E6=E5 and E6 RDE model results for diesel cars and diesel vans for the years 2015-2020, 2025 and 2030.

	Case	2015	2016	2017	2018	2019	2020	2025	2030
Total road	Present forecast	34360	30984	27887	25205	22874	20896	13708	9483
Diesel cars	Present forecast	11421	11160	10712	10274	9768	9288	6392	3780
	E6=E5	11523	11658	11773	11878	11958	12126	12269	12244
	E6 RDE	11523	11658	11773	11878	11646	11192	8194	5255
	Present vs. E5=E6	102	498	1061	1604	2191	2837	5877	8464
	Present vs. E6 RDE	102	498	1061	1604	1878	1904	1802	1475
Diesel vans	Present forecast	5517	5370	5058	4659	4277	3917	2416	1556
	E6=E5	5517	5433	5370	5327	5296	5320	5413	5532
	E6 RDE	5517	5433	5370	5327	5296	5118	3430	2258
	Present vs. E5=E6	0	64	312	668	1018	1403	2997	3976
	Present vs. E6 RDE	0	64	312	668	1018	1201	1014	702

If the Euro 6 emission legislation for diesel cars and vans proves to be ineffective (the Euro 6 = Euro 5 model case) the NO_x emissions for diesel cars*[diesel vans]* are expected to increase by 2.8 ktonnes*[1.4 ktonnes]* in 2020, and 8.5 ktonnes*[4.0 ktonnes]* in 2030, compared with the present forecast. The percentage increases for diesel cars*[diesel vans]* then become 31 %*[36 %]* in 2020 and 224 %*[256 %]* in 2030. In total for the Euro 6 = Euro 5 case, the road transport emissions increase by 20 % and 131 %, respectively, in 2020 and 2030.

In the situation when Euro 6 light vehicles comply with the emission limits measured during the new World Harmonized Light duty test Procedure (WHLP) and real traffic driving conditions (the Euro 6 RDE model case) the emission increases become considerably lower compared with the Euro 6 = Euro 5 model case. The calculated NO_x emissions for diesel cars*[diesel vans]* increase by 1.9 ktonnes*[1.2 ktonnes]* in 2020, and 1.5 ktonnes*[0.7 ktonnes]* in 2030, compared with the present forecast, and the derived percentage increases become 20 %*[31 %]* in 2020 and 39 %*[45 %]* in 2030. In total for the Euro 6 RDE case, the road transport emissions increase by 15 % and 23 %, respectively, in 2020 and 2030.

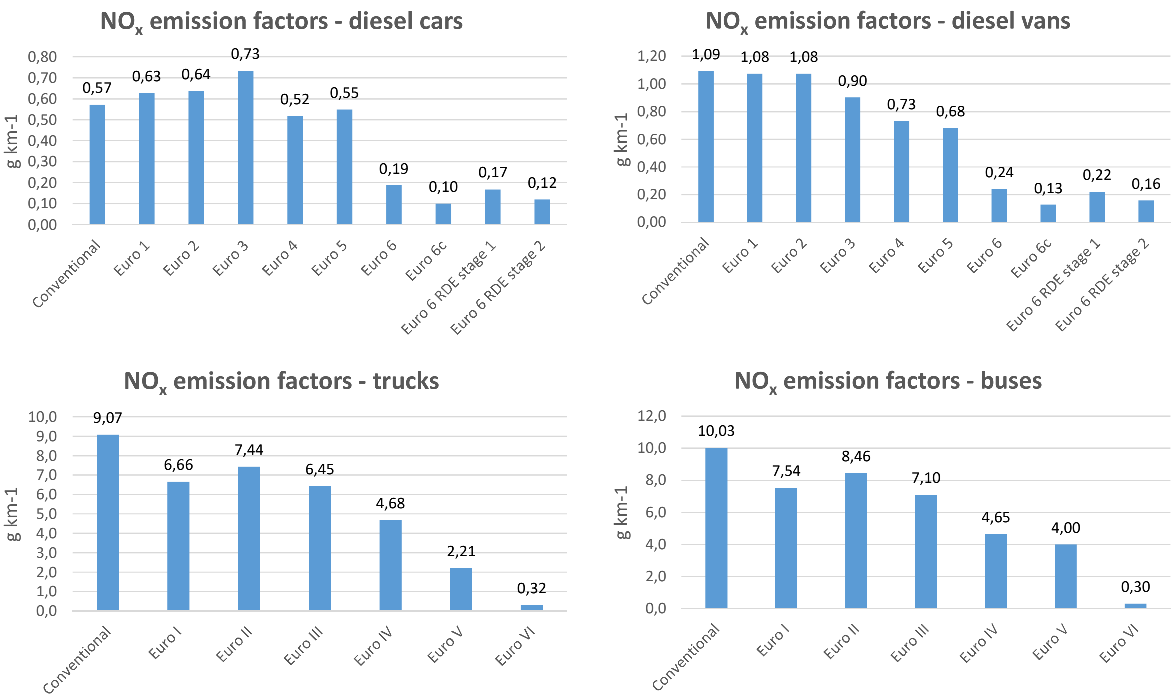

Figure 4.5 Layer specific NO_X emission factors for diesel vehicles.

The emission developments for diesel cars and vans are also shown in Figure 4.6 for the three calculation situations where:

- 2016 forecast: The present forecast using baseline emission factors from the COPERT IV model.
- Euro 6 = Euro 5: This scenario describes the situation if no emission factor improvements are gained with the introduction of the Euro 6 emission standard.
- Euro 6 RDE: In this scenario Euro 6 emission factors are kept at Euro 5 levels until the emission factors are step wise reduced for diesel cars (in 2018/2020) and diesel vans (in 2019/2021) to comply with the RDE emission legislation limits (Euro 6 RDE).

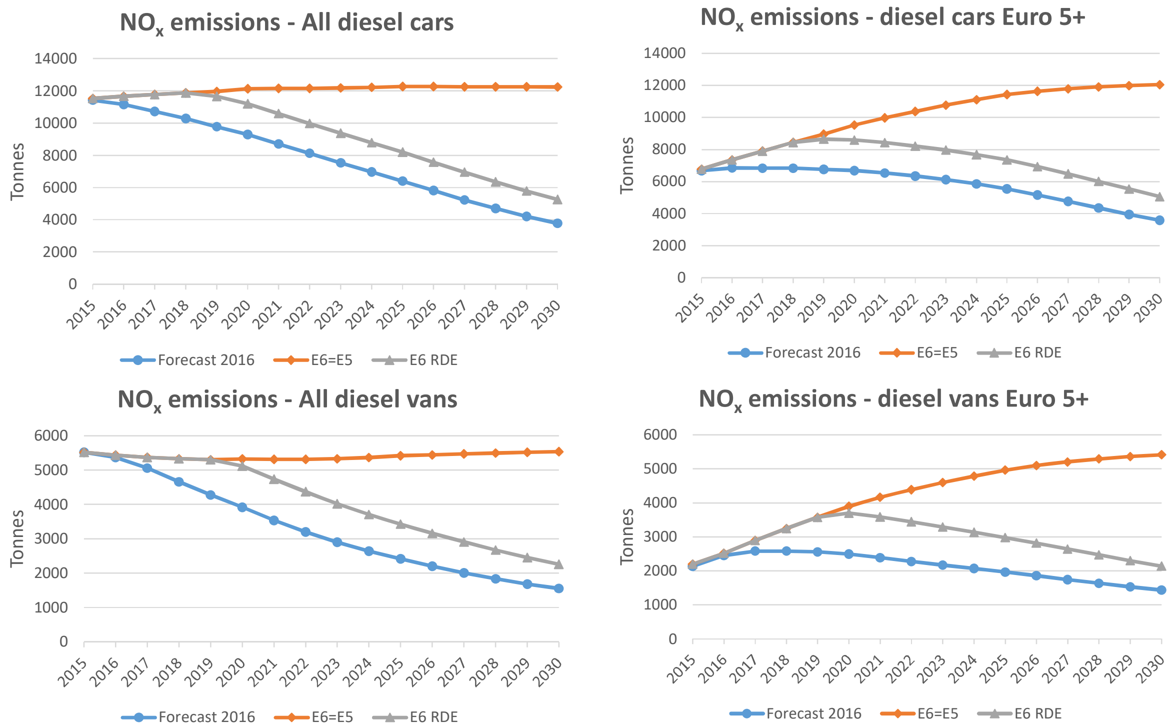

Figure 4.6 NO_X emissions from the present forecast, 2) No Euro 6 emission factor improvements (E6 = E5) and 3) Euro 6 emission factors expected from RDE legislation

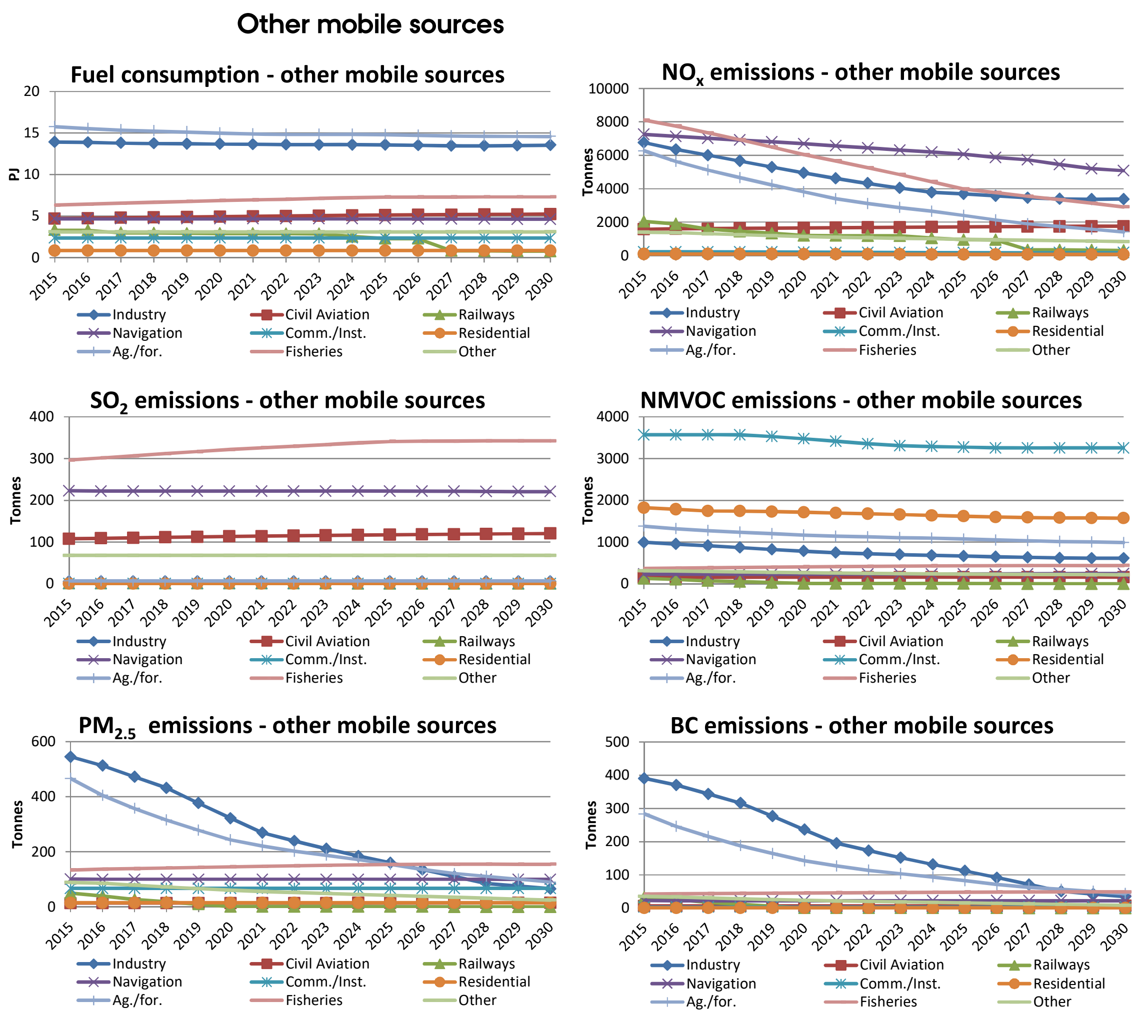

Figure 4.4 Fuel consumption, NO_X, SO_2, NMVOC, $PM_{2.5}$ and BC emissions from 2015-2030 for other mobile sources.

From 2015-2030 the total fuel consumption decreases by 5 % for other mobile sources. The emissions of SO_2 increase by 8 %, due to an increase in fuel consumption for fishery that uses marine diesel with a relatively high content of sulphur. For other mobile sources the emissions of NO_x, NMVOC, $PM_{2.5}$ and BC decreased by 55 %, 16 %, 64 % and 79 %, respectively.

The development in fuel consumption is forecasted by the DEA (2015). Agriculture/forestry/fisheries is by far the largest fuel consumption source followed by industry, navigation and civil aviation. Rather small fuel consumption totals are noted for railways, other (military and recreational boats), residential and commercial/institutional.

Small fuel reductions for industry and agriculture/forestry are achieved in the beginning of the forecast period primarily due to a gradual phase-out of old and less fuel efficient technologies. For fishing activities DEA (2015) expect an 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. However, for navigation and fisheries, the reduction of the sulphur content in heavy fuel oil used in the Baltic and North Sea SO_x emission control areas (SECAs) has had a major emission impact from 2015.

By far the most of the NMVOC emission comes from gasoline gardening machinery in commercial/institutional. The same gasoline equipment types also give considerable contributions for residential. The projected NMVOC emission reductions for commercial/institutional and residential are due to the introduction of the cleaner gasoline stage II and stage V emission technology for some types of equipment. 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 $PM_{2.5}$, industrial non road machinery is the largest emission source for other mobile sources in the beginning of the forecast period followed by agriculture/forestry, fisheries and navigation. By the end of the forecast period, fisheries and navigation become the largest emission sources. 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 $PM_{2.5}$ emissions from fishing vessels rely on the fuel consumption development, and show a stable increase throughout the forecast period. The SECA reductions in the sulphur content for heavy fuel oil have significantly reduced the $PM_{2.5}$ emissions for navigation in 2015.

Being a sub part of total PM, the decline in BC emissions throughout the forecast period is driven by the general decrease in PM emissions for diesel fuelled agriculture/forestry and industry machinery and the stepwise introduction of Stage V machinery from 2019/2020. In order to meet the Stage V PM emission standards for engines >= 19 kW particulate filters are needed which in addition are very efficient removers of BC.

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, civil aviation, residential, commercial/institutional and other.

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5 Fugitive emissions from fuels

The projection of fugitive emissions from fuels includes sources related to exploration, extraction, refining, storage, handling, and transport of fuels. The projection include emissions of SO_2 from oil and gas exploration, 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, exploration of oil and gas, 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. (2015) and Nielsen et al. (2016).

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
050204	1B2a i	Exploration of oil	Oil	SO_2, NO_x, NMVOC, PM
050303	1B2b	Off-shore activities	Natural gas	NMVOC
050304	1B2b	Exploration of gas	Natural gas	SO_2, NO_x, NMVOC, PM
050503	1B2a v	Service stations	Oil**	NMVOC
050601	1B2b	Pipelines	Natural gas	NMVOC
050603	1B2b	Distribution networks	Natural gas	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
090298	1B2c	Flaring in oil and gas extraction	Venting and flaring	SO_2, NO_x, NMVOC, PM
090299	1B2c	Flaring in oil and gas extraction	Venting and flaring	SO_2, NO_x, NMVOC, PM

* 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, 2013).

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

Emission factors are either based on the EMEP/EEA guidelines (EMEP/EEA, 2013) 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.

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

The oil and gas production prognosis

Activity data from the prognosis for the production of oil and gas (DEA, 2015b) 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 production prognosis shows relatively large fluctuation of the production rates over the projection period, while the trend for gas production is more stable. The overall trend is a decrease for gas production for the years 2015-2030. The oil production is expected to decrease from 2015 to 2025, followed by an increasing trend, leading to almost same rate in 2030 as in 2015.

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.

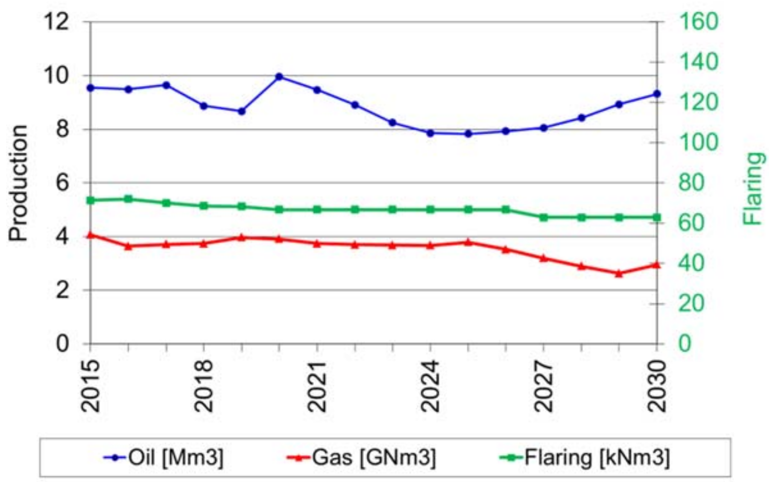

Figure 5.1 Prognosis for the production of oil and gas (DEA, 2015b).

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, emissions from 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 5.2 shows the estimation methodology for onshore loading.

Eq. 5.2 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

The energy consumption prognosis

Data from the energy consumption prognosis by the DEA (2015a) 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 (2015a).

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.

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 sulphur 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. In the energy consumption prognosis the rates for refinery gas consumption and flaring in refineries are assumed constant. In order to be consistent with this approach, the emissions in the latest historical year are 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, 2013) 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 2030 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 IPCC Guidelines (IPCC, 2006). The NMVOC emission factor for service stations is listed in Table 5.2.

Table 5.2 NMVOC emission factors for 2010-2030

Source	EF	Unit	Reference
Ships offshore	0.001	Fraction of loaded	EMEP/EEA, 2013
Ships onshore	0.00015	Fraction of loaded	EMEP/EEA, 2013 and Miljøcenter Odense, 2010
Service stations	0.541	Kg NMVOC/Mg gasoline	IPCC, 2006

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 (2013).

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

Pollutant	EF	Unit	Reference
SO_2	0.013	g/Nm^3	EMEP/EEA, 2013
NO_x	1.227	g/Nm^3	Danish EPA, 2008
NMVOC	1.482	g/Nm^3	EMEP/EEA, 2013
TSP	0.042	g/Nm^3	EMEP/EEA, 2013
PM_{10}	0.042	g/Nm^3	EMEP/EEA, 2013
$PM_{2.5}$	0.042	g/Nm^3	EMEP/EEA, 2013

Emissions of particulate matter (PM) from coal storage are estimated by the emission factors from the Coordinated European Particulate Matter Emission Inventory Program, CEPMEIP (Visschedijk 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	Visschedijk et al., 2004
PM_{10}	60	g/Mg	Visschedijk et al., 2004
$PM_{2.5}$	6	g/Mg	Visschedijk 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 factor for the latest five historical years and the activity data for the latest historical year scaled to the annual oil production given in the oil and gas production prognosis (DEA, 2015a).

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, 2015a). Emissions from refineries (processes and flaring) are kept constant at the level in the latest historical year in agreement with the approach in the energy consumption prognosis.

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

5.4 Emissions

Tables and figures in this section show data for every fifth historical year (1990-2010), the latest historical year (2014), and every fifth projection year (2015-2030).

The SO_2 emissions (Figure 5.2) 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.

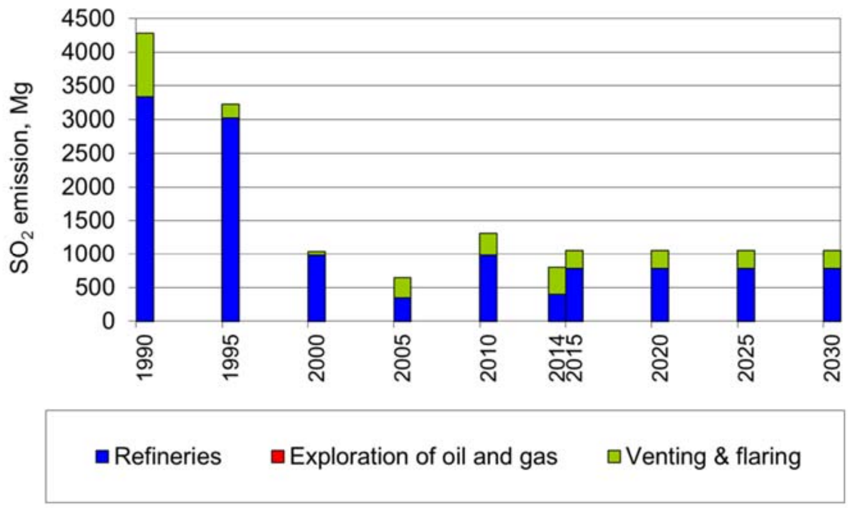

Figure 5.2 SO_2 emissions for selected historical years (1990-2014) and projection years (2015-2030).

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 (1990-2014) and projection years (2015-2030).

NFR code	Source	1990	1995	2000	2005	2010	2014	2015	2020	2025	2030
		Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg
1B2a iv	Refinery, processes	3335	3022	981	347	981	397	785	785	785	785
1B2c	Refinery, flaring	943	203	51	296	326	398	267	267	267	267
1B2c	Flaring in oil and gas production	1.4	2.0	3.3	2.5	1.6	1.1	1.0	0.9	0.9	0.8

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 2014 due to the decreasing trend for offshore flaring.

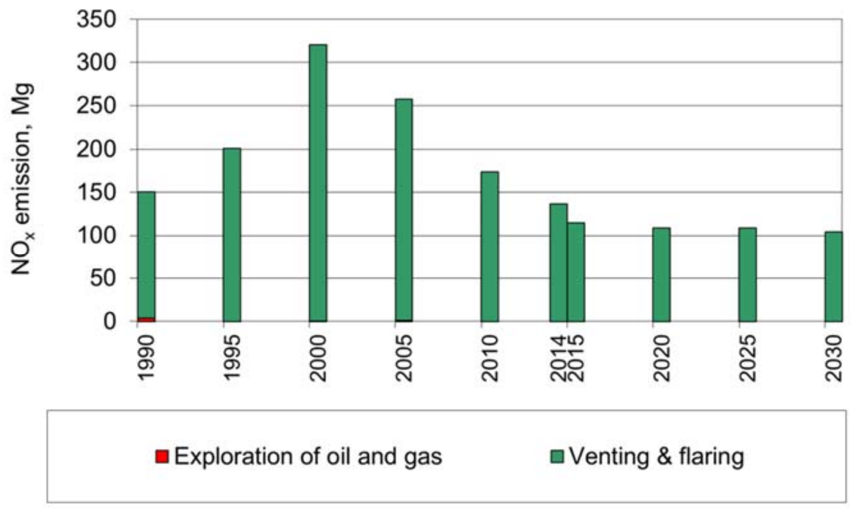

Figure 5.3 NO_x emissions for selected historical years (1990-2014) and projection years (2015-2030).

The most important source is offshore flaring in oil and gas extraction, which account for 96 % in year 2000, 82 % in 2014 and 81 % in 2030. 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 (1990-2014) and projection years (2015-2030).

NFR code	Source	1990	1995	2000	2005	2010	2014	2015	2020	2025	2030
		Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg
1B2c	Refinery, flaring	13	13	11	26	19	25	20	20	20	20
1B2c	Flaring in oil and gas production	134	188	310	231	155	111	95	89	89	84

The fugitive sector is an important source of NMVOC emissions. In 2014 the sector accounted for 9 % of the national total NMVOC emission. The major fugitive NMVOC sources are refinery processes, onshore and offshore activities in oil and gas production, 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.

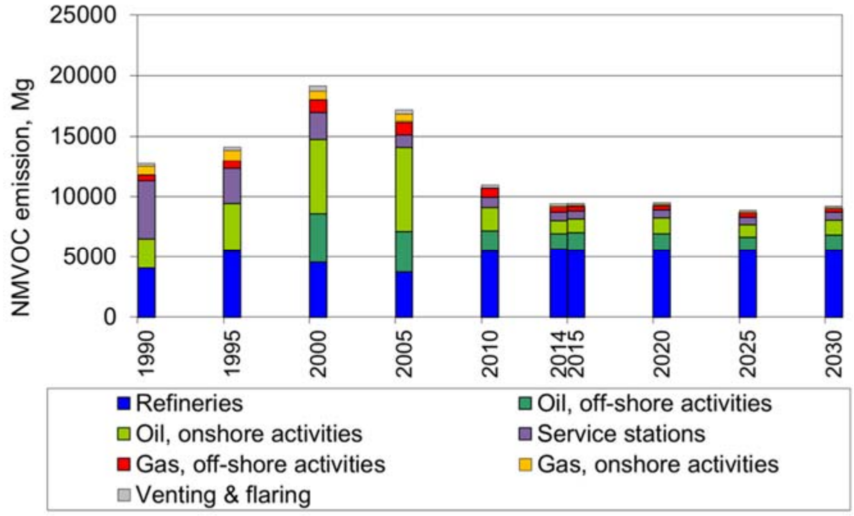

Figure 5.4 NMVOC emissions for selected historical years (1990-2014) and projection years (2015-2030).

Emissions of NMVOC are listed in more detail in Table 5.7. Emissions from offshore activities for oil and gas, from onshore activities for oil, and from flaring in oil and gas production fluctuate 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 early historical years until 2005, followed by a slight decrease in the later historical years and the projection years. Consumption of natural gas are decreasing in the projection period, leading to decreasing NMVOC emissions. Venting occur due to safety reasons in connection with construction work, inspection and maintenance, and fluctuates in an unpredictable way. The emissions are constant in the projection period, as an average of the emissions in the latest five historical years.

Table 5.7 Projected NMVOC emissions for selected historical years (1990-2014) and projection years (2015-2030).

NFR code	Source	1990	1995	2000	2005	2010	2014	2015	2020	2025	2030
		Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg
1B2a iv	Refinery, processes	4072	5500	4530	3742	5477	5620	5539	5539	5539	5539
1B2a i	Oil, offshore activities *	5	8	4037	3353	1669	1266	1464	1357	1068	1270
1B2a i	Oil, onshore activities	2404	3913	6183	6994	1950	1124	1120	1331	1047	1246
1B2a v	Service stations	4856	2965	2186	1031	851	716	697	672	651	651
1B2b	Gas, off-shore activities	472	575	1030	1050	733	410	370	356	345	269
1B2b	Gas transmission	41	135	26	36	6	33	15	12	11	11
1B2b	Gas distribution	695	722	695	604	61	57	89	77	70	70
1B2c	Venting	15	27	24	14	22	19	21	21	21	21
1B2c	Refinery, flaring	31	31	26	32	27	33	33	33	33	33
1B2c	Flaring in oil and gas production	162	227	374	276	177	125	106	99	99	94

* Offshore loading of ships were not occurring until 1999.

PM and BC emissions are reported for the years 2000 and onwards. The major fugitive source is coal storage, while emissions from flaring are of only minor importance especially regarding BC (Figure 5.5, Figure 5.6, Table 5.8 and Table 5.9). Emissions from coal storage follow the trend of the annual coal consumption. As the energy consumption prognosis (DEA, 2015a) only cover the years 2015-2025, the coal consumption is assumed constant from 2025-2030 in the emission projection.

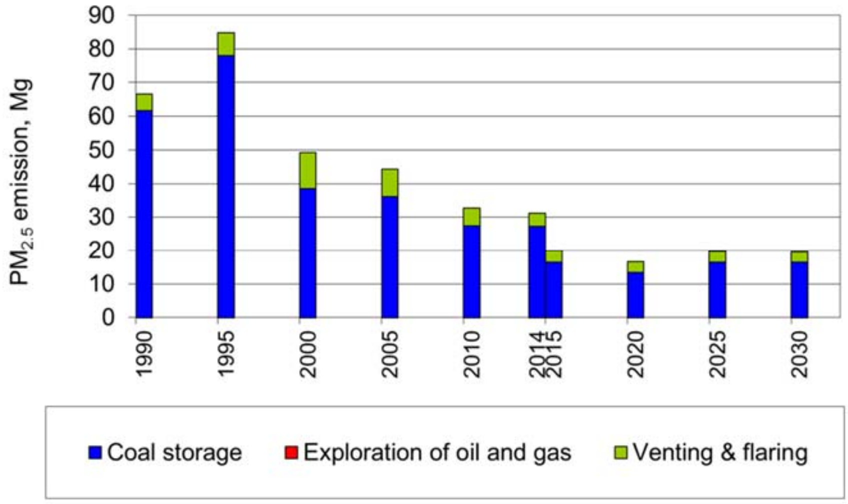

Figure 5.5 $PM_{2.5}$ emissions for selected historical years (1990-2014) and projection years (2015-2030).

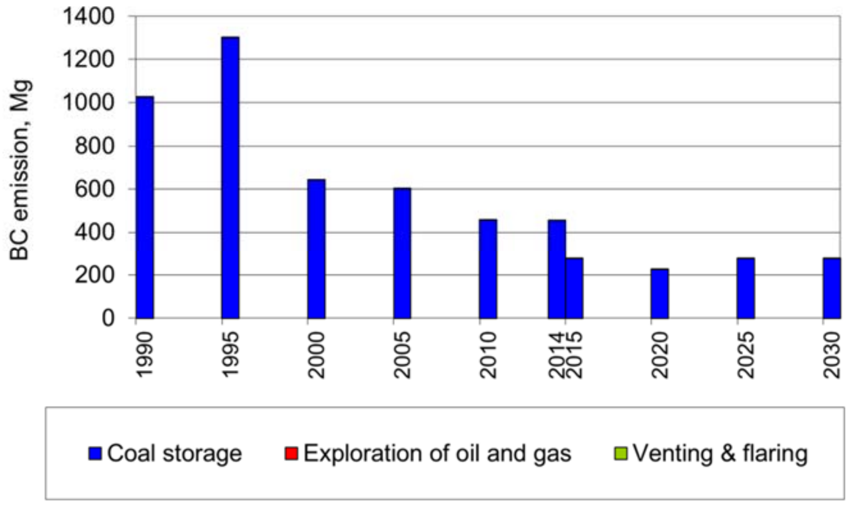

Figure 5.6 BC emissions for selected historical years (1990-2014) and projection years (2015-2030).

Table 5.8 Projected $PM_{2.5}$ emissions for selected historical years (1990-2014) and projection years (2015-2030).

NFR code	Source	2000 Mg	2005 Mg	2010 Mg	2014 Mg	2015 Mg	2020 Mg	2025 Mg	2030 Mg
1B1a	Coal storage	38	36	27	27	17	13	17	17
1B2a + 1B2b	Exploration of oil and gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1B2c	Refinery, flaring	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1B2c	Flaring in oil and gas production	10.8	8.1	5.3	3.9	3.4	3.2	3.2	3.1

Table 5.9 Projected BC emissions for selected historical years (1990-2014) and projection years (2015-2030).

NFR code	Source	2000 Mg	2005 Mg	2010 Mg	2014 Mg	2015 Mg	2020 Mg	2025 Mg	2030 Mg
1B1a	Coal storage	642	603	457	453	276	224	275	275
1B2a + 1B2b	Exploration of oil and gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1B2c	Refinery, flaring	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1B2c	Flaring in oil and gas production	2.0	1.5	1.0	0.8	0.7	0.6	0.6	0.6

5.5 Changes since previous projection

Only minor changes have been applied to the projection methodology since the last projection in 2013. Most changes of the projected emissions owe to use of updated versions of the oil and gas production prognosis (DEA, 2015b) and the energy consumption prognosis (DEA, 2015a). The largest percentage-wise change has been for NMVOC emissions from venting and flaring, as the emission factor has been updated according to the 2013 EMEP/EEA Guidebook (EMEP/EEA, 2013). The largest difference of 181 % occurs in 2015, which was the first projection year in the present projection.

Due to a change in calculation method in the emission inventory it has become possible to separate emissions from production of oil and gas. This has led to an increase of 39 % (2030) to 61 % (2019) according to the previous projection.

SO_2 emissions from refineries have been reallocated between sulphur recovery and flaring in the emission inventory, leading to a decrease of 15 % for 1B2a Oil and an increase of 29 % for 1B2c Venting and flaring.

The methodology for estimating emissions from flaring in refineries has been changed. In the present projection the emissions are based on the activity data in the latest historical year and standard emission factors, which corresponds with the approach in the energy consumption prognosis. In the previous projection, the emissions were estimated as the average for the last five years.

5.6 References

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6 Industrial processes and product use

6.1 Sources

Industrial processes and product use (IPPU) includes the NFR categories 2*A Mineral Industry, 2B Chemical Industry, 2C Metal Industry, 2D-I Other solvent and product use*. A range of sources is covered within each of these categories; the included sources are shown in Table 6.1. The contribution in 2014 to the national emissions is for SO_2 6 %, NMVOC 26 %, NO_x < 1 %, TSP 5 %, $PM_{2.5}$ 3 % and BC < 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 industry	2 Lime production	03 03 12
		3 Glass production	03 03 15/16
		5a Quarrying and mining of minerals other than coal	04 06 16
		5b Construction and demolition	04 06 24
		5c Storage, handling and transport of mineral products	04 06 90
		6 Production of ceramics	04 06 91/92
		6 Stone wool production	03 03 18
2B	Chemical industry	10a Catalyst production	04 04 16
		10a Chemical Ingredients production	04 05 00
		10a Pesticide production	04 05 25
		10a Production of tar products	04 05 27
2C	Metal production	1 Rolling mills steel production	04 02 08
		1 Grey iron foundries	03 03 03
		3 Aluminium production	03 03 10
		5 Lead production	03 03 07
2D	Other solvent and product use	3a Domestic solvent use incl. fungicides	06 04 08/11
		3b Road paving with asphalt	04 06 11
		3c Asphalt roofing	04 06 10
		3d Coating applications	06 01 00
		3e Degreasing	06 02 00
		3f Dry cleaning	06 02 02
		3g Chemical products	06 03 00
		3h Printing	06 04 03
		3i Other solvent use	06 04 00
		3h Paraffin wax use	06 06 06
2G	Other product use	4 Use of fireworks	06 06 01
		4 Use of tobacco	06 06 02
		4 Use of charcoal for barbeques	06 06 05
2H	Food and beverages industry	2 Bread production	04 06 05
		2 Wine production	04 06 06
		2 Beer production	04 06 07
		2 Spirits production	04 06 08
		2 Sugar production	04 06 25
		2 Meat curing	04 06 27
		2 Use of margarine and solid cooking fats	04 06 98
		2 Coffee roasting	04 06 99
2I	Other processes	Wood processing	04 06 20

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

The projection of emissions from industrial processes and product use is based on the national emissions inventory prepared for UNECE (Nielsen et al., 2016).

6.2 Methodology

The projections are generally based on projection of production values for the individual sources and implied emission factors (IEF) for 2014. Production values can be projected in four ways;

- By extrapolation of representative historical years using the projection values for glass, steel and cement/construction industries (Danish Energy Agency, 2015), see Table 6.2 and Figure 6.1.
- By estimating an expected future activity level and the number of years for the given source category to reach this level.
- By using an average of representable historical years.
- By linear regression of a significant trend in the historical data.

The projection values with 2014 as base year for the relevant sectors are shown below.

Table 6.2 Projection factors for extrapolating activity data for the IPPU source categories (Danish Energy Agency, 2015).

	Steel industry	Glass industry	Building and construction (and cement production)
2014	1.00	1.00	1.00
2015	1.06	1.05	1.00
2016	1.10	1.09	1.02
2017	1.15	1.14	1.05
2018	1.21	1.20	1.09
2019	1.27	1.26	1.12
2020	1.32	1.31	1.15
2021	1.37	1.35	1.18
2022	1.42	1.40	1.20
2023	1.44	1.42	1.22
2024	1.46	1.44	1.23
2025	1.47	1.45	1.24
2026	1.48	1.47	1.26
2027	1.50	1.49	1.27
2028	1.51	1.49	1.29
2029	1.52	1.50	1.30
2030	1.55	1.53	1.32

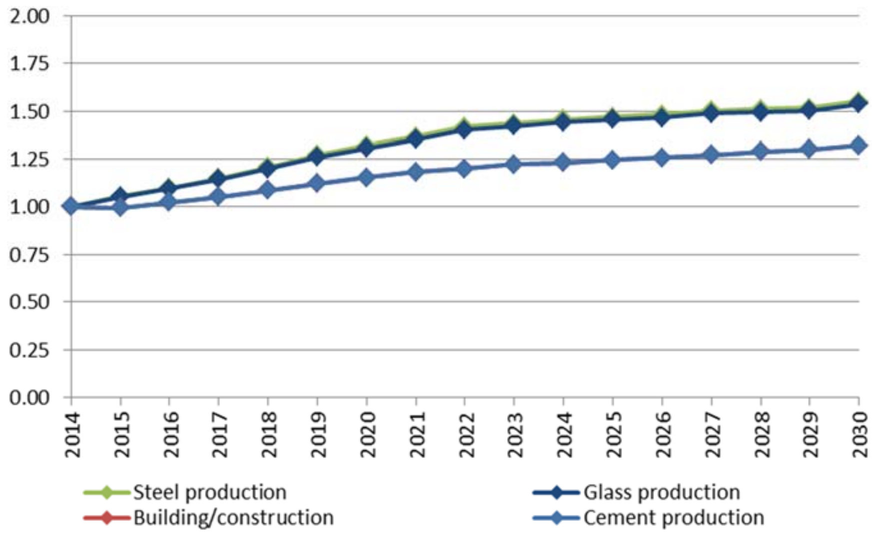

Figure 6.1 Projection factors applied for projections for 2015-2030.

The changes from the previous projection values are presented and discussed in Section 6.4.

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

Mineral industry

There are nine sources of emissions within the NFR category *2A Mineral Industry*; production of lime, glass, glass wool, bricks/tiles, expanded clay and stone wool along with quarrying/mining, construction/demolition and storage/handling/transport, see Table 6.3.

Table 6.3 Sources/processes included in *2A Mineral Industry*.

		Sources/processes
2A2	Lime production	Lime production
2A3	Glass production	Glass production
		Glass wool production
2A5	Other activities	Quarrying and mining of minerals other than coal
		Construction and demolition
		Storage, handling and transport of mineral products
2A6	Other production	Production of ceramics
		Production of bricks/tiles
		Production of expanded clay
		Stone wool production

The activity of lime production is assumed to continue its increase and reach the pre-crisis (2003-2006) level of 80 Gg CaO within four years. The glass production activity data are projected using the projection values for glass industry shown in Table 6.2 and Figure 6.1.

Activity data for "quarrying and mining of minerals other than coal" and "storage, handling and transport of mineral products" are extrapolated using the projection values for cement production which equals the building and construction projection values (although cement production only leads to process CO_2 emissions and therefore is not included in this report, cement production is the dominating industry in Denmark within the mineral industry sector).

For the remaining five source categories, activity data was projected using the building/construction projection values.

The emission factors applied for this projection for the sources within category 2A3 Glass production and 2A6 Other production are calculated 2014 implied emission factors. These factors will change for each new historical year that becomes available as they are based on measurements. Emission factors for 2A2 Lime production and the three sources in 2A5 Other activities are available from EMEP/EEA (2013) and constant for 1990-2030 (2000-2030 for particles).

The calculated emission projections are shown in the NFR tables, for more detail see section 6.3.1.

Chemical industry

There are four source categories relevant for the emission projection within NFR category *2B Chemical Industry*; production of catalysts, chemical ingredients, pesticides and tar products, all categorised under *2B10a Other chemical industry*.

There are no projection values available for these source categories and the activity data are therefore assumed as the constant average values for 2010-2014 for each source respectively (for catalyst production however only 2012-2014).

Regarding emission factors for the source categories relevant for the Danish chemical industry, the international guidebook (EMEP/EEA) provides no support. Implied emission factors are therefore calculated from the individual industries based on any available measurements from the company environmental reports. For more information on the emission factors see Nielsen et al. (2016).

Calculated emission projections are shown in the NFR tables, for more detail see section 6.3.2.

Metal industry

There are four source categories relevant for the emission projection within NFR category *2C Metal industry*; rolling mills steel production, grey iron foundries, aluminium production and lead production.

Activity data for all four source categories are projected using the projection values for steel production presented in Table 6.2 and Figure 6.1.

The applied emission factors for the rolling mills used in this projection are for particles representative for the emissions after 2010 where particle abatement was installed at DanSteel. For NMVOC, the emission factor is constant since the opening of the rolling mills, i.e. 2003-2030. The applied emission factors for grey iron foundries, aluminium production and lead production are the same as for historical years and therefore constant for 2000-2030. For more information on the emission factors see Nielsen et al. (2016).

Calculated emission projections are shown in the NFR tables, for more detail see section 6.3.3.

Other solvent and product use

The following categories are included for projection of emissions within the source category *NFR 2D3 Non-energy products from fuels and solvent use*:

- Domestic solvent use including fungicides (NFR 2D3a, SNAP 060408 & 060411)
- Road paving with asphalt (NFR 2D3b, SNAP 040611)
- Asphalt roofing (NFR 2D3c, SNAP 040610)
- Coating applications (NFR 2D3d, SNAP 0601)
- Degreasing (NFR 2D3e, SNAP 0602)
- Dry cleaning (NFR 2D3f, SNAP 060202)
- Chemical products (NFR 2D3g, SNAP 0603)
- Printing (NFR 2D3h, SNAP 060403)
- Other solvent use (NFR 2D3i, SNAP 0604)
- Paraffin wax use (No NFR category – placed in NFR 2D3h in this year's reporting, SNAP 060606)

Solvent use categories are aggregated according to the following four categories, which correspond to the grouping in IPCC (2006):

- Coating applications (NFR 2D3d)
- Degreasing (NFR 2D3e) and Dry cleaning (NFR 2D3f)
- Chemical products (NFR 2D3g)
- Domestic solvent use including fungicides (NFR 2D3a), Printing (NFR 2D3h) and Other solvent use (NFR 2D3i)

Only NMVOCs used as solvents are relevant for the projections. The sector constitutes 24 % of the total national NMVOC emissions in 2014. The methodology for the Danish NMVOC emission inventory for solvent use is based on the detailed approach described in EMEP/EEA (2013) and emissions are calculated for industrial sectors, households in the above NFR categories, as well as for individual chemicals and/or chemical groups. Further details on the inventory methodology can be seen in Nielsen et al. (2016).

Production, use, marketing and labelling of VOC containing products in Denmark is regulated by two statutory orders; BEK no. 1491 of 7/12/2015 "Bekendtgørelse om anlæg og aktiviteter, hvor der bruges organiske opløsningsmidler" and regulation on certain paints and lacquers BEK no. 1369 af 25/11/2015 "Bekendtgørelse om markedsføring og mærkning af flygtige organiske forbindelser i visse malinger og lakker samt produkter til autoreparationslakering".

Other product use

There are three source categories relevant for the emission projection within NFR category *2G Other product use*; the use of fireworks, tobacco and charcoal for barbequing.

For fireworks and charcoal, the activity data are projected as the constant average values of the historical years 2010-2014.

For tobacco, the activity data for historical years display a convincing decreasing trend, and the activity data are therefore projected using linear regression. The result is a further decrease in activity with 27 % in 2030 in relation to the 2014 consumption.

The applied emission factors for all three sources and all pollutants are the same as for historical years and therefore constant for 1990-2030. All emission factors are collected from literature studies; see Nielsen et al. (2016) for more information.

Calculated emission projections are shown in the NFR tables, for more detail see section 6.3.5.

Food and beverages industry

There are eight source categories relevant for the emission projection within NFR category *2H Food and beverages industry*; production of bread (incl. biscuits/cakes), wine (red/white/cider), beer, spirits and sugar as well as meat curing, coffee roasting and the use of margarine and solid cooking fats.

All eight source categories are projected individually as the constant average of the historical years 2010-2014.

The applied emission factors for all eight sources are the same as for historical years and therefore constant for 1990-2030. All factors are based on EMEP/EEA (2013) except for that of sugar production which is country specific and supplied by the Danish sugar industry.

Calculated emission projections are shown in the NFR tables, for more detail see section 6.3.6.

Other processes

There is only one source category relevant for the emission projection within NFR category *2I Other processes*; wood processing.

The activity data for wood processing are projected as the constant average of the historical years 2010-2014.

The applied emission factors are the same as for historical years and therefore constant for 2000-2030. The factors are based on EMEP/EEA (2013).

Calculated emission projections are shown in the NFR tables, for more detail see section 6.3.7.

6.3 Emissions

The results of the emission projections for the IPPU sector are presented for selected years in Table 6.4. The projected emissions for all years and for the seven individual subsectors (2A-2I) are available in the NFR tables. Information on the individual source categories included in each subcategory is presented in the following sections 6.3.1-6.3.7.

Table 6.4 Historical and projected emissions from IPPU.

	Unit	1990	1995	2000	2005	2010	2014	2015	2020	2025	2030
SO_2	Gg	3.8	3.9	3.5	3.4	1.5	0.7	0.7	0.8	0.8	0.9
NO_x	Gg	0.9	0.7	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1
NMVOC	Gg	42.4	49.4	45.0	35.2	30.6	27.5	28.9	27.9	27.2	26.5
TSP	Gg	-	-	7.2	9.4	7.8	5.4	6.1	6.5	6.5	6.9
PM_{10}	Gg	-	-	3.9	6.0	4.9	2.7	3.1	3.2	3.3	3.4
$PM_{2.5}$	Gg	-	-	1.3	2.4	2.1	0.7	0.7	0.8	0.8	0.8
BC	Mg	-	-	9.8	3.4	1.9	2.0	2.3	2.4	2.4	2.6

In 2014 90 % of NMVOC emissions from *Industrial processes and product use* originated from *Other solvent and product use* (2D), this fraction is not expected to have changed much in 2030 as the projections predict that 89 % of NMVOC emissions from the IPPU sector will derive from 2D in 2030.

The largest contributor to $PM_{2.5}$ emissions in 2014 are *Mineral Industries* (2A) (57 %) followed by *Other product Use* (2G) (32 %). These fractions are expected to have increased and decreased respectively in 2030 to 60 % and 21 %. The source categories contributing the most to the $PM_{2.5}$ emission in 2014 are *Quarrying and mining* (2A5a) and *Use of Tobacco* (2G4) with 209.5 Mg and 97.5 Mg, respectively.

Mineral industry

Total emissions from the mineral industry sector are available in the NFR tables. The sources within mineral industry lead to the following emissions:

Table 6.5 Overview over which source categories lead to which emissions.

Sources/processes	SO_2	NMVOC	TSP	PM_{10}	$PM_{2.5}$	BC
Lime production			x	x	x	x
Container glass production			x	x	x	x
Glass wool production		x	x	x	x	x
Quarrying and mining of minerals other than coal			x	x	x	
Construction and demolition			x	x	x	x
Storage, handling and transport of mineral products			x	x	x	
Production of ceramics	x					
Stone wool production			x	x	x	x

Seven and five sources respectively within *Mineral Industry* lead to particle and black carbon (BC) emissions; Figure 6.2 and Figure 6.3 show the distribution of the total $PM_{2.5}$ and BC emissions between the individual sources.

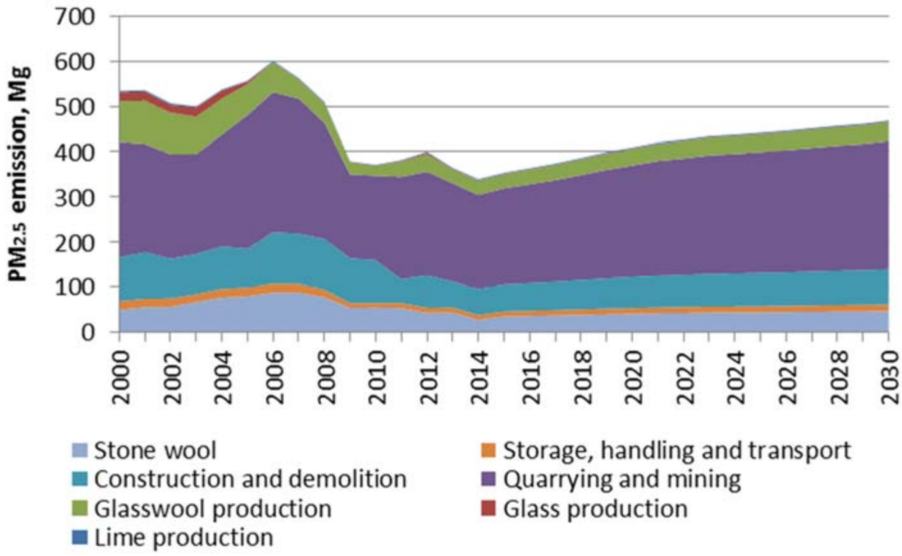

Figure 6.2 $PM_{2.5}$ emissions from *Mineral Industry*.

Particle emissions from storage, handling and transport of mineral products have due to an error not been included in the historical data in the NFR tables, they are however included in the Figure above.

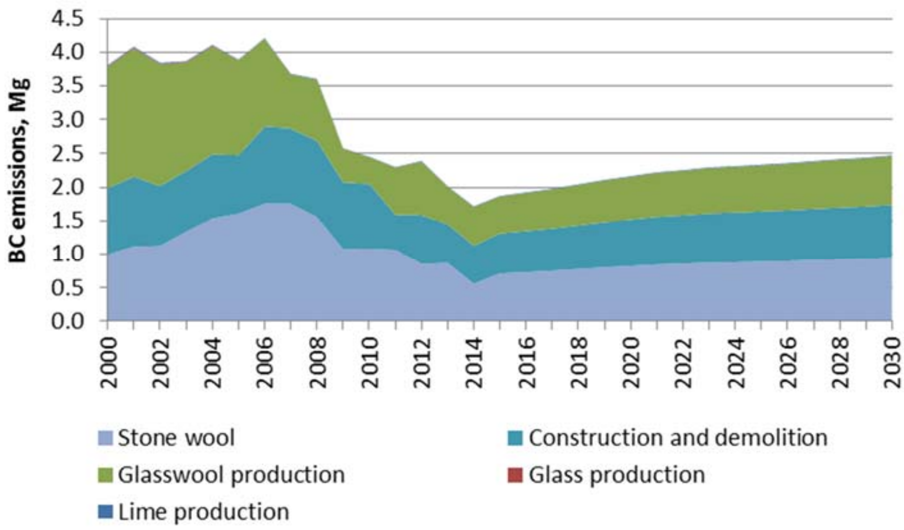

Figure 6.3 BC emissions from *Mineral Industry*.

The contributions to total BC emission from glass and lime production are so small that they are not visible in the Figure. BC emissions from construction and demolition have due to an error not been included in the historical data in the NFR tables, they are however included in the Figure above.

Chemical industry

Total emissions from the chemical industry sector are available in the NFR tables. The sources within chemical industry lead to the following emissions.

Table 6.5 Overview over which source categories lead to which emissions.

Sources/processes	SO_2	NO_x	NMVOC	TSP	PM_{10}	$PM_{2.5}$	BC
Nitric acid production[1]		x		x	x	x	x
Pesticide production	x		x				
Catalyst production		x		x	x	x	x
Chemical ingredients production			x				
Production of tar products	x		x				

[1] Closed down in 2004 (Kemira, 2004).

Since the production of nitric acid closed down in 2004, all emissions of NO_x, TSP, PM_{10}, $PM_{2.5}$ and BC from chemical industry in 2005-2030 are emitted from the production of catalysts.

In 2014, 97 % of SO_2 emissions from this subcategory were emitted by the production of tar products. All though the SO_2 emission from tar product production has been decreasing the last few years (-33 % from 2012 to 2014), this source category is still expected to be dominating the SO_2 emissions for 2015-2030 (95 %).

Three source categories within *Chemical Industry* lead to NMVOC emissions; Figure 6.4 shows the distribution of the total NMVOC emission between the individual sources.

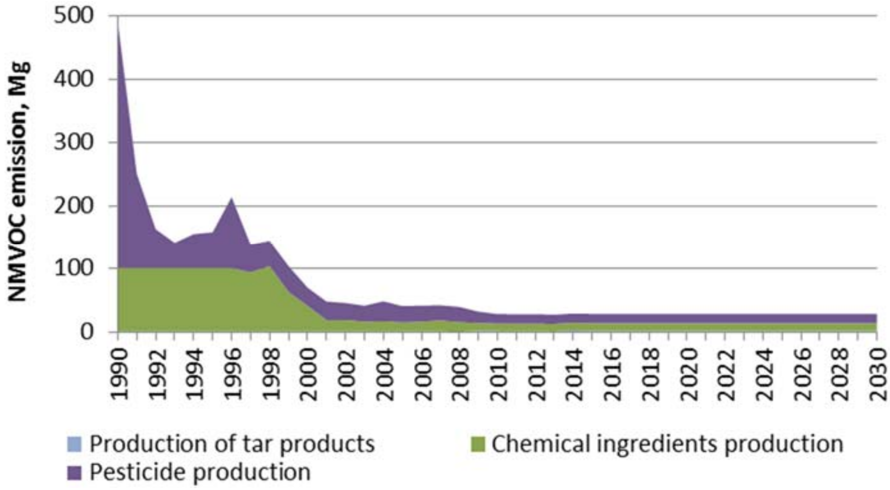

Figure 6.4 NMVOC emissions from *Chemical Industry*.

The contribution to total NMVOC emission from the production of tar products is so small that it is not visible in the Figure above.

Metal industry

Total emissions from the metal industry sector are available in the NFR tables. The sources within metal industry lead to the following emissions:

Table 6.6 Overview over which source categories lead to which emissions.

Sources/processes	NMVOC	TSP	PM_{10}	$PM_{2.5}$	BC
Electric arc furnace steel production[1]	x	x	x	x	x
Rolling mill steel production	x	x	x	x	
Grey iron foundries		x	x	x	
Secondary aluminium production		x	x	x	x
Secondary lead production		x	x	x	

[1] Only operational 1990-2002 and 2005.

The electric arc furnace steel production plant is only relevant for the historical years 1990-2002 and 2005 (where the plant reopened briefly), all NMVOC and BC emissions from the metal industry sector subsequent to 2005 are therefore alone emitted from the rolling mills and the aluminium production respectively.

Four to five source categories within *Metal Industry* lead to particle emissions; Figure 6.6 shows the distribution of the total $PM_{2.5}$ emission between the individual sources.

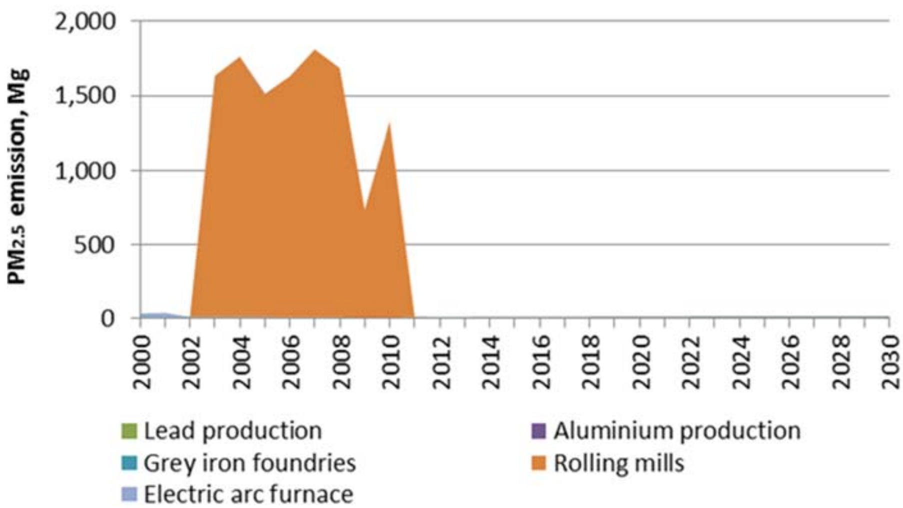

Figure 6.5 $PM_{2.5}$ emissions from *Metal Industry*.

After being overly dominating in 2003-2010, the larger of the two Danish rolling mill plants installed particle abatement in 2010. The expected distribution of $PM_{2.5}$ emissions between the four sources in 2015-2030 is: 15 % from rolling mills, 78 % from grey iron foundries, 2 % from secondary aluminium production and 5 % from secondary lead production.

Other solvent and product use

Solvent Use

The 2014 NMVOC emissions from solvent use (NFR 2D3a and NFR 2D3d-i) and its SNAP sub-categories are shown in Table 6.7. 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 Domestic solvent use, and 060314 Chemical products, manufacturing and processing: Other, comprise 51 %, 15 % and 13 %, respectively, of the total solvent NMVOC emissions. These sub-categories constitute highly diverse and diffuse activities and product uses, each comprising a number of chemicals.

Table 6.7 2014 NMVOC emission in Gg from solvent use (NFR 2D3a and NFR 2D3d-i) and its sub-categories.

SNAP	Category description	NMVOC emission 2014 (Gg)	Fraction of total 2014 emission
060101	Manufacture of Automobiles	0,037	0,15%
060102	Car Repairing	0,23	0,93%
060103	Constructions and Buildings	0,30	1,22%
060104	Domestic Use	0,32	1,30%
060105	Coil Coating	0,017	0,07%
060106	Boat Building	0,31	1,25%
060107	Wood	0,085	0,34%
060108	Other Industrial Paint Applications	1,17	4,74%
060109	Other Non-Industrial Paint Application	0,068	0,28%
	Coating applications (NFR 2D3d) (sum of above SNAP sub-categories)	2.54	10.3%
060201	Metal Degreasing	0	0%
060202	Dry Cleaning	1E-05	0,00004%
060203	Electronic Components Manufacturing	0	0%
060204	Other Industrial Dry Cleaning	0	0%
	Degreasing (NFR 2D3e) and Dry cleaning (NFR 2D3f) (sum of above SNAP sub-categories)	1E-05	0.00004%
060301	Polyester Processing	0	0%
060302	Polyvinylchlorid Processing	7E-05	0,0003%
060303	Polyurethan Foam Processing	0,23	0,95%
060304	Polystyrene Foam Processing	1,0	4,1%
060305	Rubber Processing	0	0%
060306	Pharmaceuticals Products Manufacturing	0	0%
060307	Paints Manufacturing	6E-05	0,0002%
060308	Inks Manufacturing	2E-04	0,0008%
060309	Glues Manufacturing	0	0%
060310	Asphalt Blowing	0	0%
060311	Adhesive, Magnetic Tapes, Film & Photographs Manufacturing	2E-06	0,00001%
060312	Textile Finishing	0	0%
060313	Leather Tanning	0	0%
060314	Other	3,09	12,5%
	Chemical products (NFR 2D3g) (sum of above SNAP sub-categories)	4.33	17.5%
060401	Glass Wool Enduction	6E-06	0,00002%
060402	Mineral Wool Enduction	5E-04	0,002%
060403	Printing Industry	0,01	0,040%
060404	Fat, Edible and Non-Edible Oil Extraction	0	0%
060405	Application of Glues and Adhesives	1,49	6,0%
060406	Preservation of Wood	0	0%
060407	Underseal Treatment and Conservation of Vehicles	0	0%
060408	Domestic Solvent Use (Other Than Paint Application)	3,70	15.0%
060409	Vehicles Dewaxing	0	0%
060411	Domestic Use of Pharmaceutical Products	0	0%
060412	Other (Preservation of Seeds a.o.)	12,6	51,2%
0606	Other (Use of fireworks, tobacco & charcoal for BBQs)	6E-06	0,00002%
	Domestic solvent use including fungicides (NFR 2D3a), Printing (NFR 2D3h) and Other solvent use (NFR 2D3i) (sum of above SNAP sub-categories)	17.8	72.2%
	Total NMVOC from solvent use	24.7	100%

The processes and activities that are covered by BEK 1491 and the associated fraction of the total 2014 NMVOC emissions are shown in Table 6.8. They cover 8.8 % of the total NMVOC emissions from solvent use.

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 1491, are considerably lower than the emission factors that are used in the inventory. Furthermore BEK 1491 only covers industrial installations, and adhesive coating, which constitutes the largest fraction of the emissions covered by BEK 1491, 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 1995-2014 emissions.

Table 6.8 Processes and activities (categories) that are covered by BEK 1491, associated SNAP subcategories, NMVOC emissions in 2014 and fraction of 2014 emissions from BEK 1491 category.

Categories in BEK 1491	Corresponding SNAP categories	NMVOC emission 2014 (Gg)	Fraction of total 2014 emission
Adhesive coating	060405	1.49	6.0 % (also includes diffuse use)
Coating activity and vehicle refinishing	060101, 060102, 060106, 060107	0.66	2.7 %
Coil coating and winding wire coating	060105	0,017	0,07 %
Dry cleaning	060202	1E-05	0,00004 %
Footwear manufacture	nd	nd	nd
Manufacturing of coating preparations, varnishes, inks and adhesives	060307, 060308, 060309, 060311	3E-04	0.001 %
Manufacture of pharmaceutical products	060306	0	0 %
Printing	060403	0,01	0,040 %
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 1491		2.2	8.8%

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 (2016) and SPIN (2016) 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 6.9 and Figure 6.6 show the extrapolation of the historic NMVOC emissions from 1990 to 2014 for the four solvent use categories. An exponential fit gives the best approximation with R^2 values of 0.91, 0.79, 0.87 and 0.85, respectively. All projected solvent use 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 eight years of the historic emissions; i.e. the four solvent use categories show approximately constant emissions during the latest eight years (2007 to 2014).

The most realistic projection from 2015 to 2035 is assumed to represent 25 % of the exponential fit and 75 % of the, approximately constant, historic 2007 - 2014 estimates.

Table 6.9 Projected NMVOC emissions from solvent use (NFR 2D3a and NFR 2D3d-i). NMVOC projections are calculated as 25% of the exponential fit and 75% of the constant historic 2007 - 2014 estimates.

	Unit	2014	'2014'¹⁾	2015	2020	2025	2030	2035
NMVOC emissions								
Coating applications (NFR 2D3d)	Gg	2.54	2,67	2,59	2,45	2,34	2,27	2,21
Degreasing (NFR 2D3e) and Dry cleaning (NFR 2D3f)	Gg	1E-05	7E-06	8E-06	7E-06	7E-06	7E-06	7E-06
Chemical products (NFR 2D3g)	Gg	4.31	4,61	4,63	4,46	4,31	4,19	4,09
Domestic solvent use including fungicides (NFR 2D3a),	Gg	17.8						
Printing (NFR 2D3h) and Other solvent use (NFR 2D3i)			19,3	18,8	18,2	17,7	17,2	16,8
Total NMVOC	Gg	24.7	26,6	26,0	25,1	24,3	23,7	23,1

[1)] Mean emission (2012 – 2016).

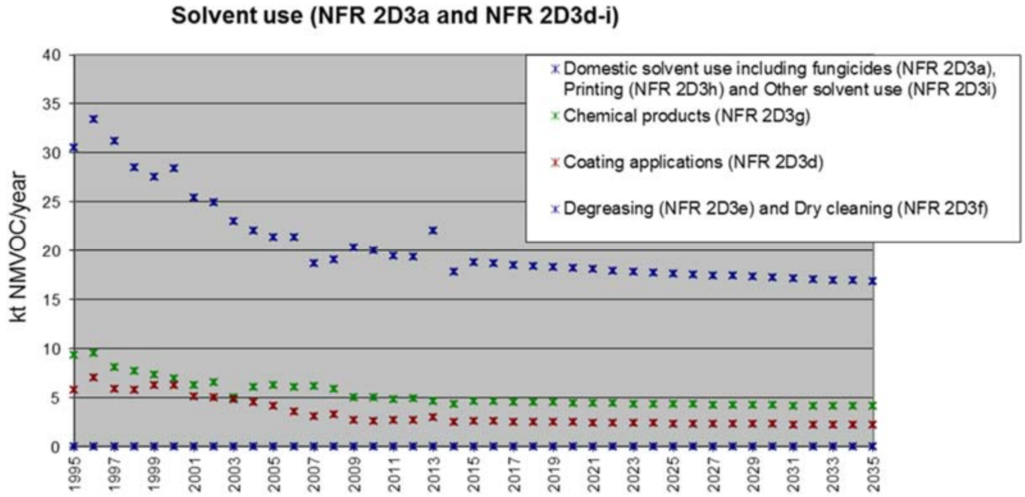

Figure 6.6 Projected NMVOC emissions from solvent use (NFR 2D3a and NFR 2D3d-i). NMVOC projections are calculated as 25% of the exponential fit and 75% of the constant historic 2007 - 2014 estimates.

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 2014 emissions for the solvent use categories.

In the graphic industry, there have been increased investments in UV hardening facilities, and furthermore 80 % of the production volume is produced at eco-labelled (Svanemærket) 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 production in Denmark has been stagnating but there is a focus on gaining global market shares, which is in accordance with CSR; "Graphic Association Denmark and HK/Privat have together compiled a CSR code, which is targeted the graphic industry. The code helps to define a standard and a practice about social responsibility for production of graphic products and services - both nationally and internationally. The graphic industry's CSR code is based on UN Global Compact's ten principles, but is made more action oriented for the graphic industry" (Bøg, 2016).

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). The emissions from the plastic industry are from thermoset plastic, as emissions of VOCs from the main part of the plastic industry, namely processing of thermoplastic (injection moulding, extrusion etc.), does not involve VOCs. 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 (Brønnum, 2016). 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 there are planned projects on improving the processes cleaning the discharges of VOCs. The general shift to water soluble and high solid products is still being implemented, but no further VOC reducing initiatives on the product side are planned in the near future (Lauridsen, 2016).

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 an ongoing project on update of the EMEP/EEA Guidebook with respect to solvent use, led by Trinomics B.V. and participation by Aarhus University, there is collaboration with the European Solvents Industry Group (ESIG). New information and data on production and sales figures as well as import/export data within and outside the EU are made available to the member countries from ESIG. With respect to projection of solvent use the European solvents industry expects a stabilized growth in Europe and probably also in Denmark (Pearson, 2016). Assuming no changes in emission factors this assumption will result in approximately constant emissions in the coming years.

In conclusion Table 6.9 shows the projected NMVOC emissions for 2015 to 2035 for the solvent use NFR categories. The projections show a 7 % decrease in total NMVOC emissions from 2014 to 2035. The four aggregated categories show a 13 %, 20 %, 6 % and 6 % decrease, respectively.

Uncertainties

The 95 % confidence interval (2* standard deviation) and the coefficient of variation (with respect to the 95 % confidence interval) of estimates from the projection model of NMVOC emissions with respect to the historic emissions (1995 – 2014), are shown in Table 6.10. In the last column the coefficient of variation (with respect to the 95 % confidence interval) based on Tier 2 Monte Carlo analysis of 2014 NMVOC emissions, allowing for uncertainties in activity data and emission factors, are shown.

Table 6.10 Uncertainties of NMVOC emissions from NFR 2D3 Non-energy products from fuels and solvent use. First two columns are uncertainties of projection model* estimates of historic (1995 – 2014) emissions, and last column are uncertainties of MC analysis of 2014 emissions, allowing for uncertainties in AD and EF.

	95 % conf. interval*	Coefficient of variation* (95 % conf. interval)	Coefficient of variation** (95 % confidence interval)
Coating applications (NFR 2D3d)	0.95	22 %	19 %
Degreasing (NFR 2D3e) and Dry cleaning (NFR 2D3f)	1.5E-6	55 %	20 %
Chemical products (NFR 2D3g)	1.04	17 %	19 %
Domestic solvent use including fungicides (NFR 2D3a), Printing (NFR 2D3h) and Other solvent use (NFR 2D3i)	3.72	16 %	24 %
Total NMVOC from solvent use	3.98	12 %	18 %

* NMVOC projections calculated as 25 % of the exponential fit and 75 % of the constant historic 2009 - 2014 estimates.

**Monte Carlo analysis of 2014 NMVOC emissions.

It is seen that the uncertainties, arising from the projection model and from the Monte Carlo uncertainty analysis of 2014 NMVOC emissions comprising uncertainties in activity data and emission factors, are comparable the uncertainties (95 % confidence interval) constitute approximately 15 % of the emission values for the solvent use sector.

Road Paving with Asphalt and Asphalt Roofing

In addition to NMVOC from solvent use, NMVOC emissions occur from the categories road paving with asphalt (NFR 2D3b, SNAP 040611) and asphalt roofing (NFR 2D3c, SNAP 040610). For road paving constant emissions corresponding to the 2014 level are projected to 2035 and for asphalt roofing emissions are projected according to Energistyrelsens Produktionsværdier (Byggeri), see Table 6.11.

Table 6.11 Projected NMVOC emissions from Road paving with asphalt (NFR 2D3b, SNAP 040611) and Asphalt roofing (NFR 2D3c, SNAP 040610).

	Unit	2014	'2014'[1)]	2015	2020	2025	2030	2035
Road paving with asphalt (NFR 2D3b, SNAP 040611)	Gg	0,0549	0.0540	0,0549	0,0549	0,0549	0,0549	0,0549
Asphalt roofing (NFR 2D3c, SNAP 040610)	Gg	0,0122	0.0114	0,0121	0,0140	0,0151	0,0160	0,0169

[1)] Mean emission (2012 – 2016).

Other product use

Total emissions from the other product use sector are available in the NFR tables. The sources within other product uses lead to the following emissions:

Table 6.12 Overview over which source categories lead to which emissions.

Sources/processes	SO_2	NO_x	NMVOC	TSP	PM_{10}	$PM_{2.5}$
Use of charcoal for barbeques	x	x	x	x	x	x
Use of fireworks	x			x	x	x
Use of tobacco	x	x	x	x	x	x

The use of charcoal for barbeques stands for 73 % of the NO_x emission and 50 % of the NMVOC emission from other product use in 2014. These percentages are both expected to increase from 2015 towards 2030 to 78 % and 56 % respectively. The reason for this increase is that consumption of tobacco is expected to decrease by 27 % from 2014 to 2030, resulting in a lowered total emission.

Three sources within other *Other product use* lead to SO_2 and particle emissions; Figure 6.7 and Figure 6.8 show the distribution of the total SO_2 and $PM_{2.5}$ emissions between the individual sources.

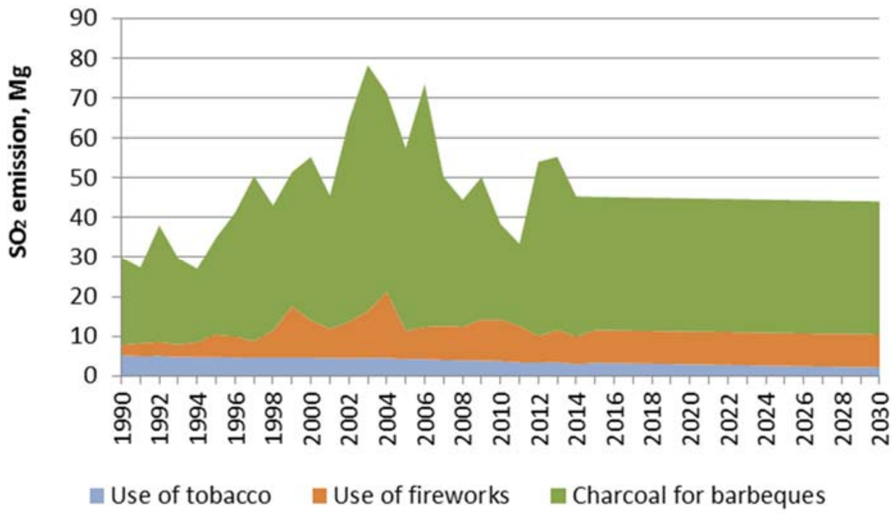

Figure 6.7 SO_2 emissions from *Other product use*.

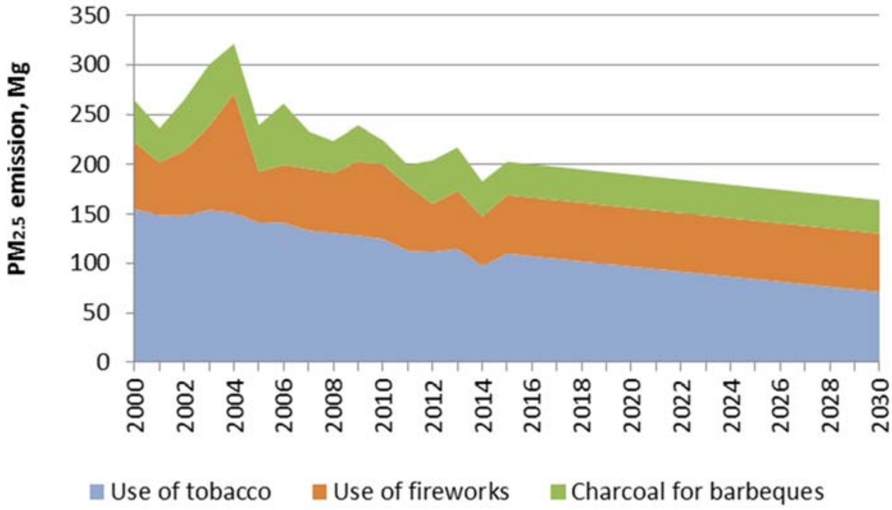

Figure 6.8 $PM_{2.5}$ emissions from *Other product use*.

Food and beverages industry

Total emissions from the food and beverages industry sector are available in the NFR tables. All sources within this subcategory emit only NMVOC.

Figure 6.9 shows the distribution of the total NMVOC emission between the individual sources categories.

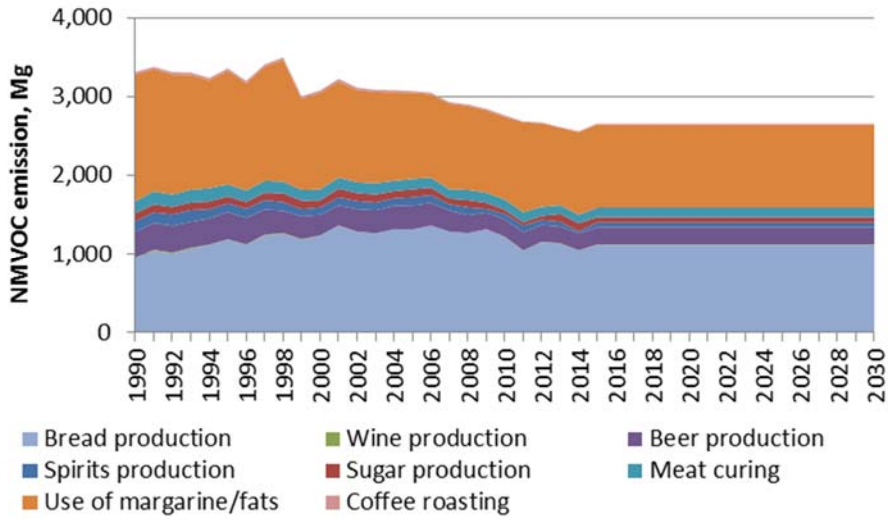

Figure 6.9 NMVOC emissions from the *Food and Beverages Industry*.

The contributions to total NMVOC emission from the productions of wine and coffee roasting are so small that they are not visible in the Figure above.

Other processes

There is only one source category included in this subcategory, and that is wood processing. Wood processing leads to emissions of particles (TSP, PM_{10} and $PM_{2.5}$). Both historical and projected emissions are available in the NFR tables.

6.4 Changes since previous projection

Since the last projection inventory was performed a new version of the EMEP Guidebook has been published. The introduction of the EMEP/EEA (2013) leads to changes in the allocation of source categories again resulting in recalculations in the distribution of total emission between subcategories. The previous categories of Industrial Processes and Solvents have been merged into Industrial Processes and Product Use (IPPU). Source categories that have been reallocated include road paving with asphalt and asphalt roofing which are both moved from category 2A to 2D.

Projected total emissions have increased for all pollutants except SO_2. These increases are generally caused by an increased completeness of the IPPU sector as many new source categories have been included as well as new pollutants for existing source categories. Table 6.13 presents newly included source categories.

Table 6.13 Overview over new source categories not included in the previous projection.

NFR code	Sources/processes	SO_2	NO_x	NMVOC	TSP	PM_{10}	$PM_{2.5}$	BC
2A3	Container glass production				x	x	x	x
2A5a	Quarrying and mining of minerals other than coal				x	x	x	
2A5b	Construction and demolition				x	x	x	x
2A5c	Storage, handling and transport of mineral products				x	x	x	
2B10a	Chemical Ingredients production			x				
2B10a	Production of tar products	x		x				
2C1	Grey iron foundries				x	x	x	
2C3	Secondary aluminium production				x	x	x	x
2H2	Wine production			x				
2I	Wood processing				x	x	x	

The source category secondary zinc production has been removed from the inventory as there is no - and has never been any, zinc production in Denmark.

New pollutants added to existing source categories include all emissions of BC and NMVOC from steel production.

Many smaller recalculations have also been performed since the previous projection, like the addition of palmin to use of margarine and cooking fats, the exclusion of production of hydraulic lime (due to double counting) and a long list of changes to existing activity data and/or emission factors.

The projection values described in section 6.2 (Table 6.2) are compared with those of the previous projection in the following. The applied projection values are based on production values within the different sectors (Danish Energy Agency, 2015).

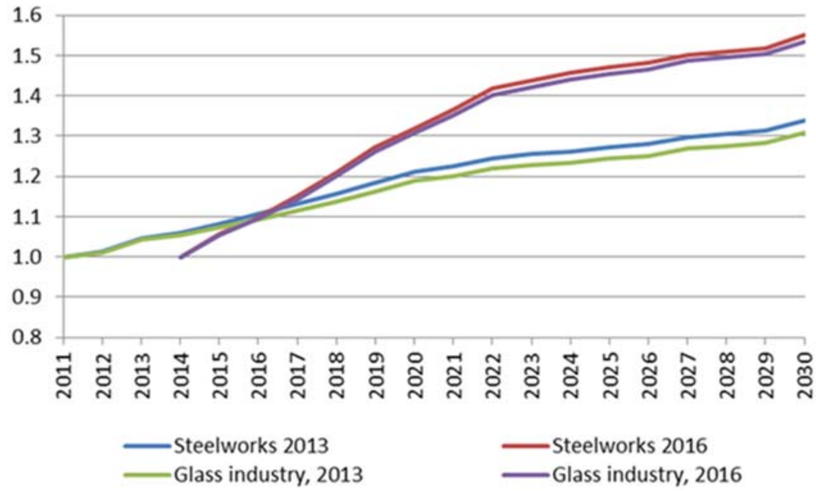

Figure 6.10 Projection values applied for the steel- and glass industries in the projection in 2013 and in 2016 respectively.

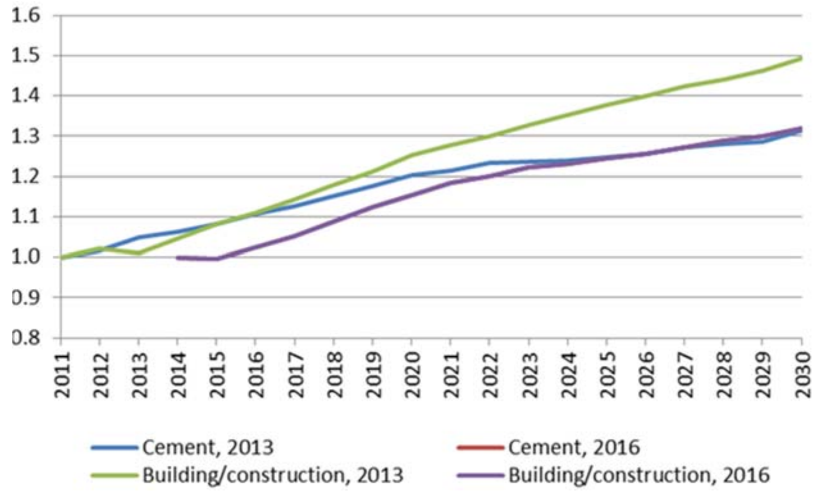

Figure 6.11 Projection values applied for the cement production and building and construction sector in the projection in 2013 and in 2016 respectively.

Table 6.14 Changes in projected emissions from the 2013 to the 2016 projection.

Total IPPU	Pollutant	Unit	2015	2020	2025	2030
2013 projection	SO_2	Gg	0.96	1.11	1.22	1.31
2016 projection	SO_2	Gg	0.70	0.78	0.84	0.88
Difference	SO_2		-28%	-29%	-31%	-33%
2013 projection	NO_x	Gg	0.08	0.08	0.08	0.08
2016 projection	NO_x	Gg	0.07	0.07	0.07	0.06
Difference	NO_x		-8%	-13%	-16%	-19%
2013 projection	NMVOC	Gg	31.38	31.76	31.47	31.37
2016 projection	NMVOC	Gg	28.87	27.94	27.18	26.54
Difference	NMVOC		-8%	-12%	-14%	-15%
2013 projection	TSP	Gg	0.66	0.72	0.77	0.82
2016 projection	TSP	Gg	5.37	6.10	6.52	6.86
Difference	TSP		718%	749%	749%	739%
2013 projection	PM_{10}	Gg	0.58	0.63	0.67	0.72
2016 projection	PM_{10}	Gg	2.71	3.07	3.27	3.43
Difference	PM_{10}		371%	387%	385%	378%
2013 projection	$PM_{2.5}$	Gg	0.52	0.57	0.61	0.65
2016 projection	$PM_{2.5}$	Gg	0.70	0.75	0.77	0.79
Difference	$PM_{2.5}$		34%	32%	27%	22%

The large increases in projected particle emissions are caused by the inclusion of new source categories (see Table 6.13) especially "Quarrying and mining of minerals other than coal" and "Construction and demolition".

Mineral industry

Table 6.15 presents the recalculations for the subcategory 2A Mineral industry.

Table 6.15 Changes in projected emissions from the 2013 projection to the 2016 projection for 2A.

2A Mineral industry	Pollutant	Unit	2015	2020	2025	2030
2013 projection	SO_2	Gg	0.89	1.03	1.13	1.23
2016 projection	SO_2	Gg	0.56	0.65	0.70	0.74
Difference	SO_2		-37%	-37%	-38%	-39%
2013 projection	NMVOC	Gg	0.65	0.71	0.74	0.78
2016 projection	NMVOC	Gg	0.04	0.04	0.05	0.05
Difference	NMVOC		-94%	-94%	-94%	-94%
2013 projection	TSP	Gg	0.15	0.17	0.19	0.20
2016 projection	TSP	Gg	4.39	5.08	5.48	5.81
Difference	TSP		2800%	2825%	2794%	2744%
2013 projection	PM_{10}	Gg	0.13	0.14	0.16	0.17
2016 projection	PM_{10}	Gg	2.21	2.55	2.76	2.92
Difference	PM_{10}		1663%	1671%	1647%	1613%
2013 projection	$PM_{2.5}$	Gg	0.09	0.11	0.12	0.13
2016 projection	$PM_{2.5}$	Gg	0.35	0.41	0.44	0.47
Difference	$PM_{2.5}$		284%	284%	277%	269%

The recalculations are caused by:

SO_2: Improvements to the calculation of SO_2 emissions from ceramics, changes were made to both activity data and emission factors.

NMVOC: The strong decrease is caused by the reallocation of the source categories asphalt roofing and road paving with asphalt from 2A to 2D.

Particles: Drastic increases in particle emissions are caused by the addition of new categories see Table 6.13.

BC: BC is new in this year's projection.

Chemical industry

Table 6.16 presents the recalculations for the subcategory 2B Chemical industry.

Table 6.16 Changes in projected emissions from the 2013 projection to the 2016 projection for 2B.

2B Chemical industry	Pollutant	Unit	2015	2020	2025	2030
2013 projection	SO_2	Mg	28.62	32.04	33.63	35.40
2016 projection	SO_2	Mg	91.02	91.02	91.02	91.02
Difference	SO_2		218%	184%	171%	157%
2013 projection	NO_x	Mg	27.98	31.32	32.88	34.61
2016 projection	NO_x	Mg	21.99	21.99	21.99	21.99
Difference	NO_x		-21%	-30%	-33%	-36%
2013 projection	NMVOC	Mg	28.96	32.42	34.03	35.82
2016 projection	NMVOC	Mg	28.38	28.38	28.38	28.38
Difference	NMVOC		-2%	-12%	-17%	-21%
2013 projection	TSP	Mg	7.32	8.19	8.60	9.05
2016 projection	TSP	Mg	13.27	13.27	13.27	13.27
Difference	TSP		81%	62%	54%	47%
2013 projection	PM_{10}	Mg	5.81	6.51	6.83	7.19
2016 projection	PM_{10}	Mg	10.43	10.43	10.43	10.43
Difference	PM_{10}		79%	60%	53%	45%
2013 projection	$PM_{2.5}$	Mg	4.41	4.94	5.18	5.46
2016 projection	$PM_{2.5}$	Mg	7.58	7.58	7.58	7.58
Difference	$PM_{2.5}$		72%	54%	46%	39%

The recalculations are primarily caused by:

General: The projection for chemical industry is kept constant for 2015-2030 due to the lack of projection values from the DEA.

SO_2: Production of tar products is a new category.

NO_x: Recalculations for the source category of catalyst production.

NMVOC: Chemical ingredient production is a new category.

Particles: Recalculations for catalyst production has resulted in increased particle emissions.

BC: BC is new in this year's projection.

Metal industry

Table 6.17 presents the recalculations for the subcategory 2C Metal industry.

Table 6.17 Changes in projected emissions from the 2013 projection to the 2016 projection for 2C.

2C Metal Industry	Pollutant	Unit	2015	2020	2025	2030
2013 projection	TSP	Mg	79.12	88.75	93.04	97.96
2016 projection	TSP	Mg	206.42	257.91	287.39	303.21
Difference	TSP		161%	191%	209%	210%
2013 projection	PM_{10}	Mg	27.21	30.51	31.96	33.65
2016 projection	PM_{10}	Mg	64.79	80.95	90.20	95.17
Difference	PM_{10}		138%	165%	182%	183%
2013 projection	$PM_{2.5}$	Mg	6.53	7.31	7.65	8.05
2016 projection	$PM_{2.5}$	Mg	11.55	14.43	16.08	16.97
Difference	$PM_{2.5}$		77%	97%	110%	111%

The recalculations are primarily caused by:

NMVOC and BC: These are new pollutants in this year's projection.

Particles: The addition of new source categories (primarily grey iron foundries) is the reason for the increased particle emissions.

Other solvent and product use

Table 6.18 presents the recalculations for the subcategory 2D Other solvent and product use.

Table 6.18 Changes in projected emissions from the 2013 projection to the 2016 projection for 2D.

2D Other solvent and product use	Pollutant	Unit	2015	2020	2025	2030
2013 projection	NMVOC	Gg	25.96	25.01	24.23	23.60
2016 projection	NMVOC	Gg	26.06	25.14	24.37	23.74
Difference	NMVOC		0%	0%	1%	1%
2013 projection	TSP	Mg	418.42	447.63	476.83	506.03
2016 projection	TSP	Mg	41.89	44.16	46.43	48.71
Difference	TSP		-90%	-90%	-90%	-90%
2013 projection	PM_{10}	Mg	418.42	447.63	476.83	506.03
2016 projection	PM_{10}	Mg	41.89	44.16	46.43	48.71
Difference	PM_{10}		-90%	-90%	-90%	-90%
2013 projection	$PM_{2.5}$	Mg	418.42	447.63	476.83	506.03
2016 projection	$PM_{2.5}$	Mg	41.89	44.16	46.43	48.71
Difference	$PM_{2.5}$		-90%	-90%	-90%	-90%

The recalculations are primarily caused by:

General: "Other solvent and product use" is a new subcategory according to EMEP/EEA (2013), it is best comparable with the previously independent category "3 Solvents". Table 6.18 presents a comparison of the new source category 2D with the old category 3.

SO_2 and NO_x: Three of the four product uses included in the old category 3 have according to EMEP/EEA (2013) been moved to subcategory 2G leaving no emissions of SO_2 or NO_x in subcategory 2D.

NMVOC: Regular recalculations and improvements to the use of solvents (including solvents contained in products) and the allocation of non-solvent based product uses to 2G. If the emissions in the coming years continue the constant trend, which is approximately seen since 2007, a possible change in the coming projection will be to assign a higher weight of the constant 2007 to present emissions compared to the exponential fit of historic 1995 – present emissions.

Particles: The drastic decrease in particle emissions is caused by the reallocation of the majority of the product use source categories to 2G.

Other product use

This is a new subcategory according to EMEP/EEA (2013) and a comparison with previous projections is therefore not possible. Emissions included in 2G Other product use is the three product uses reallocated from 2D and the relevant pollutants are SO_2, NO_x, NMVOC, TSP, PM_{10} and $PM_{2.5}$.

Food and beverages industry

Table 6.19 presents the recalculations for the subcategory 2H Food and beverages industry.

Table 6.19 Changes in projected emissions from the 2013 projection to the 2016 projection for 2H.

2H Food and beverages industry	Pollutant	Unit	2015	2020	2025	2030
2013 projection	NMVOC	Gg	4.73	6.00	6.46	6.96
2016 projection	NMVOC	Gg	2.66	2.66	2.66	2.66
Difference	NMVOC		-44%	-56%	-59%	-62%

The recalculations to NMVOC emissions are primarily caused by a re-evaluation of the activity data for meat frying (including fish and poultry) where the statistical data were found to be strongly overestimated.

Other processes

2I Other processes is a new subcategory and the one included source category (wood processing) is also new in this year's projection.

6.5 References

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7 Agriculture

The projection of air pollutants from the agricultural sector includes emission of particulate matter (PM) given as TSP, PM_{10} and $PM_{2.5}$, non-methane volatile organic compounds (NMVOC), sulphur dioxide (SO_2), nitrogen oxide (NO_X) and black carbon (BC). Table 7.1 shows the agricultural contribution of emissions to the national total in 2014.

Table 7.1 Emission 2014, reported to UNECE in January 2016.

	TSP	PM_{10}	$PM_{2.5}$	NMVOC	SO_X	NO_X	BC
National total, kt	91	31	18	106	11	113	4
Agricultural total, kt	67	11	2	38	<1	14	<1
Agricultural part, %	73	37	11	36	<1	12	<1

The emission projection of air pollutants is regularly updated in line with new scientific knowledge as a consequence of new emission sources, changes of emission factors or changes of the agricultural production conditions, e.g. changes regarding the export market or the legislation and regulation. Some of the changes can lead to revision in the historical emission inventory as well and therefore, some deviations are apparent in comparison with the projection scenarios published in previous reports. The present projection replaces the latest projection on air pollutants published in Scientific Report from DCE – Danish Centre for Environment and Energy No. 81, 2013 (Nielsen et al., 2013).

7.1 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, 2013). 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.

7.2 Assumptions

The assumptions due to expected development of livestock production are based on the same assumption as the latest greenhouse gas projection (Nielsen et al., 2014) but adjusted according to how production actually has developed over the past two years (Nielsen et al., 2016). According to Statistics Denmark, both the number of dairy cattle and fattening pigs has decreased the last two years. This has influenced the current projection so the number of cattle and pigs is lower for the overall time series compared to the previous projection.

Due to implementation of new emission sources as NMVOC and NO_x emission from manure management the total agricultural NMVOC and NO_x emission is increased considerably compared to previous projections. Furthermore, the projection of PM emission is increased due to implementation of emission from field operations.

Livestock

Cattle

Basically, the same assumption as given in the previous projection is used. However, the production of dairy cattle is adjusted downwards due to the situation in 2013 and 2014, which shows a decrease in production. The same increasing rate as established in the previous projection is used from 2015 and forward.

Table 7.2 Number of dairy cattle - historic and projected.

	1990	1995	2000	2005	2010	2014	2015	2020	2025	2030
Dairy cattle, 1000 unit	753	702	636	564	568	563	575	582	597	607

The beef cattle production is limited in Denmark and heifers represent the most important part of the category "non-dairy cattle". Hence, it is mainly driven by the production of dairy cattle. No significant change in the allocation of the subcategories of non-dairy cattle; heifers, bulls and suckling cattle, is expected until 2030. To avoid artificial dips/jumps in the time-series, the allocation of subcategories is based on an average of 2010-2014 distribution.

Swine

It is expected that the agricultural structural development towards larger farm units will contribute to additional growth in swine production. However, at the same time the development is strongly influenced by the present economic crises and stricter environmental regulations due to the Law on environmental approval of animal holdings (Law no. 1572).

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

The number of sows is essential for the production of weaners and fattening pigs. In the current projection a production level of 1 million sows is assumed for all years 2015–2030 corresponding to the same level as the last couple of years. However, the production of weaners and fattening pigs will increase as a consequence of increased productivity in the form of an increase in produced weaners per sow.

An important variable is therefore the production of weaners per sow. The assumption on efficiency development rate is based on a relatively conservative judgement, which is an increase of 0.5 piglet per sow per year until 2020 and 0.4 piglets per year for 2020-2030. This results in an average production of 37 produced weaners per sow in 2030.

The weaners will either be exported or fattened in Denmark. Thus the number of produced fattening pigs depends to a high degree on the export conditions. Export data from Statistics Denmark shows a significant increase in export from 2004 and this trend is expected to continue. The export is assumed to increase from 11.1 million weaners in 2014 to 13.5 million in 2030, which increase the number of produced weaners from 30.5 million in 2014 to 32.8 in 2020, with a further increase to 36.8 in 2030. This corresponds to a 21 % increase in production of weaners from 2014 to 2030. Because of the rising export of weaners, the production of fattening pigs is expected to only increase from 19.8 million in 2014 to 23.3 million in 2030, corresponding to 18 %.

Table 7.3 Number of produced sows, weaners and fattening pigs – historic and projected.

Swine, million produced	1990	1995	2000	2005	2010	2014	2015	2020	2025	2030
Sows	0.9	1.0	1.1	1.2	1.1	1.0	1.0	1.0	1.0	1.0
Weaners	16.5	20.9	23.8	27.0	29.2	30.5	30.3	32.8	34.8	36.8
Fattening pigs	16.5	20.7	22.6	24.0	21.6	19.8	19.0	20.8	21.8	23.3

Other livestock categories

Except from fur bearing animals, the population of all other livestock categories is kept at a level equivalent to average production conditions in 2010-2014.

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

Housing system

In 2014, around 80 % of the dairy cattle and 40 % of the heifers are placed in housing systems with cubicles. In 2020, it is assumed that 99 % dairy cattle will be housed in systems with cubicles and thus most of the tethering and housing systems with deep litter are phased out. The result is that almost all manure from dairy cattle in 2020 is handled as slurry. For heifers, the tethering housing is assumed to be phased out in 2020. It is expected, that around 16 % will be housed in deep litter systems and the remaining part is assumed to be placed in housing systems with cubicles.

In 2014 44 % of the fattening pigs are housed in systems with fully slatted floor. These systems and systems with solid floor and with deep layer of bedding are assumed to be phased out. Thus, all fattening pigs are expected to be housed in systems with partially slatted or drained floor in 2030. For sows, systems with fully slatted floor are expected to be phased out in 2020 and almost all sows are expected to be housed in systems with partly slatted floor in 2030.

Agricultural area

Historical data indicate a decrease in the agricultural area, which is expected to continue. The current projection assumes a decrease by 126 000 ha from 2014-2035, which correspond to 0.23 % per year. This reflects the same trend as seen for the development in agricultural land for 2005 – 2014 (Statistics Denmark). The decreased area is a result of urban development and infrastructure, but also due to afforestation and removal of marginal land such as soils with high organic content (histosols). It is assumed that 1000 ha of histosols is removed from the cultivated area per year, 1900 ha per year to afforestation and 3100 ha per year to settlements.

Table 7.4 Agricultural land area – historic and projected.

	1990	1995	2000	2005	2010	2014	2015	2020	2025	2030
Agricultural land area, 1 000 ha	2 788	2 726	2 647	2 707	2 646	2 662	2 646	2 616	2 586	2 556

Use of inorganic N-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 have to be covered with inorganic N-fertiliser. Amount of N from inorganic N-fertiliser are calculated as:

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

The total agricultural area is assumed to be 2 585 ha in 2020 and 2 525 ha in 2030 and it is assumed that 1.4 % is not fertilised. The historical data (2011-2014) shows an average nitrogen need of 130 kg N per ha for the total cultivated area (Statistics Denmark). Based on knowledge of nitrogen content in manure (N ex Storage) and the nitrogen which has to be included in the farmers fertilisers account, the need for nitrogen in inorganic N fertiliser can be calculated (see Table 7.5).

Table 7.5 Consumption of inorganic N-fertilisers, kt N.

	1990	1995	2000	2005	2010	2014	2015	2020	2025	2030
N in animal manure (N ex storage), which is included in the farmers' fertiliser accounts	130	122	116	143	141	141	140	145	149	154
N from sewage sludge	5	9	9	5	6	7	7	6	6	6
N in inorganic N fertilisers	395	310	246	204	188	187	190	181	173	164

The use of nitrogen in inorganic N fertilisers is assumed to decrease from 187 Gg in 2014 to 164 Gg in 2030, which is a 12 % reduction. The two main reasons for this reduction are a decrease in the agricultural area and implementation of ammonia reduction technology. The technology reduces the ammonia emission from the housings and thereby increases the content of N in the animal manure (N ex storage).

Field operations

The emission of PM from field operations is calculated by area of cultivated crops multiplied with number of operations and emission factor, for each crop type and type of operation. Operations are divided in soil cultivation, harvesting, cleaning and drying. The projection of PM from field operations is based on a level equivalent to the average emission from the years 2011-2014 combined with the area. The years 2011-2014 is chosen as base years due to steady development in number of field operations.

7.3 Emissions

This projection covers the latest official Danish reporting, which includes emissions until 2014. Thus, the projection comprises an assessment of the emissions from the agricultural sector from 2015 to 2030.

PM emission

The projected emission of PM given in $PM_{2.5}$ is estimated for the sources; manure management, field operations and field burning of agricultural residue.

Table 7.6 Historic and projected emission of $PM_{2.5}$, tonnes.

	1990	1995	2000	2005	2010	2014	2015	2020	2025	2030
Manure management	1 299	1 303	1 362	1 423	1 369	1 376	1 361	1 366	1 402	1 369
Field operations	527	524	522	488	489	485	455	454	453	452
Field burning	177	184	176	192	185	210	226	226	225	225
Total	2 003	2 071	2 140	2 085	2 026	1 998	1 986	2 019	2 051	2 090

The total emission of $PM_{2.5}$ is expected to increase slightly from 2014 to 2030 due to an increase in the emission from manure management. The increase in $PM_{2.5}$ emission from manure management is mainly due to an increase in the emission from swine. The emission of $PM_{2.5}$ from field operations and field burning of agricultural residue is expected to decrease due to decrease in agricultural area.

NMVOC emission

The projected emission of NMVOC is estimated for the sources; manure management, cultivated crops and field burning of agricultural residue.

Table 7.7 Historic and projected emission of NMVOC, tonnes.

	1990	1995	2000	2005	2010	2014	2015	2020	2025	2030
Manure management	38 010	36 744	35 623	34 994	35 436	35 736	35 981	36 843	37 567	38 377
Cultivated crops	1 989	1 570	1 483	1 423	1 510	1 944	1 692	1 672	1 653	1 634
Field burning	203	240	298	333	232	281	259	256	253	250
Total	40 201	38 554	37 404	36 751	37 179	37 962	37 932	38 771	39 473	40 262

The total emission of NMVOC is expected to be nearly unaltered from 2014 to 2030. The increase in NMVOC emission from manure management is mainly due to increase in emission from swine and dairy cattle. The emission of NMVOC from cultivated crops and field burning of agricultural residue is expected to decrease due to a decrease in the agricultural area.

NO_x emission

The projected emission of NO_x is estimated for the sources; manure management, inorganic N-fertiliser, manure applied to soil, sewage sludge and field burning of agricultural residue.

Table 7.8 Historic and projected emission of NO_x, tonnes

	1990	1995	2000	2005	2010	2014	2015	2020	2025	2030
Manure management	479	432	369	311	237	209	211	215	210	199
Inorganic N-fertiliser	15 963	12 594	10 025	8 223	7 573	7 447	7 690	7 343	7 023	6 677
Manure applied to soil	6 213	5 808	5 595	6 395	6 165	6 128	6 080	6 333	6 524	6 701
Sewage sludge	185	364	350	181	243	275	261	258	255	252
Field burning	77	91	114	127	89	107	99	98	96	95
Total	22 916	19 290	16 452	15 236	14 307	14 167	14 340	14 246	14 109	13 925

The total emission of NO_x is expected to decrease from 2014 to 2030 corresponding to a 2 % reduction. The emission from manure management decrease mainly for swine and dairy cattle due to change in housings with slurry which have a lower emission of NO_x compared to solid manure. The emission of NO_x from inorganic N-fertiliser, sewage sludge and field burning decreases due to fall in the agricultural area. Emission of NO_x from manure applied to soil increase due to increase in amount of manure applied.

SO_x and BC emission

The projected emission of SO_x and BC includes emission from field burning of agricultural residue.

Table 7.9 Historic and projected emission of SO_x from field burning of agricultural residue.

	1990	1995	2000	2005	2010	2014	2015	2020	2025	2030
SO_x	10	11	14	16	11	13	12	12	12	12
BC	16	19	24	26	18	22	21	20	20	20

Emission of both SO_x and BC from field burning of agricultural residue is expected to decrease from 2014 to 2030 due to decrease in agricultural area.

7.4 References

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8 Waste and other

This chapter covers the 2015-2030 projection of NEC gases and particle emissions from waste and other. This includes 5.C Waste Incineration (without energy recovery) and 5.D Waste Other.

During the years 2015-2030, the waste categories are projected to emit 5-6 % of the national SO_2 emission. For the remaining pollutants the contribution from the waste sector are all around or under 1 % of the national emission.

8.1 Methodology

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

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).

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.

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 7 (NFR Sector 3).

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.

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.

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.

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.

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 7 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.

8.2 Activity data

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

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 8.1 for 1990-2014

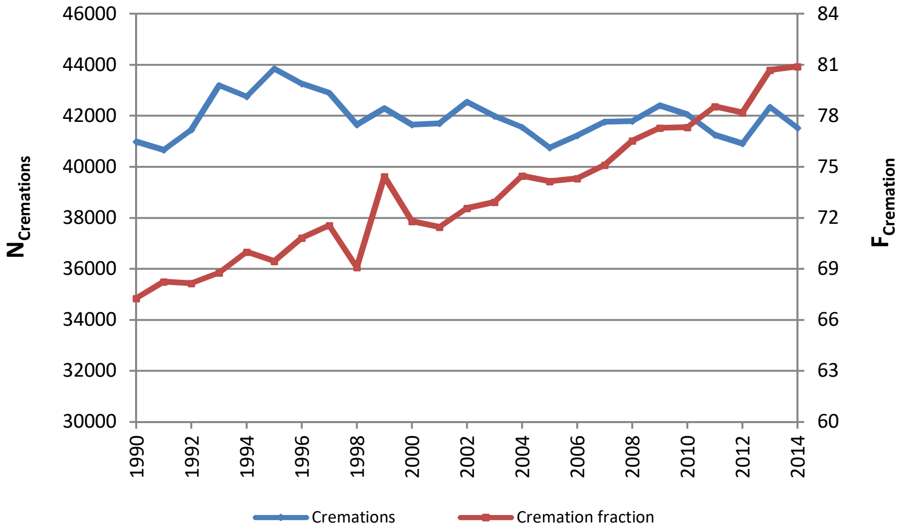

Figure 8.1 The historical development in the number of human cremations.

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 1990-2014 data. By comparing data for population with the number of deceased for the years 1901-2014, the fraction of deaths is found to be 1 %.

Table 8.1 Data on population, number of deaths and number on cremations.

	1990	2005	2010	2011	2012	2013
Population	5135409	5411405	5534738	5560628	5580516	5602628
Deaths	60926	54962	54368	52516	52325	52471
Cremation fraction	67%	74%	77%	79%	78%	81%
Cremations	40991	40758	42050	41248	40909	42349
Continued						
	2014	2015	2020	2025	2030	
Population	5627235	5648580	5746161	5865324	5974766	
Deaths	51340	56486	46484	58653	59748	
Cremation fraction	81%	79%	82%	84%	86%	
Cremations	41532	45695	46484	47448	48333	

Animal cremation

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 2015-2030 projection of activity data for animal cremation can be described by the constant average of the years 2009-2014. Figure 8.2 shows both historical and projected data for animal cremation.

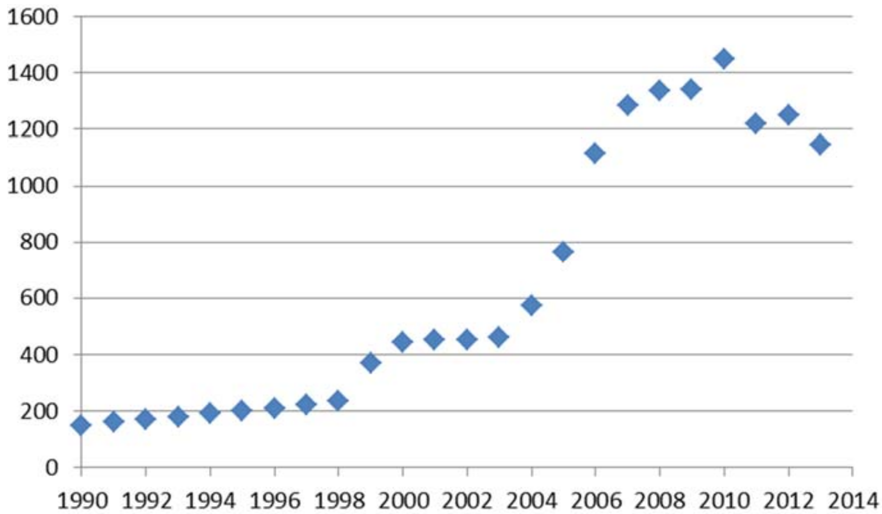

Figure 8.2 Cremated amount of carcasses, 1990-2030.

Historical data and the average constant value for the projection are provided in Table 8.2.

Table 8.2 Amount of incinerated carcasses, [Mg].

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

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 8.3 presents the average fractions of the different fires in 2007-2011.

Table 8.3 Average registered occurrence of building fires, 2009-2014, in per cent.

Size	Detached	Undetached	Apartment	Industry	Additional	Container	All building fires
Full, %	1.7	0.4	0.4	0.7	0.5	0.5	4.1
Large, %	3.3	1.1	1.7	2.3	3.6	2.2	14.2
Medium, %	4.9	2.5	5.8	4.6	6.2	11.7	35.6
Small, %	11.3	5.0	10.4	6.3	7.8	5.3	46.1
All, %	21.2	9.0	18.3	13.9	18.0	19.7	100.0

Calculations of emissions for 1990-2006 are based on surrogate data and on detailed information for 2007-2014 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 2009-2014 data.

Table 8.4 Full Scale Equivalent (FSE) accidental building fires for 2009-2014.

	2009	2010	2011	2012	2013	2014	Average
FSE container fires	799	594	729	584	584	584	645
FSE of detached house fires	876	833	818	742	761	660	782
FSE of undetached house fires	208	194	206	181	162	318	211
FSE of apartment building fires	413	348	362	327	316	299	344
FSE of industrial building fires	344	281	334	298	275	751	381
FSE additional buildings	466	429	740	610	619	577	573
All FSE building fires	3106	2678	3189	2741	2717	3189	2936

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.

Accidental vehicle fires

The Danish Emergency Management Agency (DEMA) provides data for the total number of accidental vehicle fires 2007-2014 divided into the 14 categories; passenger cars, buses, light duty vehicles, heavy duty vehicles, motorcycles/mopeds, caravans, trains, ships, airplanes, bicycles, tractors, other vehicles and machines.

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 categories of trains and ships are a calculated average of the populations in 2007-2014. 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 2009-2014 is used for 2014-2030; 3, 70 and 113, respectively.

Activity data for 2009-2014 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 2009-2014, the following fractions are calculated.

Table 8.5 Average fraction of FSE vehicle fires in relation to population, 2009-2014.

Category	Fraction, %
Passenger cars	0.03
Buses	0.11
Light duty vehicles	0.01
Heavy duty vehicles	0.13
Motorcycles/Mopeds	0.03
Caravans	0.02
Trains	0.09
Ships	0.95
Airplanes	0.05
Tractors	0.08
Combine harvesters	0.17

The number of FSE accidental vehicle fires can now be calculated by multiplying the population data with the average fractions of FSE from Table 8.5.

It is assumed that no significant changes in the current average vehicle weight will occur within 2015-2030 and the activity data for vehicle fires is calculated from the projected number of FSE fires and the average vehicle weight, Table 8.6.

Table 8.6 Projection of activity data for accidental vehicle fires, Mg.

	Burnt mass of vehicles
1990	2 555
2005	2 858
2010	3 025
2011	2 624
2012	2 319
2013	2 708
2014	2 672
2015	2 623
2020	2 638
2025	2 689
2030	2 763

8.3 Emission factors

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

Human cremation

The projection of emissions from human cremation shown in Table 8.11 is calculated by multiplying the estimated activity data from Table 8.1 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 2011-2030 according to standard bag filter efficiency (de Nevers, 2000) and conferential measurements performed at Danish crematoria.

Table 8.7 Emission factors for human cremation, g per body.

	1990-2011	2012-2030
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

Animal cremation

The projection of emissions from animal cremation shown in Table 8.11 is calculated by multiplying the estimated activity data from Table 8.2 with the emission factors known from the Nielsen et al. (2013).

Table 8.8 Emission factors for animal cremation, kg per Mg.

	Value
SO_2	1.74
NO_x	12.69
NMVOC	2.00
TSP	2.18
PM_{10}	1.53
$PM_{2.5}$	1.31

Accidental building fires

By assuming that building compositions and sizes will not significantly change from 2012-2030, the emission factors known from Nielsen et al. (2013) are used in this projection.

Table 8.9 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
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 2012-2030 are shown in Table 8.11.

Accidental vehicle fires

By assuming that vehicle compositions will not significantly change from 2012-2030, the emission factors known from Nielsen et al. (2013) are accepted for this projection.

Table 8.10 Emission factors for accidental vehicle fires, kg per Mg.

	Value
SO_2	5
NO_x	2
NMVOC	8.5
TSP	38
PM_{10}	38
$PM_{2.5}$	38

Calculated emissions are shown in Table 8.11.

8.4 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 8.11 gives an overview of the projections of the national emissions from the waste source category.

Table 8.11 Projection of the overall emissions of NEC gases and particles from the waste sector, [Mg].

Emissions		1990	2005	2010	2014	2015	2020	2025	2030
SO_2	Human cremation	4.6	4.6	4.7	4.7	5.2	5.2	5.4	5.5
	Animal cremation	0.3	1.3	2.5	2.0	2.2	2.2	2.2	2.2
	Building fires	559.3	552.4	543.0	904.5	568.6	568.6	568.6	568.6
	Vehicle fires	12.8	14.3	15.1	11.8	13.5	13.7	14.0	14.4
	Total	576.9	572.6	565.4	923.0	589.4	589.6	590.1	590.6
NO_x	Human cremation	33.8	33.6	34.7	34.3	37.7	38.3	39.1	39.9
	Animal cremation	1.9	9.7	18.4	14.7	15.8	15.8	15.8	15.8
	Building fires	31.8	31.5	31.5	41.4	37.2	37.2	37.2	37.2
	Vehicle fires	5.1	5.7	6.0	4.7	5.4	5.5	5.6	5.8
	Total	72.6	80.5	90.6	95.1	96.1	96.8	97.7	98.6
NMVOC	Human cremation	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
	Animal cremation	0.3	1.5	1.5	2.7	2.5	2.5	2.5	2.5
	Building fires	148.0	147.2	149.1	198.5	186.1	186.1	186.1	186.1
	Vehicle fires	21.7	24.3	25.7	20.1	23.0	23.2	23.7	24.5
	Total	170.6	173.5	176.9	221.8	212.2	212.4	213.0	213.7
TSP	Human cremation	1.6	1.6	1.6	0.02	0.02	0.02	0.02	0.02
	Animal cremation	0.3	1.7	3.2	2.5	2.7	2.7	2.7	2.7
	Building fires	168.6	163.9	168.8	162.3	157.8	157.8	157.8	157.8
	Vehicle fires	97.1	108.6	114.9	89.8	102.8	103.8	106.2	109.4
	Total	267.6	275.7	288.5	254.6	263.4	264.4	266.7	270.0
PM_{10}	Human cremation	1.42	1.41	1.46	0.01	0.02	0.02	0.02	0.02
	Animal cremation	0.2	1.2	2.2	1.8	1.9	1.9	1.9	1.9
	Building fires	168.6	163.9	168.8	162.3	157.8	157.8	157.8	157.8
	Vehicle fires	97.1	108.6	114.9	89.8	102.8	103.8	106.2	109.4
	Total	267.3	275.1	287.4	253.9	262.5	263.5	265.9	269.1
$PM_{2.5}$	Human cremation	1.26	1.26	1.30	0.01	0.01	0.01	0.01	0.01
	Animal cremation	0.2	1.0	1.9	1.5	1.6	1.6	1.6	1.6
	Building fires	168.6	163.9	168.8	162.3	157.8	157.8	157.8	157.8
	Vehicle fires	97.1	108.6	114.9	89.8	102.8	103.8	106.2	109.4
	Total	267.1	274.7	286.9	253.6	262.3	263.3	265.6	268.9

8.5 Changes since previous projection

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

Table 9.12 Recalculations for the waste sector.

		2013 submission, [Mg]				Difference, [%]*			
		2015	2020	2025	2030	2015	2020	2025	2030
SO_2	Human cremation	4.9	5.1	5.4	5.6	5	3	-1	-3
	Animal cremation	2.3	2.3	2.3	2.3	-6	-6	-6	-6
	Building fires	618.1	618.1	618.1	618.1	-8	-8	-8	-8
	Vehicle fires	12.9	13.1	13.5	14	5	4	3	3
	Total	638.3	638.7	639.4	640.1	-8	-8	-8	-8
NO_x	Human cremation	36	37.6	39.4	41.2	5	2	-1	-3
	Animal cremation	17	17	17	17	-7	-7	-7	-7
	Building fires	35.2	35.2	35.2	35.2	6	6	6	6
	Vehicle fires	5.2	5.3	5.4	5.6	4	3	3	3
	Total	93.3	95.1	97	99	3	2	1	0
NMVOC	Human cremation	0.6	0.6	0.6	0.6	-1	1	3	5
	Animal cremation	2.7	2.7	2.7	2.7	-8	-8	-8	-8
	Building fires	164.6	164.6	164.6	164.6	13	13	13	13
	Vehicle fires	22	22.3	23	23.8	5	4	3	3
	Total	189.8	190.2	190.9	191.8	12	12	12	11
TSP	Human cremation	189.8	190.2	190.9	191.8	-11	-9	-17	-15
	Animal cremation	189.8	190.2	190.9	191.8	-6	-6	-6	-6
	Building fires	189.8	190.2	190.9	191.8	-13	-13	-13	-13
	Vehicle fires	189.8	190.2	190.9	191.8	1839	1822	1830	1819
	Total	189.8	190.2	190.9	191.8	39	40	41	42
PM_{10}	Human cremation	189.8	190.2	190.9	191.8	-20	-20	-19	-19
	Animal cremation	189.8	190.2	190.9	191.8	-5	-5	-5	-5
	Building fires	189.8	190.2	190.9	191.8	-13	-13	-13	-13
	Vehicle fires	189.8	190.2	190.9	191.8	1839	1822	1830	1819
	Total	189.8	190.2	190.9	191.8	39	40	41	43
$PM_{2.5}$	Human cremation	189.8	190.2	190.9	191.8	42	44	47	-25
	Animal cremation	189.8	190.2	190.9	191.8	-9	-9	-9	-9
	Building fires	189.8	190.2	190.9	191.8	-13	-13	-13	-13
	Vehicle fires	189.8	190.2	190.9	191.8	1839	1822	1830	1819
	Total	189.8	190.2	190.9	191.8	39	40	41	43

*Calculated as the difference between the emissions reported in Table 8.11 and 9.12 divided by the emissions report in 2013 (Table 8.12).

For the human cremations, no changes in the emissions factors have occurred. However, the fraction of human being cremated after death is set equal to the reported value for 2014, i.e. 80.8%, throughout the projected time series. This is opposite to the last projection report in which the fraction of the population being cremated was based on a linear extrapolation of the historical time trend of the fraction of cremations of the total deaths.

For animal cremations, the projection is based on the average mass of carcasses in the period 2009-2014, i.e. 1280 Mg compared to the average value of 1336 Mg in the period 2008-2010 in the last projection. For this reason, the projected amount of emission for all emission components has decreased correspondingly; i.e. by 5 to 9 %.

For industrial building fires, the emission factors for NMVOC and NO_x have increased from respectively 120 to 225 and 24 to 45 kg per full-scale fires. This has caused the total emission from building fires for NMVOC and NO_x to increase by 13 and 6%, respectively. For the remaining components a small decrease are observed due to a reduction in the total number of building fires.

Lastly, for vehicle fires emission factors have been updated causing the emission to rise significantly. The former default emission values were according to EEA, 2009, while the new updated EF values for vehicle fires originates from measurements reported by Lönnermark & Blomqvist (2004).

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9 Conclusions

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 online at:
http://envs.au.dk/videnudveksling/luft/emissioner/projection/

9.1 NO_x

Historical and projected emissions of NO_x are shown in Figure 9.1 and Figure 9.2. The total NO_x emission shows a decrease over the time-series 1990 to 2030. The most pronounced decrease occurs in the historical years, but the trend is still decreasing and the emission is expected to decrease by 40 % from 2014 to 2030. 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 emission is projected to increase due to increased use of wood and increasing fuel consumption in relation to oil and gas extraction. 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 2030 are energy industries, transport (mainly road transport) and other mobile sources. The sectors account for 30 %, 24 % and 13 % of the total projected NO_x emission in 2030, respectively. Corresponding shares for the year 2014 and 2020 is shown in Figure 9.1.

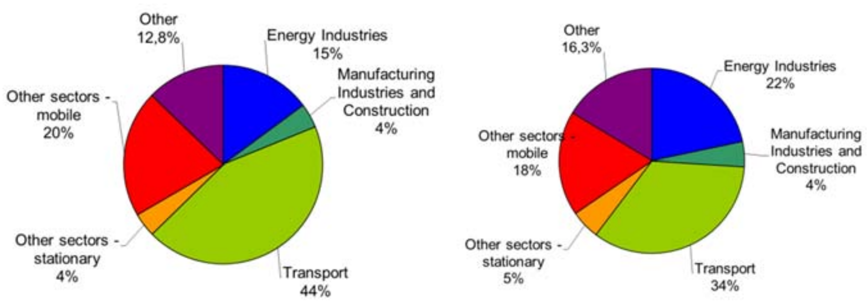

Figure 9.1 Historic and projected NOx emissions. Distribution by main sectors in 2014 (left) and 2020 (right).

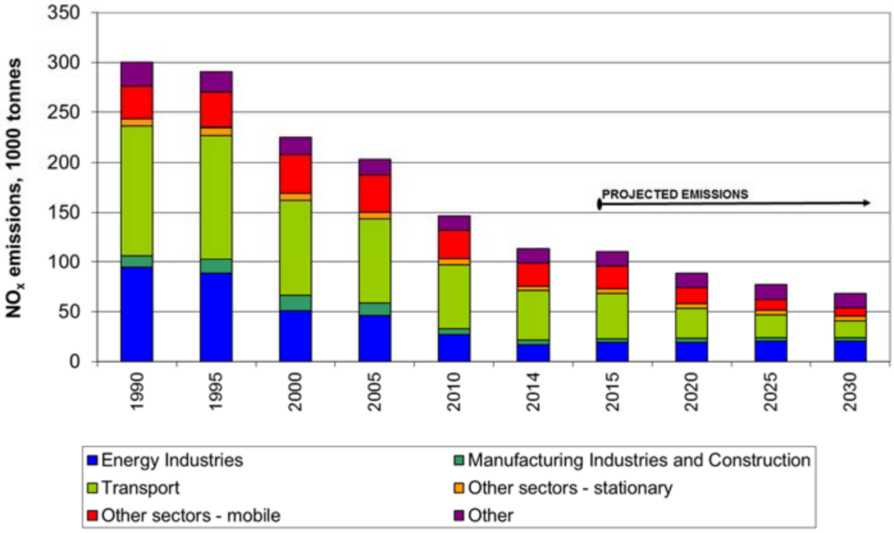

Figure 9.2 Historic and projected NO_x emissions. Time-series for selected years in the period 1990 to 2030.

9.2 SO_2

Historical and projected emissions of SO_2 are shown in Figure 9.3 and Figure 9.4. The total SO_2 emission shows a decrease over the time-series 1990 to 2030. By far the largest decrease is seen for the years 1990 to 2000, where the total SO_2 emission decreased by 82 %. The energy industry sector accounted for the major part of this decrease (78 %) due to installation of desulphurisation units at combined heat and power plants and use of fuels with lower content of sulphur in public power and district heating plants. For the years 2014 to 2030 the emissions only decrease slightly by about 10 %.

The major sources in 2030 are energy industries, manufacturing industries and construction and other sectors stationary. These sectors account for 30 %, 20 % and 18 % of the total projected SO_2 emission in 2030, respectively. Corresponding shares for the year 2014 and 2020 is shown in Figure 9.3.

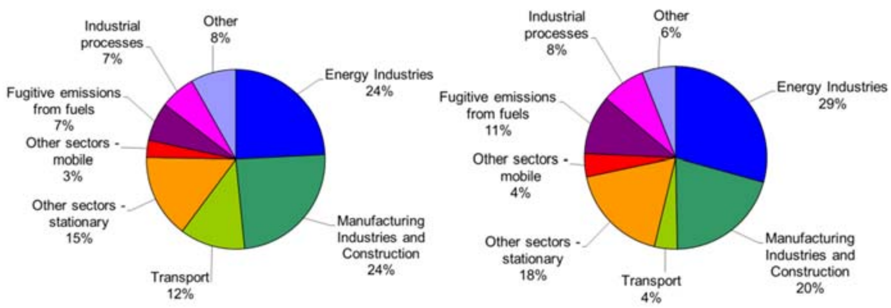

Figure 9.3 Historic and projected SO_2 emissions. Distribution by main sectors in 2014 (left) and 2020 (right).

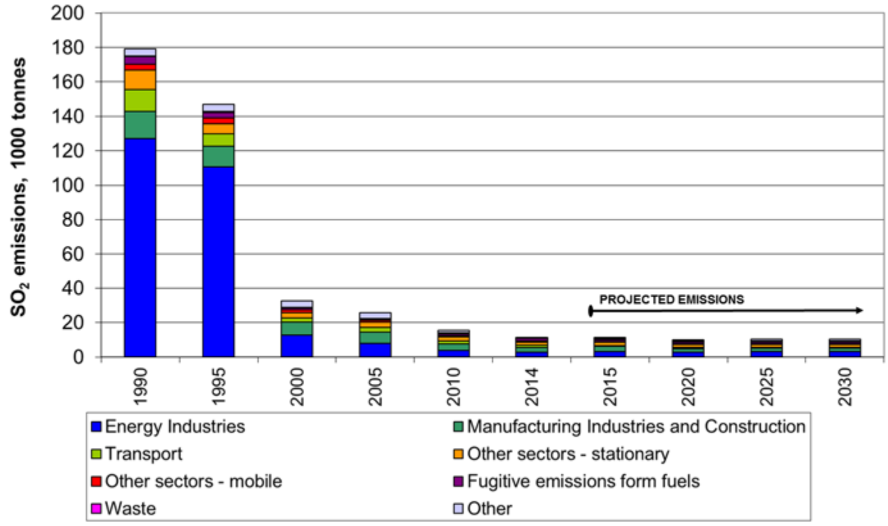

Figure 9.4 Historic and projected SO_2 emissions. Time-series for selected years in the period 1990 to 2030.

9.3 NMVOC

Historical and projected emissions of NMVOC are shown in Figure 9.5 and Figure 9.6. The total NMVOC emission shows a decrease over the time-series 1990 to 2030, (51 %) with the major part of the decrease in the years 1995 to 2014. The decrease from 1995 to 2014 mainly owe to decreasing emissions from road transport (88 %), but also the sectors industrial processes and fugitive emissions from fuels contribute to the decreasing trend (44 % and 30 %, 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 2030 is agriculture contributing 38 %. Industrial processes contribute 27 %, and fugitive emissions from fuels, other sectors stationary and transport contribute 9, 7 and 6 % respectively to the total projected NMVOC emission in 2030. Corresponding shares for the year 2014 and 2020 is shown in Figure 9.5.

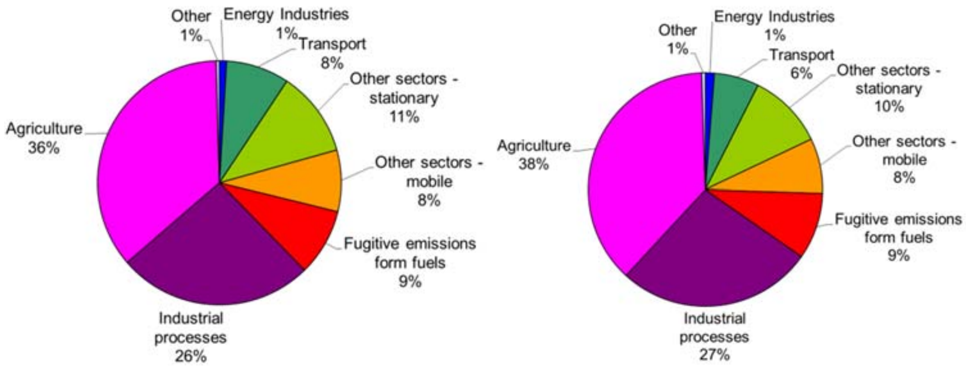

Figure 9.5 Historic and projected NMVOC emissions. Distribution by main sectors in 2014 (left) and 2020 (right).

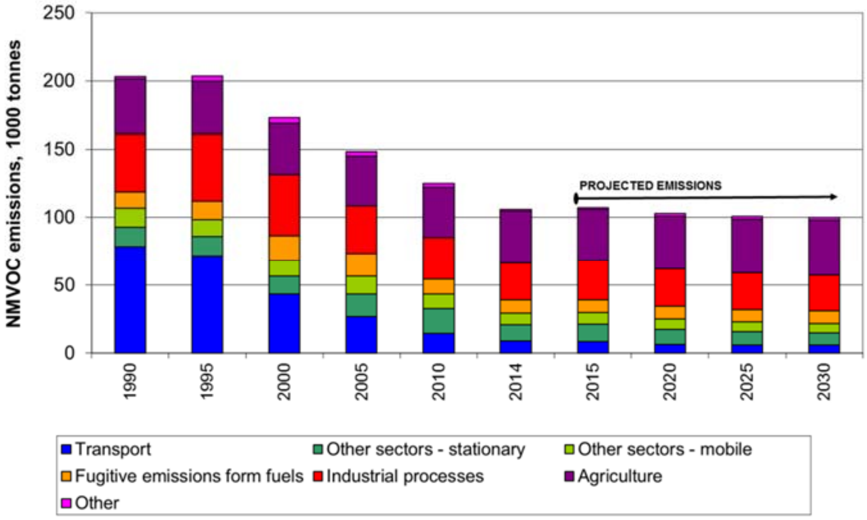

Figure 9.6 Historic and projected NMVOC emissions. Time-series for selected years in the period 1990 to 2030.

9.4 $PM_{2.5}$

Historical and projected emissions of particulate matter with a diameter below 2.5 µg ($PM_{2.5}$) are shown in Figure 9.7 and Figure 9.8. The $PM_{2.5}$ emission shows a decrease over the time-series 2000 to 2030 by 47 %. From 2000 to 2007 the $PM_{2.5}$ emission increased by 37 % mainly due to increasing emissions in other sectors – stationary because of increasing wood consumption in the residential sector. In the following period from 2007-2030, the total $PM_{2.5}$ emission decreases by 62 %. This mainly owes to replacement of older wood burning appliances with new and more efficient ones.

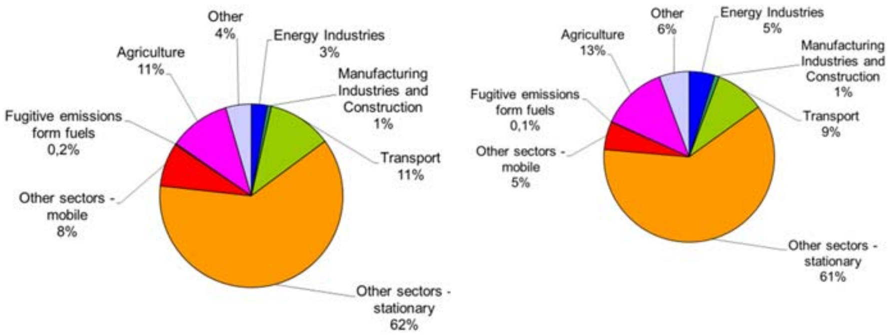

Figure 9.7 Historic and projected $PM_{2.5}$ emissions. Distribution by main sectors in 2014 (left) and 2020 (right).

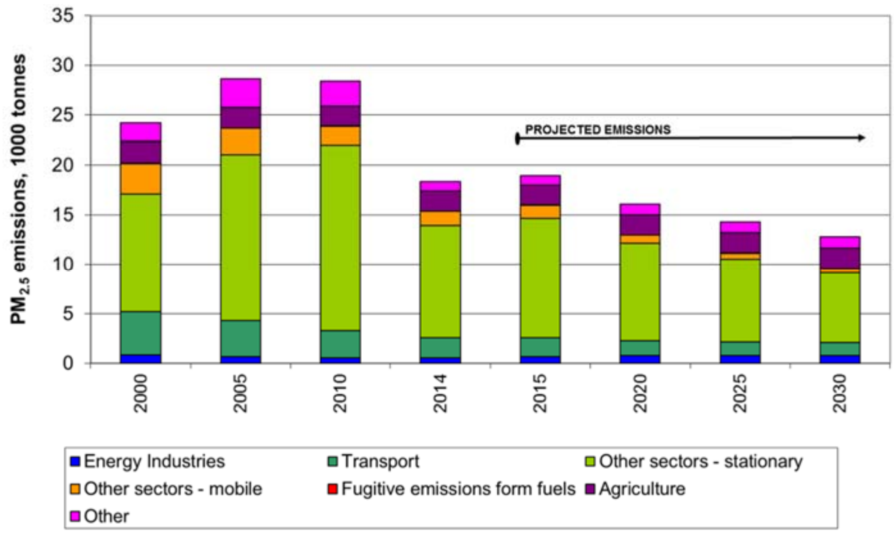

Figure 9.8 Historic and projected $PM_{2.5}$ emissions. Time-series for selected years in the period 1990 to 2030.

9.5 Black carbon

Historical and projected emissions of black carbon (BC) are shown in Figure 9.9 and Figure 9.10. The total BC emission shows a decrease over the time-series 2000 to 2035 by 64 %. The reduction mainly occurs from 2010 onwards. The reduction in emissions mainly owes to reduction in emissions from vehicles and other mobile machinery due to lower emission limit values for $PM_{2.5}$, which entails the installation of particle filters, which also reduces the emission of BC.

The major source to the projected emission in 2030 is other sectors stationary contributing 57 %. Fugitive emissions from fuels contribute by 13 %, while transport and other sectors mobile account for 12 and 6 % respectively to the total projected BC emission in 2030. Corresponding shares for the year 2014 and 2020 is shown in Figure 9.9.

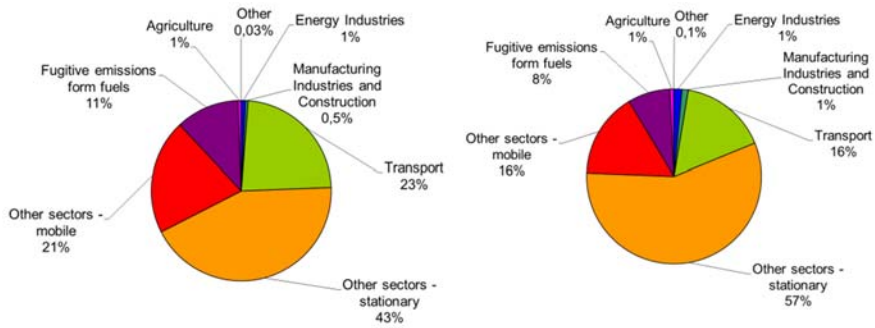

Figure 9.9 Historic and projected BC emissions. Distribution by main sectors in 2014 (left) and 2020 (right).

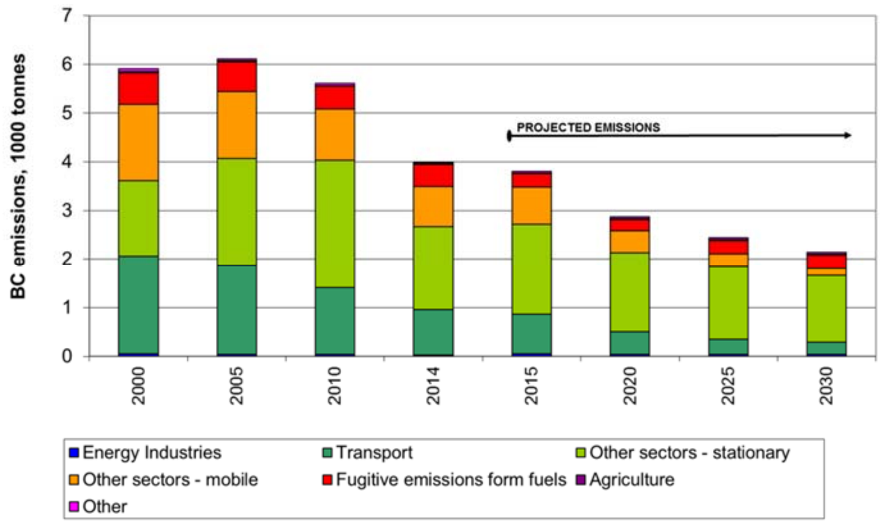

Figure 9.10 Historic and projected BC emissions. Time-series for selected years in the period 1990 to 2030.

PROJECTION OF SO_2, NO_X, NMVOC, PARTICULATE MATTER AND BLACK CARBON EMISSIONS – 2015-2030

This report contains a description of models and background data for projection of SO_2, NO_X, NMVOC, $PM_{2.5}$ and black carbon for Denmark. The emissions are projected to 2030 using basic scenarios together with the expected results of a few individual policy measures. Official Danish forecasts of activity rates are used in the models for those sectors for which the forecasts are available, i.e. the latest official forecast 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 projection models are based on the same structure and method as the Danish emission inventories in order to ensure consistency.

ISBN: 978-87-7156-252-1
ISSN: 2245-0203