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Projection Models 2010

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NERI Technical Report No. 414

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Data sheet

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Abstract: Models for projection of SO_2-, NO_x-, NMVOC- and NH_3-emissions to the atmosphere have been developed and the Danish emissions have been projected until 2010 from a basis scenario including all implemented and planned measures. The projections of the four pollutants indicate that it may be difficult to achieve the emission ceilings given in the Gothenburg Protocol and the EU directive on national emission ceilings in 2010. In addition to the basis scenario, 8 emission reduction scenarios for different sectors have been analysed in order to estimate the emission saving potential and financial and welfare-economic consequences of each scenario.

Keywords: Projection, emission(s), SO_2, NO_x, NMVOC, NH_3, reduction scenarios, welfare-economics

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Preface

This report contains a description of models for projection of SO_2, NO_x, NMVOC and NH_3 for Denmark. The emissions are projected from a basis scenario until 2010 and a number of measures are analysed in order to estimate the potential emissions reductions and the financial and welfare-economic consequences of the different measures.

The Department of Policy Analysis of the National Environmental Research Institute (NERI) and the Department of System Analysis of Risø National Laboratory have carried out the work. The project has been financed partly by the Danish Environment Protection Agency (EPA) and NERI.

The steering committee of the project consisted of the following members:

Ulrik Torp (chairman, EPA), Per B. Suhr (EPA), Lisbeth Strandmark (EPA), Jytte Boll Illerup, (NERI), Morten Winther (NERI), Jørgen Fenhann (RISØ), Jesper Schou, (NERI), and Thomas C. Jensen, (The Energy Agency).

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Summary

Introduction

The objective of the present project has been to develop Danish models for projection of SO_2-, NO_x-, NMVOC- and NH_3-emission to the atmosphere until 2010 and to make an estimate of the emissions in 2010 of the four pollutants. The emission projection models for these four pollutants cover the following economic sectors: Energy, industry, transport and agriculture.

In Europe the 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 new protocol – the Gothenburg Protocol – are to control and reduce the emissions of SO_2, NO_x, NMVOC and NH_3. Contrary to the former protocols the parties to the convention are not obliged to comply with certain reduction ratios compared with a baseline year. Instead emission ceilings have been based on knowledge of critical loads and environmental impact on ecosystems within the geographical area of Europe. Table 1 shows the emission ceilings for Denmark in 2010. The same emission ceilings are given 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.

Table 1. Emission ceilings for Denmark in 2010 (tonnes).

Pollutants	SO_2	NO_x	NMVOC	NH_3*
Emission ceilings	55000	127000	85000	69000

* The NH_3 emission ceiling excludes emission from straw treatment and crops.

The developed projection models can be used to calculate the expected emissions of the four pollutants in 2010 given an estimate of the development in each of the four sectors. The models can furthermore be used to calculate the effects of various emission reduction measures. By investigating a suitable range of emission reduction measures and the associated financial and welfare-economic costs, the models can be used as a guidance to find the most cost-effective strategy meeting the emission ceilings.

The Danish emissions have been projected from a basis scenario including all implemented and planned measures. In addition to the basis scenario, 8 emission reduction scenarios for different sectors have been analysed in order to estimate the emission saving potentials and financial and welfare-economic consequences of each scenario. The 8 emission reduction scenarios were chosen as likely examples of measures covering all four economic sectors and are used to demonstrate the capabilities of the developed models. The results are summarised in Table 2. The chosen reduction scenarios do not fully account for the projected deficit based on the assumptions made for the computation. Some of the scenarios or measures are obviously cheaper to implement than others. It is also obvious that it is not possible to choose only the cheapest measure as every measure has a maximum emission reduction capacity associated with the actual activity (e.g. the number of large power plants where a SCR unit can be installed). The results shown in Table 2 illustrate how the models can be used to find an emission reduction strategy that is technically feasible on the one hand and cost-effective on the other.

Table 2. Projected emissions in 2010 according to the basis scenario compared with the emission ceilings and the effects of the investigated reduction scenarios. The costs are calculated as welfare-economic costs.

	SO_2	NO_x	NMVOC	NH_3	Costs pr. tonne
	1000 tonnes				10^6 DKK per tonne
Projected emission 2010	56.05	146.37	83.01	82.78	-
Emission ceiling 2010	55.00	127.00	85.00	69.00	-
Deficit	1.05	19.37	-	13.77	-
The emission reduction scenarios					
1. Car painting work shops: water-based paint	0.00	0.00	0.75	0.00	NMVOC: 0.126
2. Offshore wind turbine farm (replaces coal-fired power plant)	0.51	0.23	0.01	0.00	SO_2: 0.264 NO_x: 0.586 NMVOC: 19.157
3. SCR (de-NO_x) unit installation at large power plant	0.00	6.46	0.00	0.00	NO_x: 0.013
4. Desulphurisation unit at large power plant	2.29	0.00	0.00	0.00	SO_2: 0.005
5. Electrical vehicles (70,000 in 2010)	0.02	0.05	0.20	0.00	SO_2: 34.428 NO_x: 13.501 NMVOC: 3.460
6. EGR-filter installation (heavy duty vehicles<10 yr.)	0.00	2.84	0.61	0.00	NO_x: 0.766 NMVOC: 3.456
7. Increased grazing of dairy cows	0.00	0.00	0.00	3.30	NH_3: 0.026
8. Manure application within one hour after spreading	0.00	0.00	0.00	1.31	NH_3: 0.029
Reduction total	2.82	9.58	1.57	4.61	-
Emission including reductions	53.23	136.79	81.44	78.17	

The projection models

Energy

The projection of the emissions from combustion in stationary plants is estimated in a new model developed in this project. The energy consumption data in the model is based on the energy forecast carried out by the Danish Energy Agency (DEA) according to the follow up on the Danish energy plan ‘Energy 21’. The energy consumption is calculated based on the fuel expected to be combusted in Danish plants and the emissions are therefore not corrected for international electricity trade. From 2004 the Danish export of electricity is assumed to increase with about 90 PJ compared with a national consumption of fuel of 410 PJ in stationary combustion plants.

The fuel consumption from plants larger than 25 MWe is specified for each plant together with information on abatement technology, sulphur content in the fuel, degree of desulphurisation and emission factors. The emission factors for large combustion plants are based on the assumptions made by the Danish power stations concerning sul-

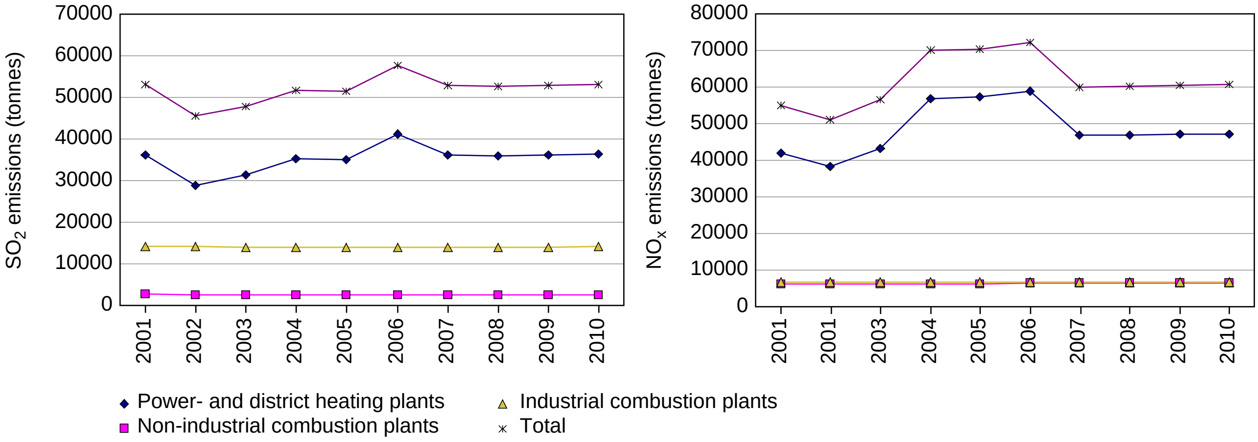


Figure 1. Projected SO_2 emissions from the energy sector.

Figure 2. Projected NO_x emissions from the energy sector.

phur content in the fuel, sulphur retention in the ash and degree of desulphurisation. For plants smaller than 25 MWe the emission factors are estimated from permit limit values for sulphur content in fuels given in the Danish legislation and from information given by the Danish power stations and other Danish companies. Measurements have shown that NO_x emission factors for gas turbines and stationary gas engines are significantly higher than for boilers. The structure of the emission model makes it possible to change the parameters for both large and small combustion plants.

The most important SO_2 emission source is power- and district heating plants followed by industrial combustion plants and non-industrial combustion plants. The SO_2 emissions from the two latter sources are almost constant throughout the period from 2001 to 2010 while the emissions from the power and heat production reflect the variation in the fuel consumption. For NO_x as for SO_2 the most important emission sources are power- and district heating plants. In the years until 2006 the NO_x emissions and the fuel consumption will develop correspondingly. From 2007 Selective Catalytic Reactors (SCR) are expected to be installed on some of the large combustion units and this will cause a significant decrease in the emissions. Contrary to the SO_2 and NO_x emissions the largest NMVOC emission source is non-industrial combustion plants. Especially combustion of wood in the residential sector contributes to the NMVOC emission. The emissions from the large combustion plants contribute with about 80% and 60% for SO_2 and NO_x respectively of the projected total emissions from power- and district heating plants.

Industry

The projected emissions from the industrial sector mainly include oil and gas extraction and use of solvents. The most important pollutant from the industrial sector is NMVOC and the largest emission sources are use of solvents, extraction of oil and gas and processes in the petroleum industry.

The emission calculation for oil and gas extraction are based on projected oil and gas production from the DEA and emission factors

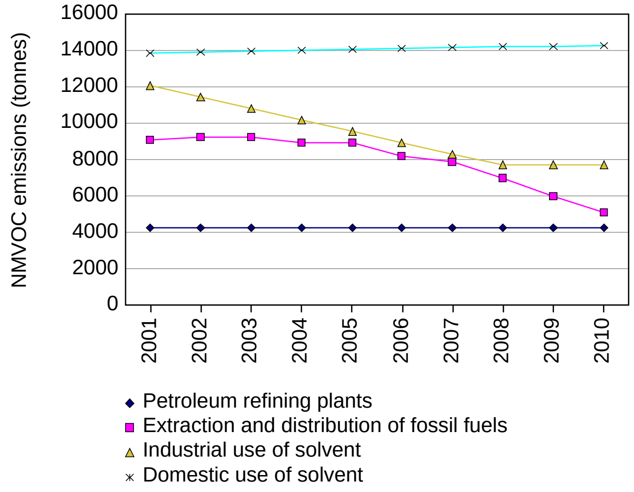


Figure 3. Projected NMVOC emissions from the main industrial sources.

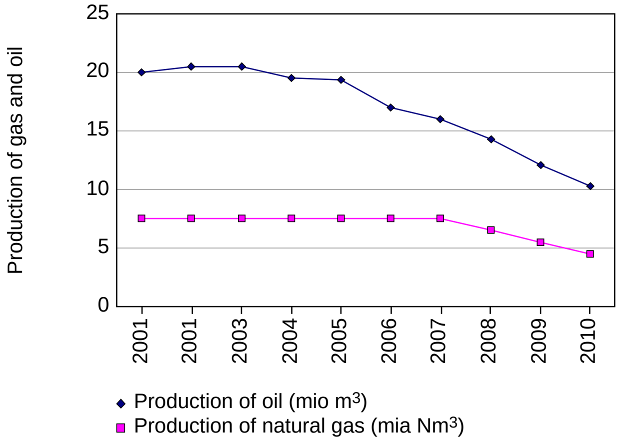


Figure 4. Projected production of oil and gas.

from the Joint EMEP/EEA Atmospheric Emission Guidebook. Especially fugitive emissions, emissions from loading of oil into ships and emissions from the natural gas network contribute to the NMVOC emissions.

The most important sectors for industrial use of solvents are: Car repairing and treatment, the chemical industry, paint application in the iron and steel industry, paint manufacturing, the plastic industry, the food industry, preservation of wood and the printing industry. For these sectors the Government and the industries agreed to reduce the emissions of NMVOC by 40 % from 1988 to 2000. As a part of the agreement the industry has collected activity and emission data for the relevant sectors. The model for calculating industrial emissions of NMVOC is based on these data. At present no projection of Danish activity and emission data for industrial use of solvent is available from 2001 to 2010. Instead it is assumed that the emissions will decrease by 57% from 1990 to 2010, the same reduction as assumed in a European project.

No detailed Danish inventory exists for domestic use of solvents. The recommended emission factor in the Joint EMEP/EEA Atmospheric Emission Guidebook is therefore used in the projections. The emission is estimated by multiplication of the emission factor and the projected population number.

Transport

For road traffic a detailed model has been developed in this project to simulate the emissions from operationally hot engines, during cold start and fuel evaporation. The emission effect of catalyst wear is also included in the model. Input data for vehicle stock and mileage is obtained from the Danish Road Directorate, and is grouped according to average fuel consumption and emission behaviour. For each group the emissions are estimated by combining vehicle and annual mileage numbers with hot emission factors, cold:hot ratios and

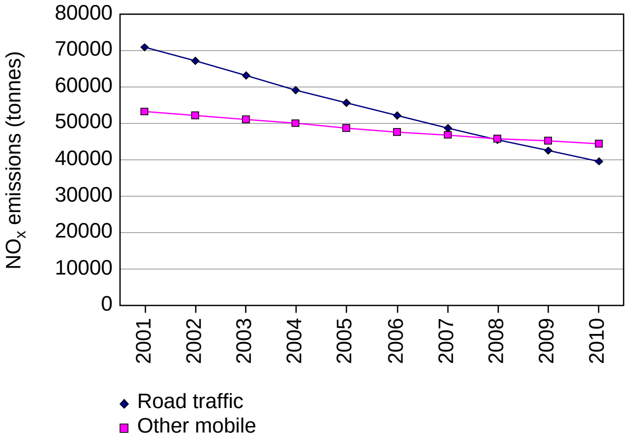


Figure 5. Projected NO_x emissions from road traffic and other mobile sources.

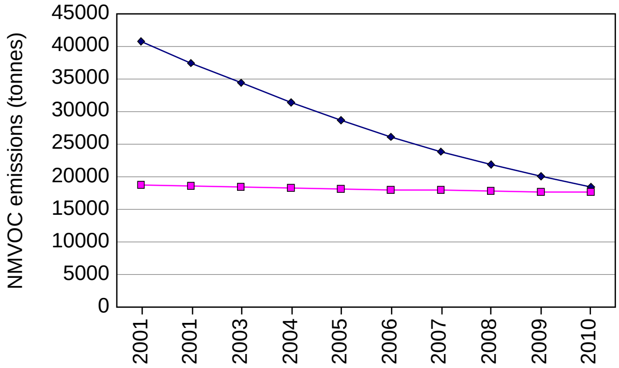


Figure 6. Projected NMVOC emissions from road traffic and other mobile sources.

evaporation factors. Consistency with historical emission figures is ensured by using background data from the European COPERT III model currently used to produce the annual Danish road traffic inventories. In this way COPERT III supplies the forecast model with e.g. hot baseline emission factors, reduction factors for future vehicle groups, catalyst deterioration factors and cold:hot ratios.

A new model has also been developed for off road working machines and equipment in the following sectors: Inland waterways, agriculture, forestry, industry and household and gardening. In general the emissions are calculated by combining information on the number of different machine types and their respective load factors, engine sizes, annual working hours and emission factors. Future emission reductions for diesel machinery are taken into account by simulating the implementation of a two-stage EU emission legislation directive. For the remaining types of machinery no real emission improvements are expected. Emission projections are made by using the latest historical fuel related emission factors in combination with the DEA energy use forecast.

The emission of NO_x and especially NMVOC from private cars has shown a constant lowering trend since the introduction of catalyst private cars in 1990. The total emission reductions are fortified by the introduction of new gradually stricter EURO emission standards for all other vehicle classes. This development is expected to continue in the future. The NO_x and NMVOC emission reduction pace for road traffic is expected to be higher from 2001 to 2010 compared with the other mobile sources. From 2001 to 2010 the projected NO_x and NMVOC shares for road traffic go from 57 and 68% respectively, to 47 and 51%.

A side effect of the introduction of catalytic converters is a dramatic increase in the emissions of NH_3. However the emissions are still small compared with the agricultural NH_3 emission totals. The pace in which the NH_3 emissions increase slows down at the end of the forecast period together with the catalyst vehicle penetration rate. The already low sulphur content of around 50 ppm in gasoline and diesel fuels is foreseen to be further reduced to 10 ppm in 2005. Consequently the sea

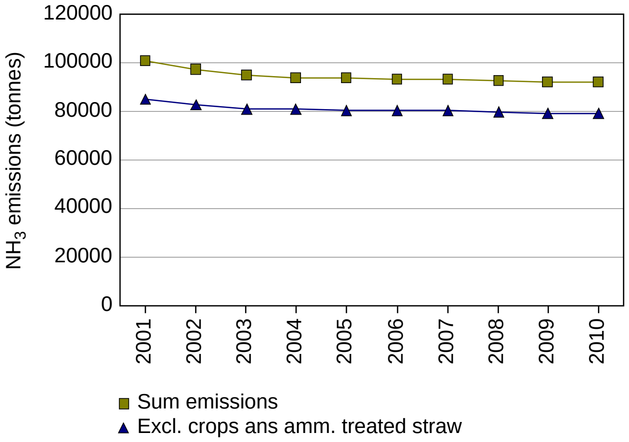


Figure 7. Projected NH_3 emissions from agricultural activities.

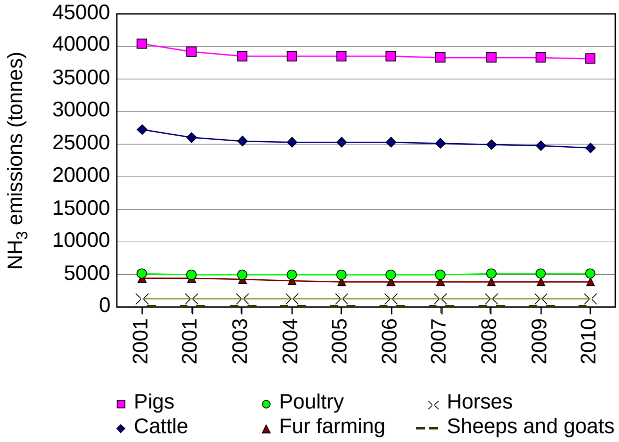


Figure 8. Projected NH_3 emissions from husbandry manure.

going vessels which use residual oil have a very dominant share from now and onwards of the SO_2 emission total for all mobile sources.

Agriculture

The NH_3 emission projections for the agricultural sector cover five different sources; livestock manure, artificial fertilisers, emissions from crops, enteric fermentation of straw and sewage sludge deposited on agricultural soil. The size of the emission depends on a number of activity parameters for each source. Among others are the number of animals, the stable type, area with crops and the amount of sewage sludge deposited. The emission is estimated as activities multiplied with emission factors.

The main part of data for agricultural activities and emission factors originates from the Danish Agricultural Advisory Centre and The Danish Institute of Agricultural Sciences. Furthermore data from The Royal Veterinary and Agricultural University, the Ministry of Environment, the Danish Plant Directorate and the Danish Forest and Landscape Research Institute has been used. The emission projection is based on the development over the last 10 years and legislative measures when these are expected to result in changes in future agricultural activities.

As part of the efforts to reduce the ammonia emission in Denmark the Ammonia Action Plan and the Action Plan on the Aquatic Environment II have been worked out. It is expected that the Plan will be incorporated in the revision of the Statutory Order Of Livestock. The projection therefore also accounts for the effects of 1) a prohibition on broad-spreading of manure, 2) the time it takes for manure to be incorporated into the soil when reduced from present 12 to 6 hours and 3) an implementation of a prohibition of ammonia treated straw. The increased awareness of environmental matters in the farm holding, particularly in relation to production expansion, implies that technical measures must be expected to contribute to emission reduction in the future. It is however difficult to estimate the full consequences of the technical measures and therefore the emission impacts of these have not been included in the present projections.

On the basis of the projection of livestock production and the other activities within the agricultural sector the emission in 2010 is expected to be 91,800 tonnes NH_3. The emission exclusive crops and ammonia treated straw will be 79,100 tonnes NH_3. This total corresponds to a reduction of 10% compared with the year 2000. The major part - nearly 80% - of the ammonia emission from agriculture comes from livestock manure and mainly from cattle and pigs. The emission from husbandry manure is expected to decrease with 8% despite the increase in the pork and poultry production. The main reason for this reduction is an expected change in the way manure is spread. It is assumed that a greater part of the slurry will be incorporated in the soil and the time between spreading of manure and ploughing down is foreseen reduced. The emission from other sources in 2010 is also expected to be reduced mainly due to a decrease in the agricultural area.

Pollutants summary

SO_2

The Danish SO_2 emission ceiling of 55 ktonnes in 2010 is almost achieved according to the basis scenario in which the emission is 56.1 ktonnes or only 1.1 ktonnes above the target (Table 3). The largest source of the emission of SO_2 is public power and district heating plants and the most important parameters for the projected emissions are: the degree of desulphurisation, the content of sulphur in the fuels and the amount of electricity exported. In the present projection the estimates of the sulphur content in the fuels rely on conservative assumptions and a large export of electricity from 2004 is assumed.

NO_x

The projected NO_x emission of 146.3 ktonnes in 2010 is somewhat higher than the emission ceiling of 127 ktonnes. The three largest – and almost equivalent in size – sources are power and district heating plants, road transport and other mobile sources. It may be difficult to achieve this target and one of the main reasons is the large electricity export envisaged in the fuel consumption forecast from the DEA.

NMVOC

The NMVOC emission projection lies slightly below the emission ceiling of 85 ktonnes. The largest emission sources of NMVOC are road traffic, other mobile sources, use of solvents, non-industrial combustion plants and offshore activities. The projected emissions for NMVOC are very uncertain. Especially the emission estimates from use of solvents and offshore activities are attached with large uncertainties and the estimated emissions might change substantially should more research be made within this area.

NH_3

The projected emissions in 2010 are estimated to be 83 ktonnes (excluding emissions from crops) and compared with the emission ceilings of 69 ktons the ceiling is expected to be exceeded with about 14 ktonnes. Almost all emissions of NH_3 result from agricultural activities and the major part comes from livestock manure. The NH_3 projections do not include future technical measures due to the difficulties to estimate the full consequences of these.

Table 3. Projected emissions in the basis scenario.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Emission ceilings
SO_2 (tonnes)	56697	48981	51349	55163	54528	60747	55774	55620	55841	56054	55000
NO_x (tonnes)	181723	172992	173192	181627	177249	174561	158030	153865	150214	146369	127000
NMVOC (tonnes)	113356	109920	106367	102640	99211	95204	91995	88483	85644	83012	85000
NH_3 (tonnes)	103108	99650	97763	96956	96732	96622	96361	96091	95776	95427	
***NH_3 (tonnes)**	87812	85060	83877	83776	83640	83618	83446	83264	83037	82777	69000

*Agriculture excl. emissions from crops and straw treatment with NH_3

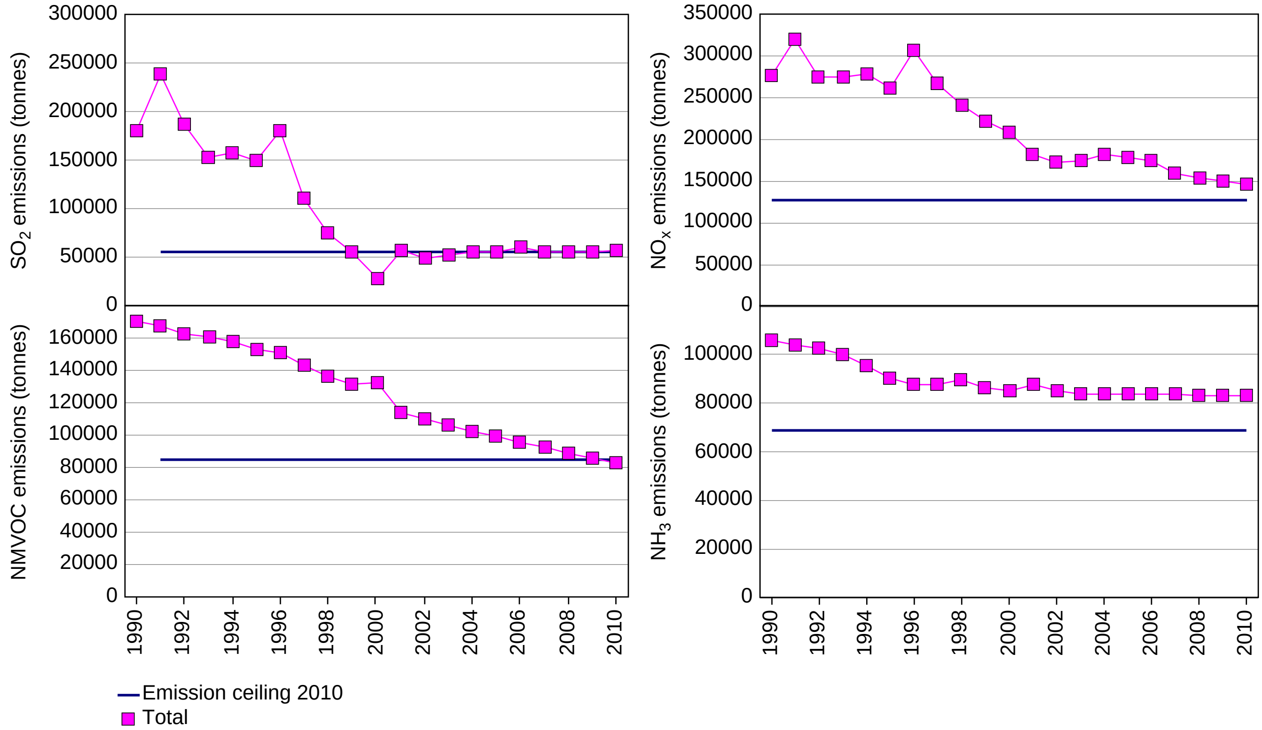


Figure 9. Historical and projected emissions together with the emissions ceiling for 2010.

Figure 9 shows the emission trends from 1990 to 2000 and the projected emissions from 2001 to 2010. For all four pollutants significant reductions are seen from 1990 to 2000.

Emission reduction scenarios

The emission projections of SO_2, NO_x, NMVOC and NH_3 show that the respective emission ceilings for Denmark will not necessarily be reached in all cases. In addition to the already implemented and planned measures included in the basis calculations it is therefore of interest to investigate the potential emission savings for selected emission reduction options in the different sectors. Technical measures have been chosen. It was outside the scope of this project to further examine the effect of changes in behaviour resulting from economic or political regulation or due to an increased environmental awareness in the public. In general the measures were selected from the sectors and activities that contribute with the larger emissions. Eight measures were analysed in order to determine their emission reducing capacity and the associated financial and welfare-economic costs.

Table 4. Additional emission reduction measures**.**

Reduction options not included in the reference scenario	Option SO_2 kt/year	Accum. SO_2 kt/year	Option NO_x kt/year	Accum. NO_x kt/year	Option NMVOC kt/year	Accum. NMVOC kt/year	Option NH_3 kt/year	Accum. NH_3 kt/year
1. Car-painting workshops: water-based paint	0.00	0.00	0.00	0.00	0.75	0.75	0.00	0.00
2. Offshore wind turbine farm (replaces coal-fired power plant)	0.51	0.51	0.23	0.23	0.01	0.76	0.00	0.00
3. SCR (de-NOx) unit installation at large power plant	0.00	0.51	6.46	6.69	0.00	0.76	0.00	0.00
4. Desulphurisation unit at large power plant	2.29	2.80	0.00	6.69	0.00	0.76	0.00	0.00
5. Electrical vehicles (70.000 in 2010)	0.02	2.82	0.05	6.74	0.20	0.96	0.00	0.00
6. EGR-filter installation (heavy duty vehicles < 10 yr.)	0.00	2.82	2.84	9.58	0.61	1.57	0.00	0.00
7. Increased grazing of dairy cows	0.00	2.82	0.00	9.58	0.00	1.57	3.30	3.30
8. Manure application within one hour after spreading	0.00	2.82	0.00	9.58	0.00	1.57	1.31	4.61
2010 emission:								
In the reference scenario		56.05		146.37		83.01		82.78
Extra reductions included		53.23		136.79		81.44		78.17
ECE goals (Emission ceilings)		55.00		127.00		85.00		69.00

Regarding the industry the substitution of solvent-based paint with a water-based alternative in all Danish car-painting workshops is an option (1). In the energy sector the building of an offshore wind turbine farm was considered in two cases substituting electricity produced on a natural gas and a coal-fired power plant (2). Installations of De-NO_x and desulphurisation units at large power plants were also examined (3 and 4 respectively). EGR (Exhaust Gas Recirculation) installations on heavy duty vehicles were analysed for three situations: The first two options combine the retrofitting of EGR on vehicles less than 10 or 5 years old, respectively, with line installation on new vehicles, while the third option only considered new vehicles (5). The effect of replacing a) yearly new sales of 10,000 small gasoline cars and b) all new sales of small gasoline cars from 2004 to 2010 with electrical vehicles was also examined (6). The effects of increasing the amount of grazing days for dairy cows (7) and changes in the application of manure (8) were investigated for the agricultural sector.

It is important to emphasise that the measures selected do not represent a complete picture of all existing emission reduction options in the different sectors. The options should be considered only as possible measures and not as a complete list of measures necessary to achieve the emission ceilings. In Table 4 the emission reduction measures considered in this project are listed along with the emission ceilings and the emission reductions achieved for each of the options.

The SO_2 target could be achieved by implementation of the desulphurisation option (reducing with 2.29 ktonnes). Use of fuels with lower content of sulphur than assumed in the basis calculations would also lead to further reduction of the emissions. It may be difficult to achieve the emission target of NO_x. About half of the emission gap (9.6 ktonnes out of 19.4 ktonnes NO_x) could be covered by implementing the options shown in Table 4. Especially the de-NO_x unit (SCR) and Exhaust Gas Recirculation (EGR) on all heavy-duty vehicles less than 10 years old would reduce the emission substantially.

The potential emission savings of NMVOC from car painting workshops are in the order of 0.75 ktonnes. The NMVOC emission reduction estimated in the transport sector option is 0.81 ktonnes leading to a NMVOC emission total even further below the emission ceiling.

Table 4 illustrates that the implementation of the two extra measures in the agricultural sector could reduce the emission gap with about 4.6 ktonnes NH_3. The reduction of the NH_3 emission needs to be considerable in order to achieve the emission ceiling. However, the NH_3 projections do not include future technical measures in relation to production expansion and these might potentially be sufficient to meet the emission goal. Examples of future technical solutions could be improved feeding methods and technology, slurry separation technologies and stable system improvements. However, at present no detailed knowledge exists about the potential for emission reductions and costs involved for the introduction of these measures.

Some of the assumptions made in the basis scenario have to be analysed further in order to conclude whether new environmental regulations of the sectors are necessary. Especially the consequences of the European directive for Large Combustion Plants should be considered along with the future technical measures in the agricultural sector.

Financial and welfare-economic analysis

The additional emission reduction measures result in extra costs for the private entities implementing them (e.g. companies, private consumers, energy producing utilities, etc.) and for the society as such. In this project these extra costs have been valuated through a financial and welfare-economic analysis.

The financial (or budgetary) cost-benefit analysis calculates the financial costs and benefits from the point of view of single actors or subgroups of the population in an economy: the state, the private investor, or the consumer. The prices used are the market prices either paid on the market for inputs in the form of producer or consumer goods or obtained on the market for selling products, including all non-refundable taxes and subsidies.

The welfare-economic evaluation seeks to determine the improvement in welfare for the population of a country by calculating the benefits and costs from the point of view of the country as a whole. The evaluation is based on so-called applied welfare economics (in this study the “accounting-price”-method is used). It considers that society’s resources are limited and that the use of these resources in one situation causes opportunity costs in terms of foregone benefits from the next best alternative usage.

The welfare economic analysis accounts for the value/benefit of the avoided environmental impacts. This is not considered in the financial analysis.

Table 5. Financial costs for the investigated reduction measures.

Reduction options not included in the reference scenario	Primary sector affected	Investment costs	Annual costs	SO_2	NO_x	NMVOC	NH_3-N
		MDKK	MDKK/yr	1000 DKK/tonne			
1.Car-painting workshops: water-based paint	Industry	123.5	78.5			104.7	
2. Offshore vind turbine farm (replaces coal-fired power plant)	Energy	1599.0	96.0	189.0	420.0	13700.0	
3. SCR (de-NO_x) unit installation at large power plant	Energy	350.0	62.7		9.7		
4. Desulphurisation unit at large power plant	Energy	60.0	9.2	4.0			
5. Electrical vehicles (70.000 in 2010)	Households	3511.1	-266.3	-13300.0	-5200.0	-1300.0	
6. EGR-filter installation (heavy duty vehicles < 10 yr.)	Transport	8350.0	1619.9		570.0	2640.0	
7. Increased grazing of dairy cows	Agriculture	176.7	98.1				22.9
8. Manure application within one hour after spreading	Agriculture	0.0	33.1				30.7

Financial analysis

The financial analysis shows the investment costs and the annual costs. The calculations demonstrate the costs for the primary sectors affected for each reduction option. It has not been possible to calculate the distributional effects for the remaining society, e.g. in case the energy sector passes on the costs to the consumers.

The results of the financial calculations (Table 5) show that the electrical vehicle option is the cheapest way of reducing SO_2, NOx and NMVOC emissions, since the annual extra cost is lower than the cost of the gasoline. This is, however, seen only from the viewpoint of the consumer whereas it is the most expensive option seen for the society as a whole (see Table 6 below). The de-NOx and desulphurisation options have relatively low costs, but since almost all large power plants already have or is planned to have these SO_2 and NOx emission reducing installations, the impact will be small. For the low cost option of reducing NMVOC at car painting workshop there could be a large potential also in other industrial branches using solvents and paints. Increasing the amount of grazing days for dairy cows is a little cheaper than manure application within one hour after spreading.

Welfare-economic analysis

Ideally a welfare-economic analysis would include estimates of the different environmental and health effects (positive and negative) and other non-market effects associated with the implementation of a project. Given the high uncertainty associated with placing a monetary value on those non-market effects, their reporting is often restricted to physical units, e.g. tonnes of emissions reduced. In the main part of the analyses in this report welfare-economic cost-effectiveness measures in terms of costs-per-tonnes have been calculated for each project and each type of emission reduction. Table 6 below shows a first ranking of initiatives based on their cost-effectiveness estimates for the different emissions.

Table 6. Contribution of the different measures to emission reductions in 2010, ranking based on costs per tonne emission reduced (welfare-economic prices).

Ranking	SO_2-emissions		
		MDKK/ton	Amount 2010 (tonnes)
1.	4. Desulphurisation unit at large power plant	0.005	2292
2.	2. Offshore wind turbine farm (replaces coal-fired power plant)	0.264	508
3.	5. Electrical vehicles (70.000 in 2010)	34.428	20
	NO_x-emissions		
		MDKK/ton	Amount 2010 (tonnes)
1.	3. SCR (de-NOx) unit installation at large power plant	0.013	6460
2.a	2. Offshore wind turbinefarm (replaces natural gas-fired power plant)	0.259	236
2.b	2. Offshore wind turbine farm (replaces coal-fired power plant)	0.586	229
3.a	6. EGR-filter installation (heavy duty vehicles < 10 yr.)	0.766	2838
3.b	6. EGR-filter installation (heavy duty vehicles < 5 yr.)	0.785	1850
3.c	6. EGR-filter installation (heavy duty vehicles; only new)	0.870	692
4.	5. Electrical vehicles (70.000 in 2010)	13.501	51
	NMVOC emissions		
		MDKK/ton	Amount 2010 (tonnes)
1.	1. Car-painting workshops: water-based paint	0.126	750
2.a	6. EGR-filter installation (heavy duty vehicles; only new)	2.646	227
2.b	6. EGR-filter installation (heavy duty vehicles < 5 yr.)	3.205	453
3.	5. Electrical vehicles (70.000 in 2010)	3.460	199
	6. EGR-filter installation (heavy duty vehicles < 10 yr.)	3.546	613
4.a	2. Offshore wind turbine farm (replaces natural gas-fired power plant)	6.103	10
4.b	2. Offshore wind turbine farm (replaces coal-fired power plant)	19.157	7
	NH_3 emissions		
		MDKK/ton	Amount 2010 (tonnes)
1.	7. Increased grazing of dairy cows	0.026	3299
2.	8. Manure application within one hour after spreading	0.029	1309

The two offshore wind turbine farm scenarios and the three different scenarios calculated for EGR-filter installations are mutually exclusive.

Based on the cost-effectiveness estimates summarised in Table 6 marginal cost curves for emission reductions of SO_2, NO_x, NMVOC and NH_3 can be constructed, and as an example the marginal cost function for reducing NO_x emissions is shown in Figure 10. Total costs of implementing the present options are found as the area under the marginal cost function. The marginal cost function could serve as an inspiration to achieve certain emission reductions in the most cost-effective way.

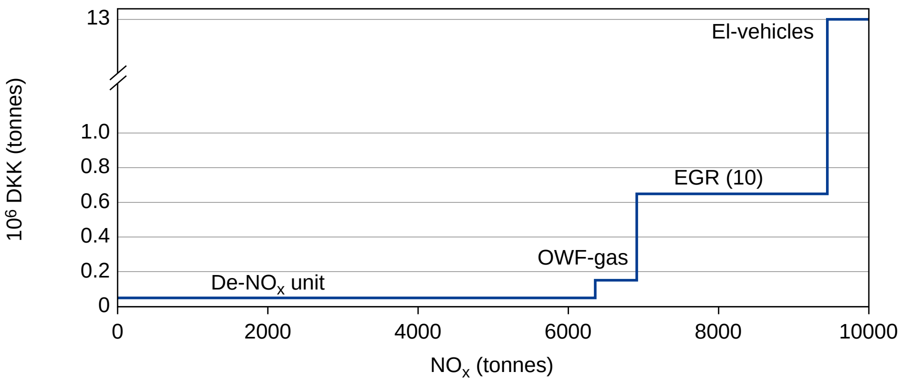


Figure 10. Marginal cost function for future reductions of NO_x emissions.

The welfare-economic calculations have been based on a social time preference rate of 3%. This time preference rate has been applied for the calculations of present value costs, capital recovery factors and return on investment factors. Altering the social time preference rate to 6% would lead to a reduction of annual costs for the different measures. However, applying a social time preference rate of 6% instead of 3% does not change the ranking of initiatives based on their cost-effectiveness measures. Cost reductions per tonne of emission reduced range from 1.9% to 32% and are highest for those measures that require extremely high up-front investments (i.e. building an offshore wind turbine farm) or investments over a longer period of time, e.g. the replacement of conventional vehicles with electrical ones in the time period 2004 – 2010. Cost savings per tonne emission reduced are only modest for those measures that require relatively small investments (e.g. fencing equipment for increased grazing) or where modest investment expenses results in high emission savings, e.g. the installation of de-NO_x and desulphurisation units at large power plants.

The reduction measures suggested in this report also contribute to the reduction of other emission components such as particulates, CO_2 and CH_4. These side benefits are included in a separate welfare-economic cost-effectiveness analysis, using basis, minimum and maximum estimates per tonne of emission published in a Danish inter-ministerial report. The estimates are regarded as extremely uncertain (especially the potential damage costs for CO_2) and the analysis should therefore solely be seen as an illustrative example. With respect to the ranking of measures based on their cost-effectiveness the inclusion of monetary values primarily effects the NO_x- and NMVOC reducing initiatives. Building an offshore wind turbine farm will replace de-NO_x unit installations as the least expensive measure reducing Danish NO_x emissions. The offshore wind turbine farm emission reduction option is also the most cost-effective measure for NMVOC emission reduction, although the total emission reduction in this case will be rather small: 10 or 7 tonnes per year respectively, depending on which type of conventional power production will be replaced.

Many emission reduction measures reduce more than one type of emission covered under the UNECE Convention on Long-Range Transboundary Air Pollution. In addition, the measures suggested in this report also contribute to the reduction of non-UNECE emission, i.e. particulates, CO and CO_2. For a consistent comparison of the cost-effectiveness of the different types of emission reduction initiatives it would therefore be useful to include monetary values for these environmental benefits. The valuation is however very uncertain and a sensitivety analysis has been conducted to illustrate this.

Including monetary values for environmental and health effects can have an impact on the final result of the analysis and the ranking of different emission reduction measures. Valuation of non-market goods and services can thus serve as an indication of where other side effects should be taken into consideration, when making policy decision about implementing different measures. However, it is also essential to keep in mind that any valuation attempt due to its inherent uncertainty and lack of ability to cover all non-market effects only provides an incomplete picture of all positive and negative side effects associated with a particular measure.

Table 7 shows a ranking of the different measures according to their benefit-cost ratios. As can be seen, installing desulphurisation unit at large power plants yields the highest benefits per DKK invested. For each DKK invested in the installation society gets about DKK 6.48 worth of benefits, in terms of the monetary value of emissions reduced by these measures. The replacement of conventional vehicles with electrical ones, on the other hand, produces only DKK 0.07 in benefits for each DKK invested.

Table 7. Ranking of measures according to their benefit-cost ratios.

	Costs	**Benefits**	**Benefit/cost**
	MDKK/year		ratio
Desulphurisation unit at large power plant	12.2	79.1	6.48
SCR (de-NO_x) unit installation	82.1	216.4	2.64
Offshore wind farm (replaces natural gas-fired power plant)	61.0	106.6	1.75
Offshore wind turbine farm (replaces coal-fired power plant)	134.1	139.72	1.04
Car-painting workshops: water based paint	94.2	38.1	0.40
EGR-filter installation (< 10 years)	2173.4	405.1	0.19
EGR-filter installation (only new vehicles)	601.7	108.2	0.18
EGR-filter installation (< 5 years)	1451.4	257.9	0.18
Electrical vehicles	688.6	51.1	0.07

Sammenfatning

Introduktion

Formålet med nærværende projekt har været at udvikle danske modeller til fremskrivning af SO_2-, NO_x-, NMVOC- og NH_3-emissionerne til atmosfæren frem til 2010 og at estimere emissionerne i 2010 for de fire stoffer. Emissionsfremskrivningerne dækker følgende økonomiske sektorer: Energi, industri, transport og landbrug.

I Europa reguleres den regionale luftforurening af en række protokoller under FN's konvention om langtransporteret, grænseoverskridende luftforurening (United Nations Economic Commission for Europe Convention on Longe Range Transboundary Air Pollution (CLRTAP)). Formålet med den nye protokol – Gøteborg-protokollen – er at kontrollere og reducere emissionerne af SO_2, NO_x, NMVOC og NH_3. I modsætning til de tidligere protokoller er parterne i protokollen ikke forpligtede til at reducere emissionerne med en bestemt procent i forhold til emissionerne i et basisår. I stedet er der for hvert land fastlagt emissionslofter, bestemt ud fra den viden der findes om kritiske belastninger og miljømæssige påvirkninger indenfor Europas geografiske område. Tabel 1 viser emissionslofterne for Danmark i 2010. De samme emissionslofter er givet i EU-direktivet: Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants.

Tabel 1. Emissionslofter for Danmark i 2010 (tons).

Stoffer	SO_2	NO_x	NMVOC	NH_3*
Emissionslofter	55.000	127.000	85.000	69.000

* NH_3 emissionsloftet er eksklusiv emissioner fra afgrøder og ammoniakbehandlet halm.

Projektets modeller kan bruges til at beregne de forventede emissioner af de fire stoffer i 2010 udfra antagelser om udviklingen indenfor hver af de fire sektorer. Modellerne kan også anvendes til at beregne effekten af forskellige emissionsreduktionsscenarier. Ved at undersøge de mulige reduktionstiltag og de tilhørende budget- og velfærdsøkonomiske omkostninger kan modellen anvendes som et redskab til at finde den mest omkostningseffektive strategi for at nå emissionslofterne.

Emissionerne er fremskrevet på baggrund af et basisscenarium, som inkluderer alle implementerede og planlagte tiltag. Udover basisscenariet er otte ekstra scenarier blevet analyseret for at estimere potentielle emissionsreduktioner og de budget- og velfærdsøkonomiske konsekvenser af hvert scenarium. De 8 emissionsreduktionsscenarier indeholder sandsynlige reduktionstiltag indenfor alle 4 sektorer og bruges til at demonstrere modellens anvendelighed. Resultaterne er sammenfattet i tabel 2. Udfra de givne forudsætninger vil de fremskrevne emissioner for NO_x og NH_3 stadig ligge over emissionslofterne for disse stoffer. Det er ikke muligt kun at vælge de billigste tiltag da alle tiltag har en maksimal emissionsreduktionskapacitet (fx antallet af anlæg hvor det er muligt at installere de-NO_x-anlæg). Resultaterne i tabel 2 indikerer de muligheder der er for at anvende modellen til at finde en reduktionsstrategi, der samtidig er teknisk mulig og mest omkostningseffektiv.

Tabel 2. Emissionsfremskrivningerne i 2010 på baggrund af basisscenariet sammenlignet med emissionslofterne og konsekvenserne af de undersøgte reduktionsscenarier. Omkostningerne er beregnet som velfærdsøkonomiske omkostninger.

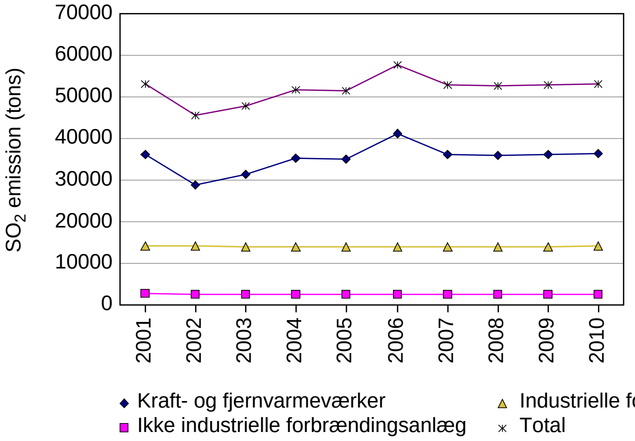
	SO_2	NO_x	NMVOC	NH_3	Omkostninger pr. ton
	1000 tons				Mill. DKK pr. ton
Fremskrevne emissioner 2010	56,05	146,37	83,01	82,78	-
Emissionslofter 2010	55,00	127,00	85,00	69,00	-
Manko	1,05	19,37	-	13,77	-
Emissionsreduktionsscenarierne					
1. Autolakerere: vandbaseret maling	0,00	0,00	0,75	0,00	NMVOC: 0,126
2. Havvindmølleparker (erstatter kulfyrede kraftværker)	0,51	0,23	0,01	0,00	SO_2: 0,264 NO_x: 0,586 NMVOC: 19,157
3. SCR (de-NOx)-anlæg på stort kraftværk	0,00	6,46	0,00	0,00	NO_x: 0,013
4. Afsvovlingsanlæg på stort kraftværk	2,29	0,00	0,00	0,00	SO_2: 0,005
5. Elektriske biler (70.000 i 2010)	0,02	0,05	0,20	0,00	SO_2: 34,428 NO_x: 13,501 NMVOC: 3,460
6. EGR-filter installation (tunge køretøjer < 10 år gamle)	0,00	2,84	0,61	0,00	NO_x: 0,766 NMVOC: 3,456
7. Forøget antal græsningsdage for malkekøer	0,00	0,00	0,00	3,30	NH_3: 0,026
8.Nedfældning af gødning inden for en time efter spredning	0,00	0,00	0,00	1,31	NH_3: 0,029
Reduktion total	2,82	9,58	1,57	4,61	-
Emissioner inklusiv reduktionerne	53,23	136,79	81,44	78,17	

Fremskrivningsmodeller

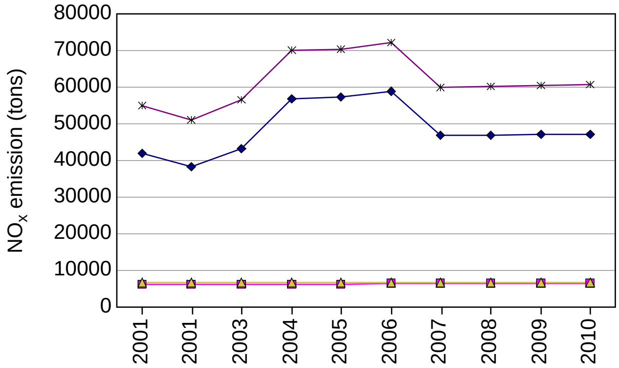
Energi

Fremskrivningen af emissionerne fra stationære forbrændingsanlæg er estimeret ved hjælp af en ny model udviklet i nærværende projekt. Energiforbruget i modellen er baseret på Energistyrelsens fremskrivning af energiforbruget i henhold til opfølgningen på den danske energiplan 'Energi 21'. Emissionsfremskrivningen er baseret på den mængde brændsel som forventes at blive forbrændt på danske værker og er altså ikke korrigeret for international handel med elektricitet. Fra 2004 er der antaget at den danske eksport af elektricitet stiger med ca. 90 PJ således at det totale brændselsforbrug på stationære forbrændingsanlæg stiger til 410 PJ.

For værker større end 25 MWe er brændselsforbruget specificeret tillige med oplysninger om emissionsbegrænsende foranstaltninger, svovlindhold i brændsler, afsvovlingsgrader og emissionsfaktorer. Disse oplysninger er baseret på elværkernes antagelser om de fremtidige forhold for hvert enkelt blok. For anlæg mindre end 25 MWe er emissionsfaktorerne beregnet udfra emissionsgrænseværdier i bekendtgørelser og vejledninger, oplysninger fra elværkerne og andre danske virksomheder. Målinger har vist at NO_x-emissionsfaktorerne



Figur 1. Fremskrivning af SO_2-emissionen for energisektoren.



Figur 2. Fremskrivning af NO_x-emissionen for energisektoren.

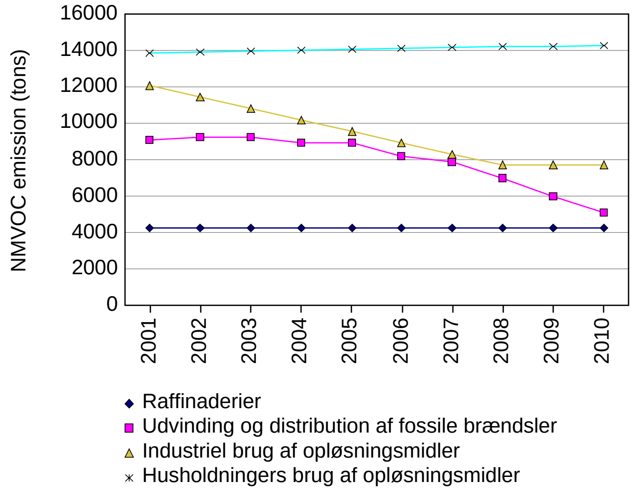
er højere for gasturbiner og stationære gasmotorer end for kedler. Modellen er opbygget så det er muligt at ændre alle vigtige parametre for såvel små som store forbrændingsanlæg.

De vigtigste kilder til SO_2-emissionen er kraft- og fjernvarmeværker efterfulgt af industrielle- og ikke-industrielle forbrændingsanlæg. SO_2-emissionen fra de to sidstnævnte kilder er næsten konstante i hele perioden fra 2001 til 2010. Emissionerne fra kraft- og fjernvarmeproduktionen følger brændselsforbruget for denne sektor, og den øgede eksport fra 2004 resulterer i en stigning i emissionen fra dette år. For NO_x-emissionen er den vigtigste kilde – ligesom for SO_2-emissionen – kraft- og fjernvarmeværker. Fra 2006 ses et brat fald i emissionen, da de-NO_x-anlæg forventes at blive installeret på nogle af de store kraftværksblokke. I modsætning til SO_2- og NO_x-emissionerne er den største kilde til NMVOC-emissionen ikke-industrielle forbrændingsanlæg. Specielt forbrænding af træ i husholdningssektoren bidrager til NMVOC-emissionen. SO_2- og NO_x-emissionerne fra kraftværker større end 25 MWe bidrager med henholdsvis 80% og 60% af de totale emissioner fra kraft- og fjernvarmeværker.

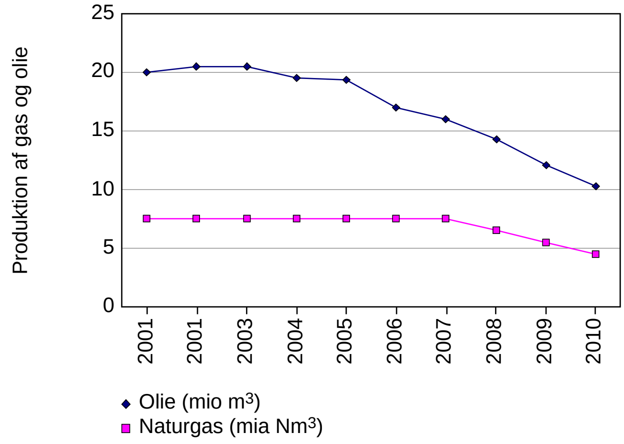
Industri

De fremskrevne emissioner fra industrisektoren omfatter hovedsageligt emissioner fra olie- og gasudvinding og brug af opløsningsmidler. NMVOC er det stof der emitteres i størst mængde og de vigtigste kilder er brug af opløsningsmidler, udvinding af olie og gas samt produktionsprocesser på raffinaderier. Beregning af emissionerne fra olie- og gasindustrien er baseret på Energistyrelsens fremskrivning af olie- og gasproduktionen samt emissionsfaktorer fra den europæiske vejledning til beregning af emissioner (the Joint EMEP/EEA Atmospheric Emission Guidebook). Specielt emissioner fra produktionsprocesserne, emissioner fra lastning af olie til skibe og emissioner fra naturgasnettet bidrager til NMVOC-emissionerne.

Anvendelse af opløsningsmidler i industrien finder i stor udstrækning sted i forbindelse med autoreparationer og vedligeholdelse, i den kemiske industri, ved anvendelse af maling i jern- og



Figur 3. Fremskrivning af NMVOC-emissionen for de vigtigste kilder.



Figur 4. Fremskrivning af olie- og gasproduktionen.

metalindustrien, ved fremstilling af maling, i plastindustrien, i nærings- og nydelsesmiddelindustrien, ved anvendelse af træbeskyttelse og i den grafiske branche. For disse områder aftalte regeringen og de relevante brancher at reducere emission af NMVOC med 40% fra 1988 til 2000. Som en del af aftalen har industribrancherne indsamlet emissionsdata for de forskellige industrier. Modellen til beregning af de industrielle emissioner er baseret på disse data. Der findes ingen fremskrivninger af danske aktivitets- og emissionsdata for industriel brug af opløsningsmidler, og det er derfor antaget at emissionerne vil falde med 57% fra 1990 til 2010 hvilket er den samme reduktion som antaget i et europæisk projekt.

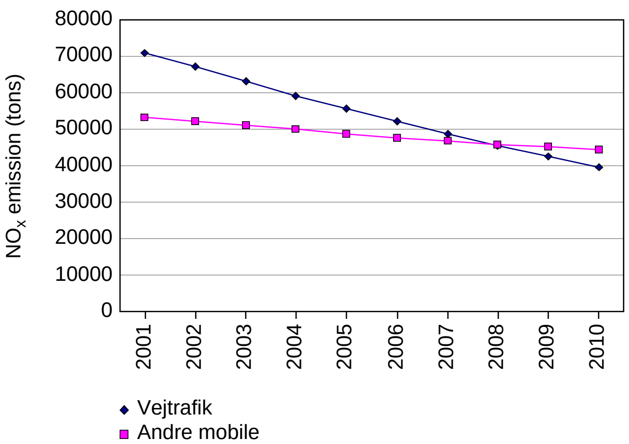
Der findes ingen detaljeret opgørelse over husholdningers brug af opløsningsmidler. Den anbefalede emissionsfaktor fra den europæiske vejledning til beregning af emissioner er derfor anvendt ved emissionsfremskrivningen. Emissionerne er estimerede ved at gange emissionsfaktoren med de fremskrevne befolkningstal.

Transport

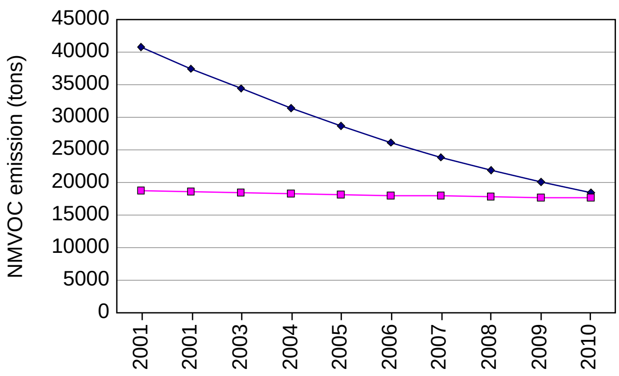
Vejtrafikkens emissioner fra biler hvor motorerne er blevet varme, koldstart og fordampning af brændstof er beregnet med en ny model udviklet i dette projekt. Modellen inkluderer også emissionseffekten af katalysatorslid. Trafik- og bestandsdata er oplyst af Vejdirektoratet og er efterfølgende samlet i grupper med samme gennemsnitlige emissioner og energiforbrug. For hver køretøjsgruppe beregnes emissionerne ved at kombinere antallet af køretøjer og årskørslen med emissionsfaktorer for varme motorer, forholdet mellem emissioner fra kolde og varme motorer og faktorer for fordampning. Konsistensen mellem emissionsprognosen og de historiske emissionsopgørelser opnås ved at bruge baggrundsdata fra den europæiske COPERT III emissionsmodel, der bruges til at opgøre de årlige danske emissioner. På denne måde anvendes COPERT III prognosemodellens emissionsdata såsom basisemissionsfaktorer for varme motorer, reduktionsfaktorer for fremtidige køretøjsteknologier, forværrelsesfaktorer for katalysatorbiler og kold:varm forhold.

En ny model er også udviklet til beregning af emissionerne fra fritidsfartøjer, landbrugsmaskiner, skovbrugsmaskiner, industrikøretøjer samt have- og husholdsredskaber. Ved beregningerne kombineres oplysninger om bestanden af forskellige maskiner og deres respektive motorstørrelser, belastningsfaktorer, årlige driftstimer og emissionsfaktorer. Fremtidige emissionsreduktioner tages i betragtning i modellen ved at inkludere effekten af to EU emissionsdirektiver. For de resterende transportkategorier forventes ingen reelle emissionsreduktioner. Emissionsprognosen for disse beregnes ved at bruge de seneste historiske emissionsfaktorer sammen med Energistyrelsens energifremskrivning.

Personbilernes NO_x- og NMVOC-emissioner er faldet konstant siden 1990, hvor katalysatorkravet blev indført for benzinbiler. De totale emissionsreduktioner er siden blevet forstærket med nye gradvist skrappere emissionskrav for alle køretøjskategorier. Denne udvikling forventes at fortsætte i fremtiden. Den relative emissionsændring fra 2001 til 2010 forventes for NO_x og NMVOC at være større for vejtrafikken end for de øvrige transportsektorer. I perioden falder vejtrafikkens NO_x og NMVOC andele fra hhv. 57 og 68% til hhv. 47 og 51%.



Figur 5. Fremskrivning af NO_x-emissionen for vejtrafik og andre mobile kilder.

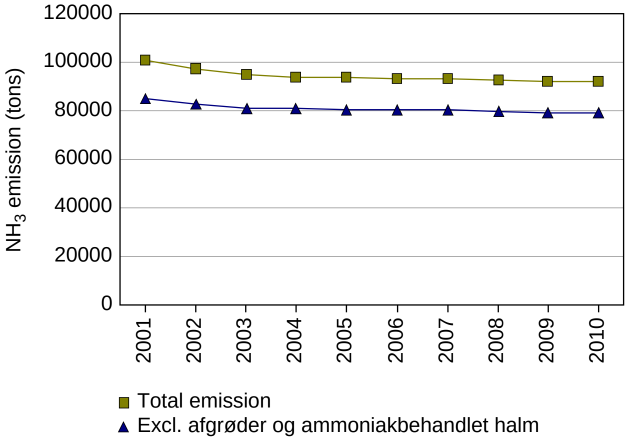


Figur 6. Fremskrivning af NMVOC-emissionen for vejtrafik og andre mobile kilder.

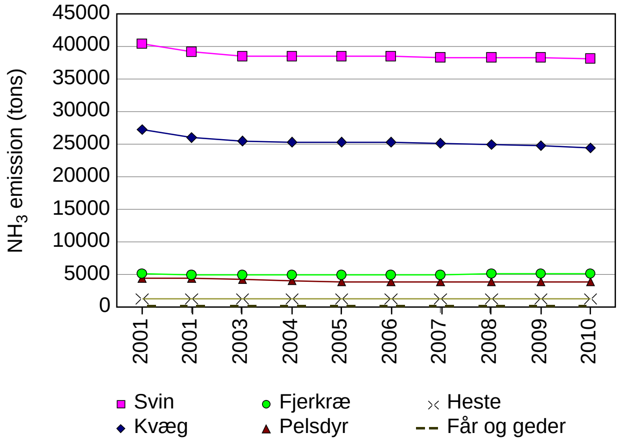
Brugen af katalysatorbiler gør, at NH_3-emissionen stiger markant. Stigningstakten bliver mindre i slutningen af prognoseperioden, hvor næsten alle konventionelle benzinbiler er erstattet med katalysatorbiler. Den allerede lave svovlprocent på 50 ppm for benzin og diesel forventes yderligere nedsat til 10 ppm i 2005. Som en følge heraf vil SO_2-emissionen fra skibe der bruger svær olie udgøre en stigende andel af transportsektorens totale emission.

Landbrug

Ammoniakemissionen fra landbruget stammer hovedsaglig fra fem forskellige kilder: Husdyrgødning, handelsgødning, afgrøder, ammoniakbehandlet halm til foder og spildevandsslam udledt på landbrugsjord. For hver af kilderne er der en række aktiviteter, der har betydning for omfanget af fordampningen så som antal dyr, staldtype, afgrødeareal og mængde spildevandsslam. Den samlede am-



Figur 7. Fremskrivning af ammoniakemissionen for landbruget.



Figur 8. Fremskrivning af ammoniakemissionen for husdyrgødning.

moniakemission opgøres som summen af aktiviteterne multipliceret med emissionsfaktoren for hver aktivitet.

Aktiviteter og emissionsfaktorer er hovedsageligt baseret på oplysninger fra Landbrugets Rådgivningscenter og Dansk Jordbrugsforskning. Derudover er anvendt informationer fra Landbohøjskolen, Plantedirektoratet, Forskningscenteret for Skov- og Landskab og Miljøstyrelsen. Fremskrivningen er fortrinsvis estimeret udfra udviklingstendenserne de seneste ti år. Lovmæssige tiltag som forventes at medvirke til ændringer i den fremtidige landbrugsdrift, er ligeledes inddraget.

I Danmark er der gennemført en række tiltag for at reducere ammoniakemissionen, hvilket er udmøntet i Ammonaikhandlingsplanen og Vandmiljøplan I og II. Det forventes at Ammoniakhandlingsplanen vil blive implementeret i forbindelse med revideringen af husdyrbekendtgørelsen. I fremskrivningen er der således taget højde for 1) forbud mod bredspredning af husdyrgødning 2) reduktion af henliggetiden fra 12 til 6 timer, 3) forbud mod ammoniakbehandling af halm. Den stigende fokusering på miljøhensyn og særlig i forbindelse med udvidelse af husdyrproduktionen betyder, at fremtidige tekniske foranstaltninger vil medvirke til en reduktion af ammoniakfordampningen. Det er dog vanskeligt at vurdere, hvor stor effekten vil være for den samlede emission. Fremskrivningen er derfor baseret på den nuværende teknologi der anvendes i landbruget og inddrager således ikke effekten af mulige fremtidige ammoniakreducerende tekniske foranstaltninger.

På baggrund af fremskrivningen af husdyrproduktionen og de øvrige aktiviteter i landbrugssektoren forventes ammoniakemissionen i år 2010 at udgøre 91.800 tons NH_3. Emissionen eksklusiv emissionen fra afgrøder og ammoniakbehandlet halm udgør 79.100 tons NH_3. Det betyder en forventet reduktion på 10% sammenlignet med år 2000. Den største andel af ammoniak kommer fra håndtering af husdyrgødning – svarende til ca. 80% og omfatter hovedsageligt gødning fra kvæg og svin. Det forventes at emissionen fra husdyrgødning vil falde med 8% på trods af en stigning i produktionen af slagtesvin- og slagtefjerkræ. En af de væsentligste årsager til reduktionen skyldes forventningen om, at der vil ske en ændring i udbringningspraksis. En større del af gyllen vil blive nedfældet og henliggetiden vil blive reduceret betydeligt. Emissionen fra de øvrige kilder forventes ligeledes at blive reduceret i år 2010, hvilket skyldes et fald i det dyrkede areal.

Emissionsfremskrivninger

SO_2

Det danske SO_2 emissionsloft på 55 ktons er næsten nået. Emissionen er på baggrund af basisscenariet estimeret til 56,1 ktons eller kun 1,1 ktons over målet (tabel 3). Den største kilde til SO_2-emissioner er kraft- og fjernvarmeværker og de faktorer der har størst indflydelse på de fremskrevne emissioner er: svovlindholdet i brændslerne, afsvovlingsgraden og mængden af elektricitet der eksporteres. I nærværende fremskrivning er der regnet med forholdsvis høje svovlprocenter og en stor eksport af elektricitet fra 2004.

NO_x

Den fremskrevne NO_x-emission på 146,4 ktons i 2010 er noget højere end emissionsloftet på 127 ktons. De tre største og næste lige store kilder er kraft- og fjernvarmeværker, vejtrafik og andre mobile kilder. En af hovedårsagerne til at det kan blive vanskeligt at nå målet er den store eksport af elektricitet, der er regnet med i Energistyrelsens energifremskrivning.

NMVOC

NMVOC-emissionsfremskrivningen ligge lige under emissionsloftet på 85 ktons. De største kilder til emissionen er vejtrafik, andre mobile kilder, opløsningsmidler, brændeovne og offshore-aktiviteter. De estimerede emissioner er meget usikre. Det gælder specielt for emissionsberegningerne for brug af opløsningsmidler og offshore-aktiviteter og emissionsfremskrivningerne vil kunne ændres en del, hvis der opnås mere viden inden for disse områder.

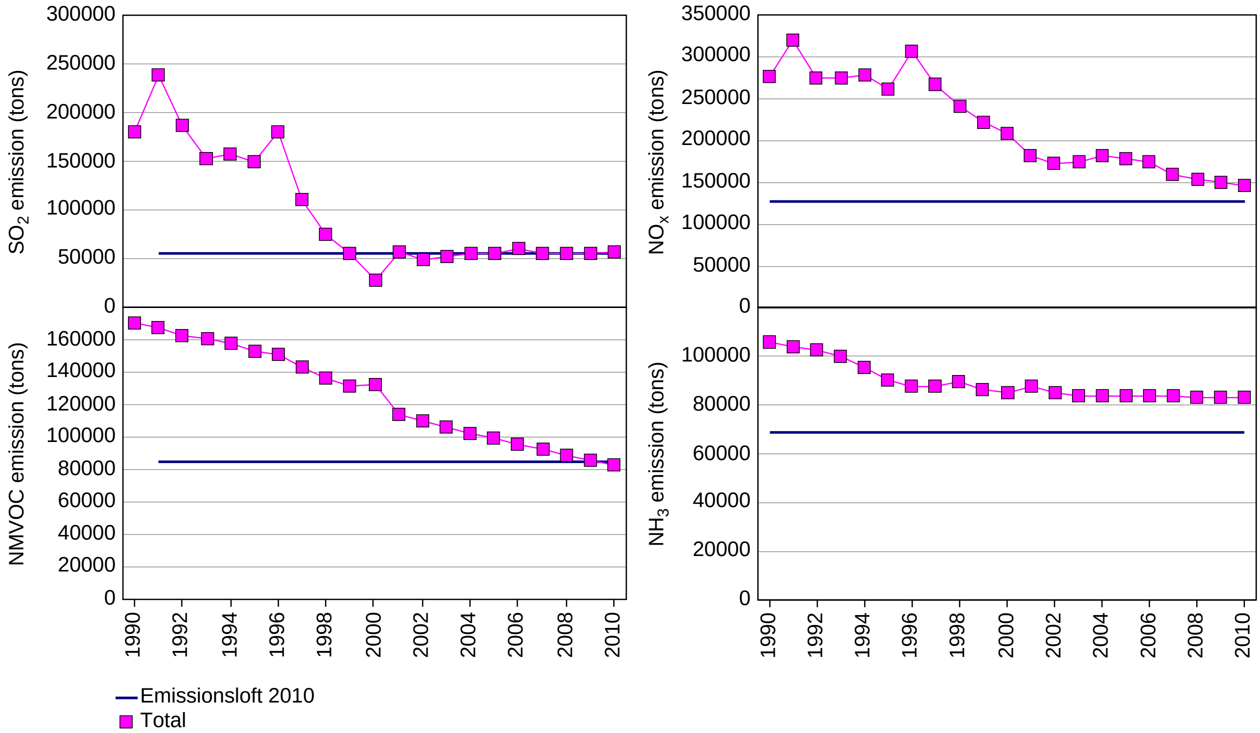
NH_3

De fremskrevne emissioner i 2010 er estimeret til 83 ktons (eksklusiv emission fra afgrøder) og sammenlignet med emissionsloftet på 69 ktons er dette 14 ktons over målet. Næsten hele emissionen stammer fra landbruget og hovedkilden er husdyrgødning. I NH_3-fremskrivningen er der ikke taget højde for fremtidige tekniske tiltag, da det på nuværende tidspunkt ikke har været muligt at beregne de emissionsmæssige konsekvenser af disse.

Tabel 3. Emissionsfremskrivninger på baggrund af basisscenariet.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Emissions-lofter
SO_2 (tons)	56697	48981	51349	55163	54528	60747	55774	55620	55841	56054	55000
NO_x (tons)	181723	172992	173192	181627	177249	174561	158030	153865	150214	146369	127000
NMVOC (tons)	113356	109920	106367	102640	99211	95204	91995	88483	85644	83012	85000
NH_3 (tons)	103108	99650	97763	96956	96732	96622	96361	96091	95776	95427	
$^*NH_3$ (tons)	87812	85060	83877	83776	83640	83618	83446	83264	83037	82777	69000

*Landbrug eksklusiv emissioner fra afgrøder og ammoniakbehandlet halm.



Figur 9. Historiske og fremskrevne emissioner sammenlignet med emissionslofterne for 2010.

Figur 9 viser emissionsudviklingen fra 1990 til 2000 samt de fremskrevne emissioner fra 2001 til 2010. For alle fire stoffer ses en signifikant reduktion af emissioner fra 1990 til 2000.

Emissionsreduktionsscenarier

Emissionsfremskrivningerne af SO_2, NO_x, NMVOC og NH_3 viser at emissionslofterne i visse tilfælde overskrides. Det er derfor interessant at undersøge de mulige emissionsreduktion der kan opnås for udvalgte reduktionsscenarier for de forskellige sektorer i tilgift til de allerede implementerede og planlagte begrænsningstiltag. Kun tekniske tiltag er undersøgt, da det har været uden for dette projekts rammer at opstille scenarier for adfærdsmæssige ændringer som resultat af økonomisk eller politisk regulering eller pga. en stigende miljøbevidsthed i befolkningen. Generelt er reduktionstiltagene udvalgt ud fra hvilke sektorer og aktiviteter der har de største emissionsandele. Otte tiltag er undersøgt for at finde emissionsbesparelsen og de tilknyttede budget- og velfærdsøkonomiske omkostninger.

Tabel 4. Reduktionsscenarier yderligere undersøgt i projektet.

Reduktionsscenarier	Scen. SO_2 (kt/år)	Akkum. SO_2 (kt/år)	Scen. NO_x (kt/år)	Akkum. NO_x (kt/år)	Scen. NMVOC (kt/år)	Akkum. NMVOC (kt/år)	Scen. NH_3 (kt/år)	Akkum. NH_3 (kt/år)
1. Autolakerere: vandbaseret maling	0,00	0,00	0,00	0,00	0,75	0,75	0,00	0,00
2. Havvindmølleparker (erstatter kulfyrede kraftværker)	0,51	0,51	0,23	0,23	0,01	0,76	0,00	0,00
3. SCR (de-NO_x)-anlæg på stort kraftværk	0,00	0,51	6,46	6,69	0,00	0,76	0,00	0,00
4. Afsvovlingsanlæg på stort kraftværk	2,29	2,80	0,00	6,69	0,00	0,76	0,00	0,00
5. Elektriske biler (70.000 in 2010)	0,02	2,82	0,05	6,74	0,20	0,96	0,00	0,00
6. EGR-filter installation (tunge køretøjer < 10 år gamle)	0,00	2,82	2,84	9,58	0,61	1,57	0,00	0,00
7. Forøget antal græsningsdage for malkekøer	0,00	2,82	0,00	9,58	0,00	1,57	3,30	3,30
8. Nedfældning af gødning inden for en time efter spredning	0,00	2,82	0,00	9,58	0,00	1,57	1,31	4,61
2010 emission:								
Basisfremskrivning		56,05		146,37		83,01		82,78
Medregnet yderligere emissionsreduktioner		53,23		136,79		81,44		78,17
ECE mål (emissionslofter)		55,00		127,00		85,00		69,00

For industrisektoren er der set på effekter af at erstatte oliebaseret maling med vandbaseret maling ved autolakering (1). I et scenarie for energisektoren overvejes det at opføre en havvindmøllepark hvis elproduktion kan erstatte elproduktionen på et naturgas- og et kulfyret kraftværk (2). Installation af de-NO_x- og afsvovlingsanlæg på store kraftværker er også undersøgt (3 og 4). For transportsektoren er tre EGR (Exhaust Gas Recirculation) scenarier opstillet: De første to tiltag inkluderer eftermontering af EGR på ældre køretøjer (hhv. mindre end 10 og 5 år gamle) mens det tredje tiltag udelukkende beregner effekten af EGR på nye køretøjer (5). Et andet transporttiltag undersøger effekten af at lade elbiler erstatte a) et årligt nysalg på 10.000 små benzinpersonbiler og b) alle små benzinpersonbiler fra 2004 til 2010 (6). For landbrugssektoren indeholder scenarierne (7) en øgning af antallet af dage på græs for malkekvæg og (8) en ændret gødningspraksis hos landmændene.

Det skal understreges at de udvalgte tiltag ikke giver et komplet billede af mulighederne for emissionsbesparelser i de forskellige sektorer. Scenarierne skal kun ses som mulige tiltag og er altså ikke en komplet liste over tiltag, der er nødvendige for at nå emissionslofterne. I tabel 4 er de otte tiltag og deres mulige emissionsreduktioner vist sammen med emissionslofterne.

SO_2 loftet kan opnås ved at implementere tiltaget med afsvovlingsanlæg på store kraftværker (reduktion: 2,29 ktons). Brug af brændsler med et lavere svovlindhold end forudsat i basisfremskrivningen vil også give lavere emissioner. Med de givne forudsætninger bliver det vanskeligt at overholde emissionsloftet for NO_x. Omkring halvdelen af den overskydende NO_x-emission (19,4 ktons) kan fjernes ved at implementere de otte reduktionstiltag (9,6 ktons). Specielt installation af de-NO_x-anlæg (SCR) på store kraftværker og EGR på tunge køretøjer, der er mindre end 10 år gamle, vil bidrage til at reducere NO_x-emissionen.

Den potentielle NMVOC-emissionsbesparelse for autolakering er omtrent 0,75 ktons. Emissionsbesparelsen for EGR-tiltaget er 0,81, hvilket bringer den totale NMVOC-emission ned på 81,44.

Indførelsen af de to landbrugstiltag kan reducere NH_3-emissioner med 4,6 ktons NH_3 (jvf. tabel 4), men NH_3-emissionen skal reduceres yderligere, hvis emissionsloftet skal overholdes. Det gælder dog, at NH_3-fremskrivningen ikke inkluderer fremtidige teknologiske løsninger i forbindelse med produktionsudvidelse og disse er måske tilstrækkelige til at NH_3-emissionsmålet kan nås. Eksempler på fremtidige teknologiske tiltag er mere effektive fodermetoder og -teknologier, metoder til gylleseparering samt forbedrede staldtypesystemer. På nuværende tidspunkt findes der ingen detaljeret viden om potentialet for emissionsreduktion og omkostningerne forbundet med at indføre disse teknologiske muligheder.

Visse af antagelserne i basisfremskrivningen skal analyseres nærmere før det kan konkluderes om nye miljøreguleringer er nødvendige i de enkelte sektorer. Specielt konsekvenserne af EU-direktivet for store forbrændingsanlæg skal vurderes sammen med de fremtidige teknologiske reduktionsmuligheder for landbruget.

Budget- og velfærdsøkonomisk analyse

De ekstra reduktionstiltag medfører yderligere omkostninger - både for de forskellige sektorer (såsom selskaber, den private forbruger, energiproducerende foretagender osv.) og for samfundet i det hele taget. I dette projekt er disse ekstra omkostninger belyst via en budget- og velfærdsøkonomisk analyse.

Den budgetøkonomiske analyse omfatter de finansielle omkostninger og gevinster set ud fra de enkelte aktørers eller befolkningsgruppers synsvinkler; dvs. staten, den private investor eller forbrugeren. De priser, der bruges er markedspriser, som enten betales på input-markedet i form af produktions- eller forbrugsvarer eller som opnås på markedet for produktsalg, inklusiv alle ikke-refunderbare skatter og subsidier.

I den velfærdsøkonomiske vurdering forsøger man at bestemme velfærdsudviklingen for et lands befolkning ved at beregne omkostninger og gevinster for landet som helhed. Vurderingen er baseret på velfærdsøkonomisk teori og i denne undersøgelse er ”beregningspris-metoden” anvendt. Denne metode bygger på at samfundets resurser er begrænsede og det forhold, at resurser anvendt i én situation medfører alternativomkostninger ved at samfundet mister mulige gevinster ved en anden anvendelse.

Gevinster ved reducerede påvirkninger af miljøet er taget i betragtning i den velfærdsøkonomiske analyse.

Tabel 5. Budgetøkonomiske omkostninger for de ekstra reduktionsscenarier.

Reduktionsoptioner som ikke er inkluderet i reference scenarium	Sektor der primært påvirkes	Investerings-udgifter	Årlige udgifter	SO_2	NO_x	NMVOC	NH_3-N
		MDKK	MDKK/år	1000 DKK/ton			
1. Autolakerere: vandbaseret maling	Industri	123,5	78,5			104,7	
2. Havvindmølleparker (erstattes af kul-drevne kraftværker)	Energi	1599,0	96,0	189,0	420,0	13700,0	
3. SCR (de-NO_x)-anlæg på stort kraftværk	Energi	350,0	62,7		9,7		
4. Afsvovlingsanlæg på stort kraftværk	Energi	60,0	9,2	4,0			
5. Elektriske biler (70.000 i 2010)	Husstand	3511,1	-266,3	-13300,0	-5200,0	-1300,0	
6. EGR-filter installation (tunge køretøjer < 10 år gamle)	Transport	8350,0	1619,9		570,0	2640,0	
7. Forøget antal græsningsdage for malkekøer	Landbrug	176,7	98,1				22,9
8. Nedfældning af gødning indenfor en time efter spredning	Landbrug	0,0	33,1				30,7

Budgetøkonomiske analyse

Den budgetøkonomiske analyse omfatter investeringsomkostninger/udgifter samt de årlige udgifter for de sektorer, der primært berøres af hvert reduktionstiltag. Det har ikke været muligt at beregne de fordelingsmæssige påvirkninger på resten af samfundet, som kunne opstå fx hvis energisektoren påførte forbrugeren ekstra udgifter.

Resultaterne af de budgetøkonomiske beregninger (tabel 5) viser, at skift fra benzindrevne biler til elektriske biler er det billigste alternativ, både med hensyn til reduktion af SO_2,-, NO_x- og NMVOC-emissioner, idet den årlige ekstraudgift er lavere end den sparede udgift til benzin. Det er dog kun for forbrugeren, at dette alternativ er billigst - for samfundet som helhed er det det dyreste alternativ (se tabel 6). Afsvovlings- og de-NO_x-alternativerne har relativt lave omkostninger, men da næsten alle store kraftværker allerede enten har, eller har planer om, at installere SO_2- og NO_x-reducerende teknologi, vil indvirkningen fra disse alternativer være begrænset. Hvad angår den relativt billige mulighed for at reducere NMVOC i de bilværksteder, hvor maling af biler foregår, kunne der også være stort potentiale i andre industrielle foretagender der bruger opløsningsmidler og maling. Forøgelse af græsningsdage for malkekøer er en smule billigere end hurtigere nedfældning af gødning.

Velfærdsøkonomisk analyse

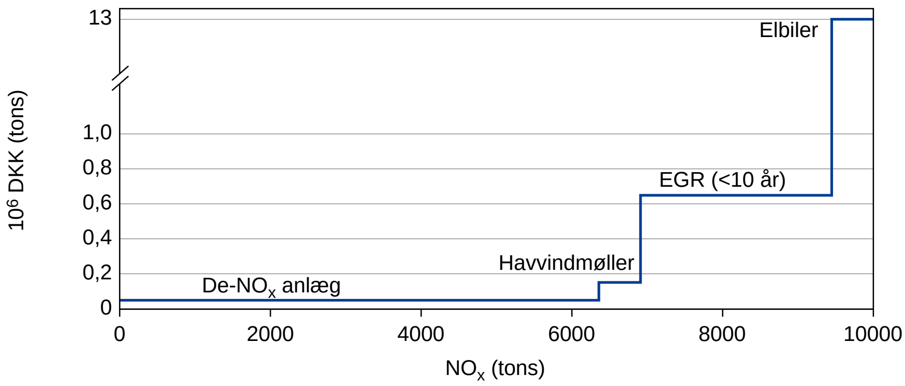
Under ideelle omstændigheder ville en velfærdsøkonomisk analyse omfatte en monetær vurdering af forskellige (positive eller negative) virkninger på miljø og sundhed, samt andre ikke-markedsrelaterede virkninger som ville kunne opstå ved at gennemføre et givent tiltag. Da en monetær værdisætning for disse ikke-markedsrelaterede virkninger er behæftet med stor usikkerhed bliver vurderingen af dem som regel begrænset til fysiske enheder som fx tons af emissioner reduceret . I den centrale del af alle analyserne i denne rapport er der derfor for hvert projekt samt hver type af reduktionstiltag udregnet den velfærdsøkonomiske omkostningseffektivitet udtrykt i omkostning per ton. Tabel 6 viser en rangordning af scenarierne, baseret på deres omkostningseffektivitet i forhold til de forskellige udslip.

Tabel 6. Forskellige reduktionsscenariers bidrag til emissionsreduktioner i 2010 listet på grundlag af omkostning per ton reduktion (velfærdsøkonomiske priser).

Rangering	SO_2-udslip		
		MDKK/ton	Antal 2010 (ton)
1.	4. Afsvovlingsanlæg på stort kraftværk	0,005	2292
2.	2. Havvindmølleparker (erstatter kulfyrede kraftværker)	0,264	508
3.	5. Elektriske biler (70.000 i 2010)	34,428	20
	NO_x-udslip		
		MDKK/ton	Antal 2010 (ton)
1.	3. SCR(de-NO_x)-anlæg på stort kraftværk	0,013	6460
2.a	2. Havvindmøllepark (erstatter naturgasfyret kraftværk)	0,259	236
2.b	2. Havvindmøllepark (erstatter kulfyret kraftværk)	0,586	229
3.a	6. EGR-filter installation (tunge køretøjer< 10 år gamle)	0,766	2838
3.b	6. EGR-filter installation (tunge køretøjer < 5 år)	0,785	1850
3.c	6. EGR-filter installation (tunge køretøjer; kun nye)	0,870	692
4.	5. Elektriske biler (70.000 i 2010)	13,501	51
	NMVOC udslip		
		MDKK/ton	Antal 2010 (ton)
1.	1. Autolakerere: vandbaseret maling	0,126	750
2.a	6. EGR-filter installation (tunge køretøjer; kun nye)	2,646	227
2.b	6. EGR-filter installation (tunge køretøjer < 5 år.)	3,205	453
3.	5. Elektriske biler (70.000 i 2010)	3,460	199
	6. EGR-filter installation (tunge køretøjer< 10 år gamle)	3,546	613
4.a	2. Havvindmøllepark (erstatter naturgasfyret kraftværk)	6,103	10
4.b	2. Havvindmøllepark (erstatter kulfyret kraftværk)	19,157	7
	NH_3 udslip		
		MDKK/ton	Antal 2010 (ton)
1.	7. Forøget antal græsningsdage for malkekøer	0,026	3299
2.	8. Nedfældning af gødning indenfor 1 time efter udbringning	0,029	1309

De to havvindmølleparkscenarier samt de tre scenarier, beregnet for EGR-filter installationer udelukker gensidigt hinanden.

På grundlag af vurderingen af omkostningseffektivitet (opsummeret i tabel 6) kan der konstrueres marginale omkostningskurver for emissionsreduktioner for henholdsvis SO_2, NO_x, NMVOC og NH_3. Som eksempel vises den marginale omkostningsfunktion for reduktion af NO_x udslip i figur 10. De samlede udgifter ved at implementere de nuværende muligheder kan beregnes som området under den marginale udgiftsfunktion. Den marginale udgiftsfunktion kan dermed fungere som inspirationskilde til opnåelse af bestemte emissionsreduktioner på den mest omkostningseffektive måde.



Figur 10. Den marginale omkostningsfunktion for fremtidige reduktioner af NO_x-emissioner.

De velfærdsøkonomiske beregninger er baseret på en kalkulationsrente på 3 %, som anvendes ved beregning af nutidsværdi og investeringskalkuler. Ændres diskonteringsfaktoren til 6 %, ville den årlige omkostning reduceres for de forskellige scenarier, men det har ikke betydning for de enkelte tiltags indbyrdes rangordning. Omkostningsreduktionen pr. ton for reduceret udslip svinger fra 1,9 % til 32 % og er højest for de alternativer, som kræver ekstremt dyre kapitalinvesteringer (fx oprettelsen af havvindmølleparker) eller investeringer over en længere tidsperiode, fx overgangen fra benzindrevne til elektriske biler i perioden 2004-2010. Besparelsen pr. ton reduceret udslip er kun moderat for de alternativer der kræver forholdsvis små investeringer (fx udstyr til indhegning til forøget græsgang) eller hvor beskedne investeringsomkostninger resulterer i store emissionsbesparelser, fx installeringen af de-NO_x- og afsvovlingsanlæg på store kraftværker.

De reduktionsscenarier der er nævnt i denne rapport bidrager også til begrænsningen af andre udslipskomponenter såsom partikler**,** CO_2 og CH_4. Disse afledte miljøgevinster er inkluderet i en separat velfærdsøkonomisk omkostningseffektivitetsanalyse, der benytter sig af hhv. basis, minimum og maksimum værdier pr. ton udslip. Denne analyse blev publiceret i en dansk inter-ministeriel rapport. Beregningerne anses som meget usikre, især de potentielle skadeomkostninger for CO_2. Analysen skal derfor udelukkende betragtes som et illustrativt eksempel. I henhold til rangordningen af de forskellige alternativer påvirker den monetære prissættelse særligt de-NO_x- og NMVOC-reducerende initiativer. Etableringen af en havvindmøllepark vil erstatte installering af de-NO_x-enhederne som det billigste alternativ til at reducere det danske NO_x-udslip. Bygning af en havvindmøllepark er også det mest prisbesparende alternativ i forhold til reduktionen af NMVOC udslippet, på trods af, at den samlede emissionsreduktion er ret begrænset: 10 eller 7 tons pr. år, afhængig af hvilken type konventionel elproduktion der erstattes.

Mange af tiltagene reducerer mere end ét stof og som tidligere nævnt bidrager tiltagene også til reduktion af partikler, CO og CO_2. For en konsistent sammenligning af omkostningseffektiviteten for de forskellige tiltag, vil det være væsentligt at indregne disse miljøgevinster i den velfærdsøkonomiske analyse. Vurderingen er dog meget usikker og en følsomhedsanalyse er blevet gennemført for at illustrere dette. At medtage monetære værdier for miljø– og helbredsmæssige påvirkninger kan have en effekt både på det endelige resultat af analysen og på prioriteringen af forskellige emissionsreduktionsscenarier. Vurderingen af ikke-markedsbaserede goder og service kan ydermere fungere som indikator for hvilke andre side-effekter der skal tages hensyn til, når man træffer en politisk beslutning for implementeringen af de forskellige alternativer. Det er imidlertid meget vigtigt at holde sig for øje at enhver prissætning, grundet dens indbyggede usikkerhed og mangel på evne til at dække alle ikke-markedsbaserede effekter**,** ikke giver et fuldt dækkende billede af alle de positive og negative påvirkninger, der er forbundet med et givent tiltag. Men det bidrager til at strukturere beskrivelsen af de enkelte tiltags effekter, hvilket i sig selv er et væsentlig formål.

Tabel 7 viser en opgørelse over de forskellige tiltags benefit-cost-forhold. Som det fremgår er det mest omkostningseffektive alternativ installationen af afsvovlingsanlæg på større kraftværker. For hver DKK som bliver investeret i installeringen af disse anlæg er den velfærdsøkonomiske gevinst ca. DKK 6. Denne gevinst kan ses i modsætning til udskiftningen af konventionelle biler med elektriske biler, hvor gevinsten kun er DKK 0,07 for hver investeret DKK.

Tabel 7. Rangering af alternativer i forhold til deres respektive omkostningseffektivitet.

	Omkostning	**Gevinst**	**Gevinst/omkostning**
	MDKK/år		forhold
Afsvovlingsanlæg på stort kraftværk	12,2	79,1	6,48
SCR (de-NO_x)-anlæg på stort kraftværk	82,1	216,4	2,64
Havvindmølleparker (erstatter naturgasfyrede kraftværker)	61,0	106,6	1,75
Havvindmølleparker (erstatter kulfyrede kraftværker)	134,1	139,72	1,04
Autolakerere: vandbaseret maling	94,2	38,1	0,40
EGR-filter installering (tunge køretøjer < 10 år gamle)	2173,4	405,1	0,19
EGR-filter installering (kun nye køretøjer)	601,7	108,2	0,18
EGR-filter installering (< 5 år)	1451,4	257,9	0,18
Elektriske biler (70.000 i 2010)	688,6	51,1	0,07

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1 Introduction

The objective of the present project is to develop Danish models for projection of SO_2-, NO_x-, NMVOC- and NH_3-emissions until 2010. The emissions are projected from a basis scenario including all implemented and planned measures. In addition to the already implemented and planned measures a number of measures from different sectors are analysed in order to estimate the potential emission reductions and the financial and welfare economic consequences of the different measures.

1.1 Obligations

The 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 new protocol – the Gothenburg Protocol – is to control and reduce the emissions of SO_2, NO_x, NMCOV and NH_3 resulting in reducing exceedence of the critical loads of acidification, eutrophication and the effect of photochemical air pollution (ozone). In contrast to the former protocols the individual countries are not obliged to achieve a certain reduction target, but from the knowledge of critical loads and effects on the ecosystems within the geographic area of Europe emission ceilings have been set in order to reduce the exceedence of the critical loads. Emission ceilings for Denmark in 2010 according to the Gothenburg Protocol are shown in Table 1.1.1.

Table 1.1.1. Emission ceilings for Denmark in 2010 (tonnes).

Pollutants	SO_2	NO_x	NMVOC	NH_3*
Emission ceilings	55000	127000	85000	69000

* The NH_3 emission ceiling is excluding emissions from straw treatment and crops.

These emission ceilings 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 protocol and the directive Denmark is obliged to report annual emissions of SO_2, NO_x, NMVOC and NH_3 and data on projected emissions and current reduction plans. The expected development in the emissions until 2010 can be illustrated using the projection models developed in the present project and based on the projected emissions it will be possible to decide whether it is necessary to implement further regulation of the emissions of the individual sectors emissions.

1.2 Environmental problems

The emissions of SO_2, NO_x, NMVOC and NH_3 are especially related to regional environmental problems and may cause acidification, eutrophication or photochemical smog.

Acidification

Acid deposition of sulphur and nitrogen compounds mainly derives from emissions of SO_2, NO_x and NH_3. The effects of acidification show up in a number of ways, including defoliation and reduced vitality of trees, 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^-) in either the atmosphere or after deposition resulting in the formation of two and one H^+-ion, respectively. NH_3 may react with H^+ to form ammonium (NH_4^+) and by nitrification in soil NH_4^+ is oxidised to NO_3^- and two H^+-ions are formed (Wark and Warner, 1981).

The total emissions in terms of acid equivalents can be calculated by means of equation 1.2.1. Figure 1.2.1 shows the distribution of emissions of SO_2, NO_x and NH_3 for 2000 in terms of acid equivalents.

$$Total\ acid\ equivalents = \frac{m_{SO_2}}{M_{SO_2}} \cdot 2 + \frac{m_{NO_x}}{M_{NO_x}} + \frac{m_{NH_3}}{M_{NH_3}} \qquad (1.2.1)$$

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

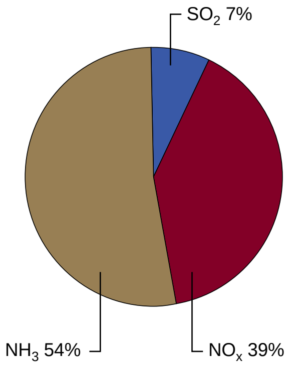


Figure 1.2.1. Distribution of emissions of sulphur and nitrogen compounds for 2000 expressed in terms of acid equivalents (Illerup et al., 2002).

The figure illustrates that the most important acidification factor in Denmark today is ammonia nitrogen. However, over longer distances SO_2 and NO_x are still the most important acidifying gases.

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 area where the soil minerals easily weather or have a high chalk content, acid deposition will be relatively easily neutralised (Holten-Andersen, 1997).

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).

An increased complexity of atmospheric reaction is brought about by the presence of hydrocarbons. 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 is, as acidification, a so-called transboundary air pollution. That means that ozone is spread across national borders in Europe. In pure air ozone has a life span of several weeks and can therefore mix into the air and spread over virtually the whole of the Northern Hemisphere before it is chemically degraded or physically removed.

Harmful effects are seen both on vegetation and man. 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 man, ozone is a respiratory tract and eye irritant. The street level in Danish towns rarely exceeds the critical concentration suggested by the World Health Organisation (Holten-Andersen et al., 1998).

Eutrophication

Eutrophication means the effect of 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 the 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 largest effect of atmospheric deposition of nitrogen compounds is seen on ecosystems vulnerable to nitrogen loading. Examples of such systems are heath bogs and dry grasslands.

Exceedence of the critical load for eutrophication has resulted in an altered composition of animal and plant species in these areas and in decreasing numbers of species.

1.3 Historical emission data

Distribution of the emissions on main sectors is shown for SO_2, NO_x, NMVOC and NH_3. The figures are based on the emissions reported to UNECE for 2000 (Illerup et al., 2002).

Table 1.3.1. Danish emissions, 2000.

		SO_2	NO_x	NMVOC	NH_3
SNAP code		tonne	tonne	tonne	tonne
1	Combustion in energy and transformation industry	12971	48839	5587	0
2	Non-industrial combustion plants	3067	7482	12359	0
3	Combustion in manufacturing industry	7271	15033	828	0
4	Production processes	981	413	5449	0
5	Extraction and distribution of fossil fuels	1	0	4782	0
6	Solvent and other product use	0	0	38007	0
7	Road transport	550	74513	41912	2274
8	Other mobile sources and machinery (**)	2611	58356	21003	7
9	Waste treatment and disposal	54	3122	877	0
10	Agriculture*	0	0	1194	101341
11	Other sources and sinks	0	0	14095	0
	TOTAL	27504	207757	146094	103621

* Excl. horses at riding schools and goats.

SO_2

The main part of the SO_2 emissions originate from the combustion of fossil fuels – mainly coal and oil – on public power plants and district heating plants. However, the emissions from this sector have decreased by 94% from 1980 to 2000 due to the increased use of low-sulphur fuels and installation of desulphurization plants. This means that combustion in manufacturing industry and non-industrial combustion plants have become an important source to the SO_2 emission. National sea traffic contributes with about 70% of the SO_2 emission from other mobile sources.

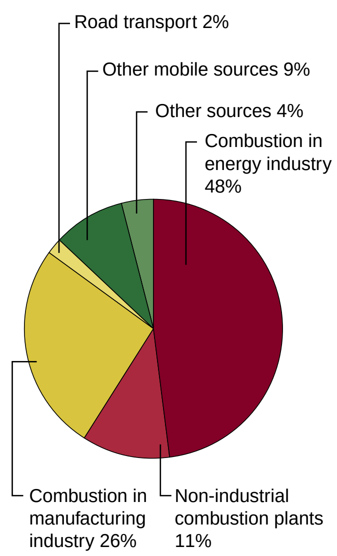


Figure 1.3.1. SO_2 emissions distributed on sectors, 2000.

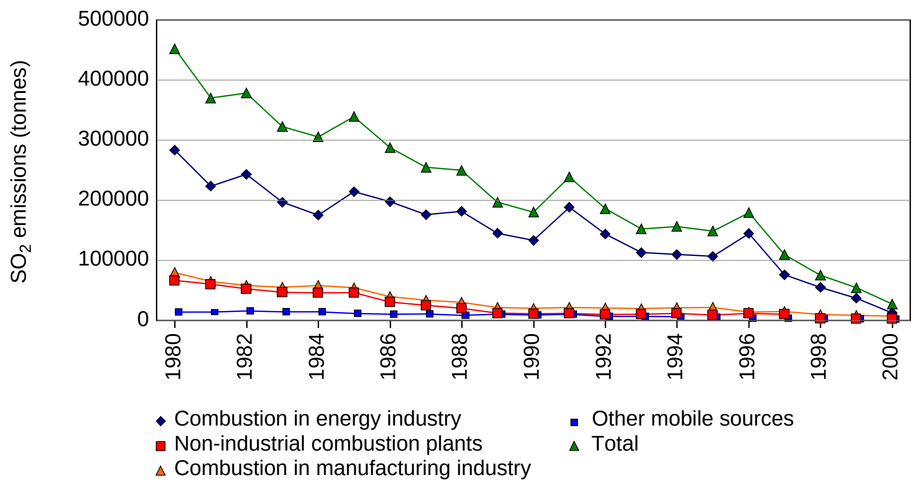


Figure 1.3.2. SO_2 emission trends.

NO_x

The transport sector is the sector contributing most to the emission of NO_x and in 2000 63% of the Danish emissions of NO_x stemmed from road transport and other mobile sources. Another large source is public power plants, which however have decreased their emissions by 32% from 1985 to 2000. The total NO_x emission has decreased by 62%.

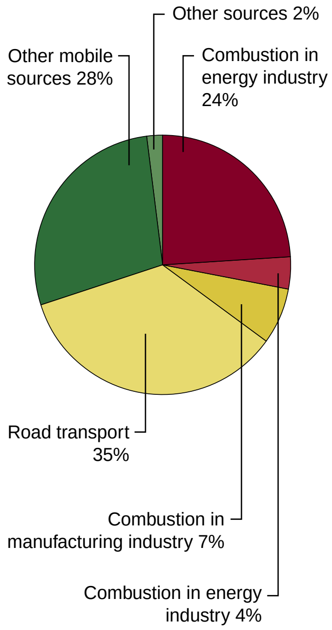


Figure 1.3.3. NO_x emissions distributed on main sectors, 2000.

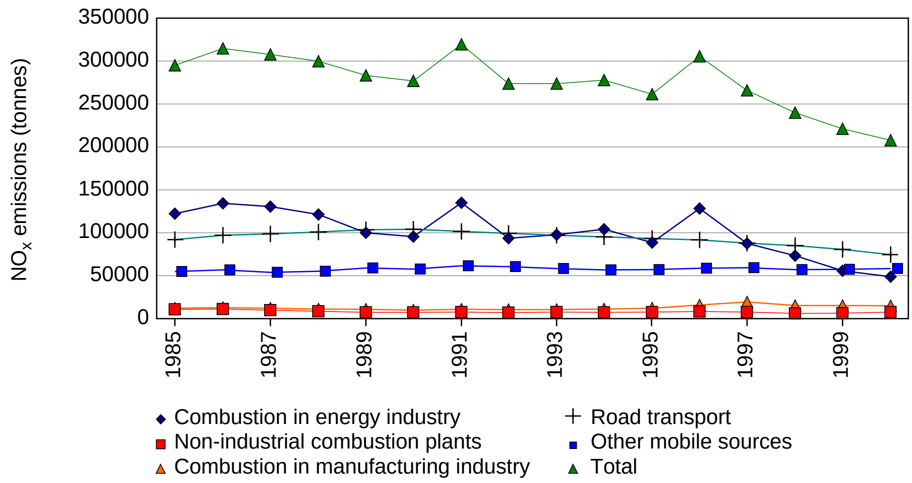


Figure 1.3.4. NO_x emission trends.

NMVOC

The emissions of NMVOC originate from many different sources – both anthropogenic and natural – and can be divided into two main types: Incomplete combustion and evaporation. The main sources of NMVOC emissions from incomplete combustion processes are road vehicles and other mobile sources such as sea vessels and off-road machinery. Road transportation vehicles are still main contributors even though the emissions have declined since the introduction of catalyst cars in 1990. The evaporative emissions mainly originate from forestry and the use of solvent. The total anthropogenic emissions have decreased by 33% from 1985 to 2000.

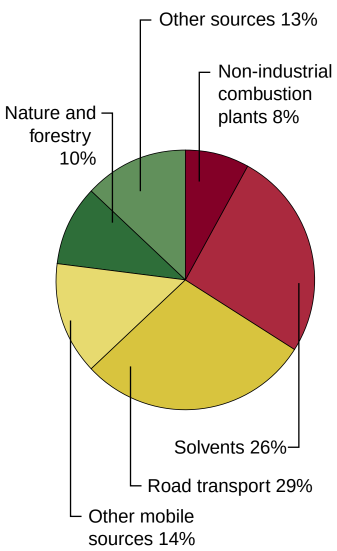


Figure 1.3.5. NMVOC emissions distributed on main sectors, 2000.

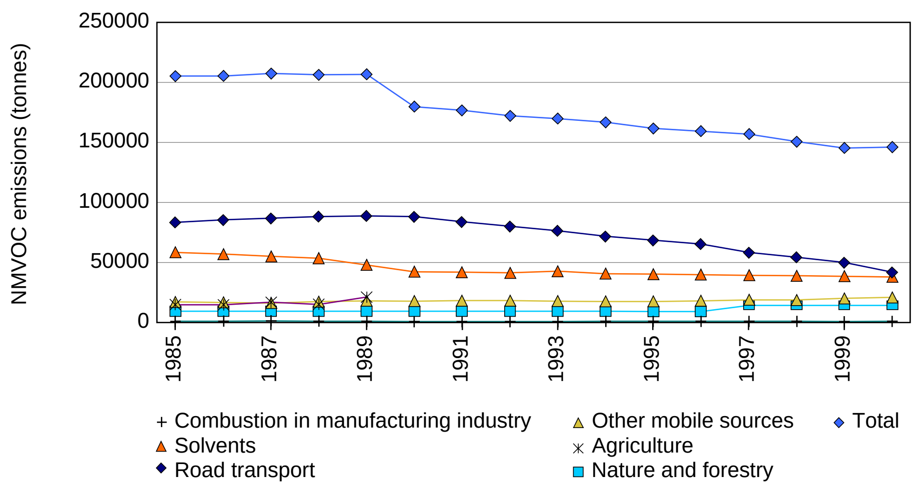


Figure 1.3.6. NMVOC emission trends.

NH_3

Almost all atmospheric-emissions of NH_3 result from agricultural activities. Only a minor part originates from road traffic. This part however is increasing due to increasing use of catalyst cars. The main part of the emission from agriculture comes from manure (78%). Other contributions come from use of chemical fertilisers (7%), crops (13%) and ammonia used for straw treatment (2%). Despite increasing animal production the ammonia emission has decreased by 25 % from 1985 to 2000 due to increase fodder efficacy and change in manure handling.

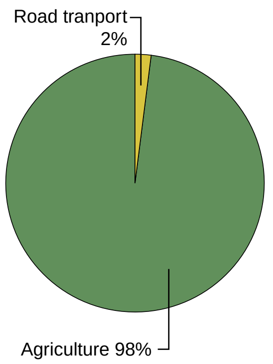


Figure 1.3.7. NH_3 emissions distributed on main sectors, 2000.

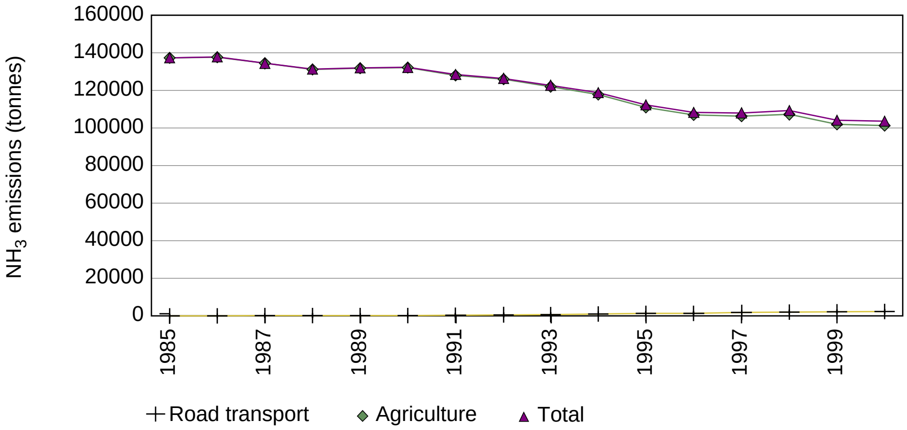


Figure 1.3.8. NH_3 emission trends.

2 Projection of emissions

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

$$E = \sum_{s} A_s(t) \cdot \overline{EF}_s(t) \qquad (2.1)$$

where A_s is the activity for sector s for the year t and $EF_s(t)$ is 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 on an appropriate level on 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 2.2.

$$\overline{EF}_s(t) = \sum_{k} P_{s,k}(t) \cdot EF_{s,k}(t) \qquad (2.2)$$

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

Official Danish forecast of activity rates is used in the models for those sectors from which the forecasts are available. For other sectors projected activity rates are estimated in co-operation with relevant research institutes and other organisations. The emission factors are based on recommendations from the Joint EMEP/CORINAIR Guidebook (Richardson, 1999) and data from measurements on Danish plants. The influence of legislation and ministerial orders on the development of the emission factors has been estimated and included in the models.

The projection models are based on the same structure and method as the Danish emission inventories in order to ensure consistency. In Denmark the emissions are estimated according to the CORINAIR method (Richardson, 1999) and the SNAP (Selected Nomenclature for Air Pollution) sector categorisation and nomenclature is used. The detailed level makes it possible to aggregate to both the UNECE/EMEP nomenclature (NFR) and IPCC nomenclature (CRF).

2.1 Combustion in stationary plants

2.1.1 Sources

Combustion of fossil fuels and biomass is one of the main sources to emissions of SO_2, NO_x and NMVOC. This chapter includes all sectors combusting fuel for energy production except the transport sector. The main sectors are energy, industry, residential, service and agriculture. The corresponding SNAP-codes are:

0101 Public power
0102 District heating plants
0103 Petroleum refining plants
0105 Oil / gas extraction

0201 Commercial and institutional plants
0202 Residential plants
0203 Plants in agriculture, forestry and aquaculture

03 Combustion in industrial plants

In Denmark almost all waste is combusted at power and district heating plants and the emissions from waste incineration is therefore included in SNAP-code 0101 or 0102.

Emissions from flaring in oil refinery (090203) and flaring in gas and oil extraction (090206) are estimated in Chapter 2.2 on Industry.

As seen in Figures 1.1.2 and 1.1.3 in Chapter 1 the sector contributing most to the emissions of SO_2 and NO_x is the energy sector. Emissions of NMVOC from combustion in stationary plants are mainly due to incomplete combustion of fuels in the non-industrial sector.

2.1.2 Activity data

The fuel consumption from 2001 to 2010 is based on the energy projection carried out by the Danish Energy Agency according to the follow up on the Danish energy plan 'Energy 21'. The energy projection in this project is based on the amount of fuel expected to be combusted on Danish plants and the emissions are therefore not corrected for electricity trade with other countries.

When estimating SO_2 and NO_x from the energy sector the large combustion plants are especially of interest. The fuel consumption from each plants larger than 25 MWe is therefore specified along with information on abatement technology, sulphur content in the fuel, degree of desuphurisation and emission factors. Table 2.1.1 shows the different types of fuel used in the emission projection.

Table 2.1.1. Fuel types.

Fuel code	Fuel
102	Coal
110	Pet. coke
225	Orimulsion
114	Waste
117	Straw
111	Wood
203	Fuel oil
205	Gas oil
206	Kerosene
301	Natural gas
309	Biogas
303	LPG

All the large combustion plants are placed in SNAP 0101. Figure 2.1.1 and 2.1.2 show the fuel consumption for SNAP groups 01, 02 and 03 and the fuel consumption separate for the large combustion plants as a function of time.

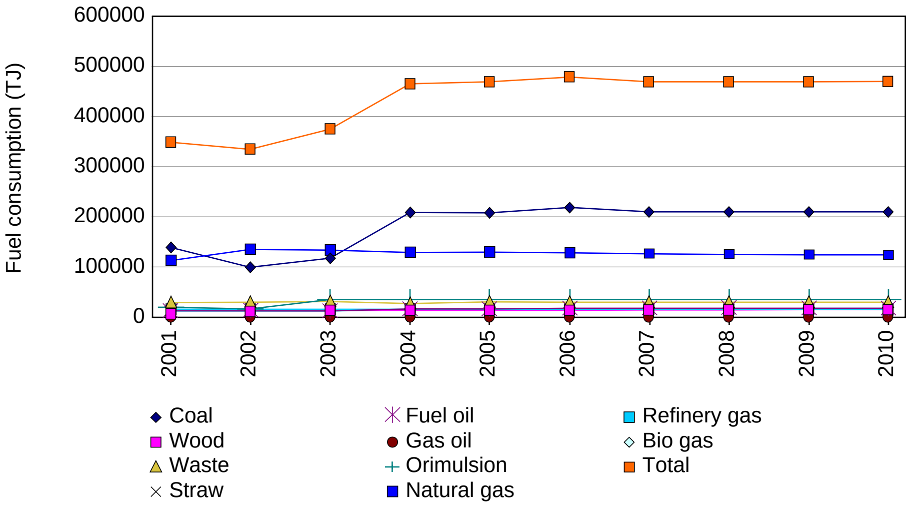


Figure 2.1.1. Fuel consumption for SNAP 01, 02 and 03.

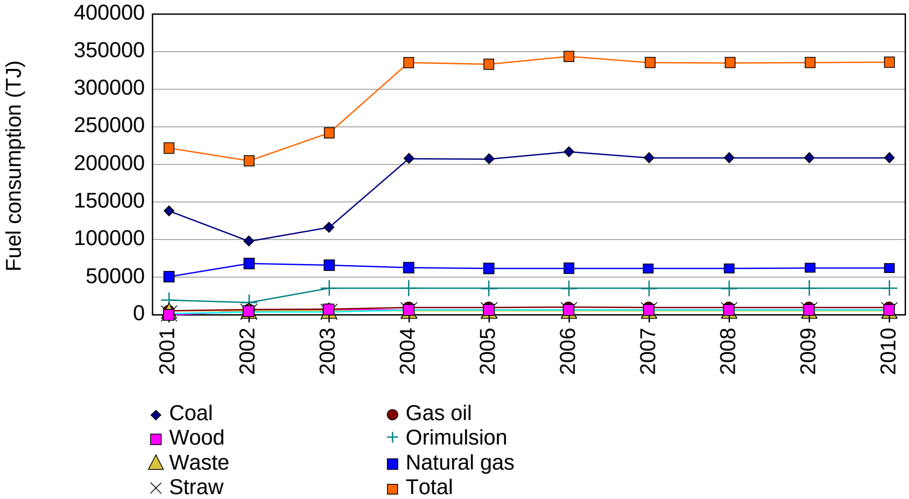


Figure 2.1.2. Fuel consumption for the large combustion plants bigger than 25 MWe.

The figures illustrate that the consumption of coal and orimulsion increases substantially from 2002 to 2004. This increase is due to an expected large export of electricity from 2004 when the export is about 100 PJ. Figure 2.1.2 illustrates that this fuel is expected to be combusted on large combustion plants. From 2004 to 2010 the fuel consumption is more or less expected to be constant.

2.1.3 Emission factors

SO₂

The emission factors for SO_2 are calculated from the sulphur content in the fuel as given in equation 2.1.1.

$$EF_{SO_2} = 2 \cdot \frac{[S_{fuel}\%]}{HV} \cdot \left(1 - \frac{[S_{ash}\%]}{100}\right) \cdot \left(1 - \frac{[S_{desulph}\%]}{100}\right) \cdot 10^4 \quad (2.1.1)$$

Where EF_{SO2} is the SO_2 emission factor (g/GJ), S_{fuel} is the sulphur content in the fuel, S_{ash} is the sulphur retention in ash, $S_{desulph}$ is the sulphur retention in desulphurisation plants and HV is the lower heating value of the fuels (GJ/tonne).

The emission factors for the large combustion plants are based on the assumptions given in information from the Danish power stations (Elkraft/Eltra, 2001) concerning sulphur content in the fuel, sulphur retention in the ash and degree of desulphurisation. The emission factor for the plants smaller than 25 MWe are estimated from permit limit values for sulphur content in fuels given in Danish legislation and from information from the Danish power stations and other Danish companies.

The sulphur content in the fuels combusted in large combustion plants and smaller plants are given in Tables 2.1.2 and 2.1.3.

Table 2.1.2. Sulphur content in fuels. Combustion plants smaller than 25 MWe.

Fuel	Sulphur %
Coal	0,9
Pet. coke	1
Waste	0,24
Straw	0,15
Wood	0,1
Fuel oil	0,7
Gas oil	0,05
Kerosene	0,01
Natural gas	0,00074
Biogas	0,00074
LPG	0

Table 2.1.3 Sulphur content in fuels. Combustion plants larger than 25 Mwe.

Fuel	Sulphur %
Coal	0,75-2.5
Pet. coke	1
Orimulsion	2,7
Waste	0,24
Straw	0,15
Wood	0,1
Fuel oil	1
Gas oil	0,2
Kerosene	0,01
Natural gas	0,00074
Biogas	0,00074
LPG	0

Coal with low sulphur content is assumed to be used on plants without desulphurisation units.

Table 2.1.4. Degree of desulphurisation for different technologies.

Technology	Removal (%)
Wet	95-97
Semi dry	96.5-97
SNOX	95

NO_x

The NO_x emission factors for large combustion plants depend on the fuel, the size of the plant, the burner design and whether the plants are equipped with $deNO_x$ devices or not. The emission factors for the large combustion plants are given by the Danish power stations (Elkraft/Eltra). For the smaller plants the emission factors are based on permit limit values given in Danish legislation and information on Danish combustion plants. Measurements on gas turbines and stationary gas engines have shown that the emission factor for NO_x is significantly higher for these technologies than for boilers (Table 2.1.5).

Table 2.1.5. NO_x emission factors for different technologies (g/GJ).

	Gas oil	Natural gas	Biogas
Boilers	52/65	30	31
Gas turbines	350	174	-
Gas engines	700	193	605

Since the projection of fuel consumption does not contain a distribution on different technologies, the ratio between the fuels combusted in boilers, gas turbines and gas engines in 2000 is used to estimate an aggregated emission factor for the various sectors for 2001 to 2010 (Table 2.1.6). The aggregated emission factor for a given pollutant is calculated using equation 2.1.2.

$$\overline{EF}_s(t) = \sum_k P_{s,k}(t) \cdot EF_{s,k}(t) \qquad (2.1.2)$$

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

Table 2.1.6. Aggregated NO_x emission factors (g/GJ).

		Gas oil	Natural gas	Bio gas
0101	Public power	187	131	551
0102	District heating plants	52	30	31
0105	Oil/gas extraction	52	31	605
02	Residential	65	51	317
03	Industry	52	59	31

NMVOC

The emission factors for NMVOC are also depending on the combustion technology. The emission factors for the various fuels and sectors are shown in Tables 2.1.7 and 2.1.8.

Table 2.1.7. NMVOC emission factors for different technologies (g/GJ).

	Gas oil	Natural gas	Biogas
Boilers	1,5	4	4
Gas turbines	5	1	4
Gas engines	100	163	4

Table 2.1.8. Aggregated NMVOC emission factors (g / GJ).

		Gas oil	Natural gas	Bio gas
0101	Public power	1,5	58	4
0102	District heating plants	1,5	4	4
0105	Oil/gas extraction	1,5	4	4
02	Residential	1,5	24	4
03	Industry	1,5	9	4

2.1.4 Emissions

The emissions are calculated as a sum of emissions from large combustion plants and combustion plants smaller than 25 Mwe. The emission for a given pollutant is calculated by equation 2.1.3 in which A_s is the activity for sector s for the year t and $EF_s(t)$ is the aggregated emission factor for sector s.

$$E = \sum_s A_s(t) \cdot \overline{EF}_s(t) \qquad (2.1.3)$$

Table 2.1.9 shows the emissions for SO_2, NO_x and NMVOC for 2001 distributed on subsectors.

Table 2.1.9. Emissions for 2001.

Sector	SNAP-code	SO_2 (tonnes)	NO_x (tonnes)	NMVOC (tonnes)
Public power	0101	32515	37277	1079
District heating plants	0102	3322	3313	547
Petroleum refining plants	0103	375	627	66
Oil/gas extraction	0105	7	761	98
Commercial and institutional plants	0201	364	1309	391
Residential plants	0202	819	3667	8193
Plants in agriculture, forestry and aquaculture	0203	1511	1160	1485
Combustion in industrial boilers	03	14189	6812	643

2.1.5 Projections

The emissions for the sectors on SNAP1 level are shown from 2001 to 2010 in Figures 2.1.3, 2.1.4, 2.1.5 and Table 2.1.10.

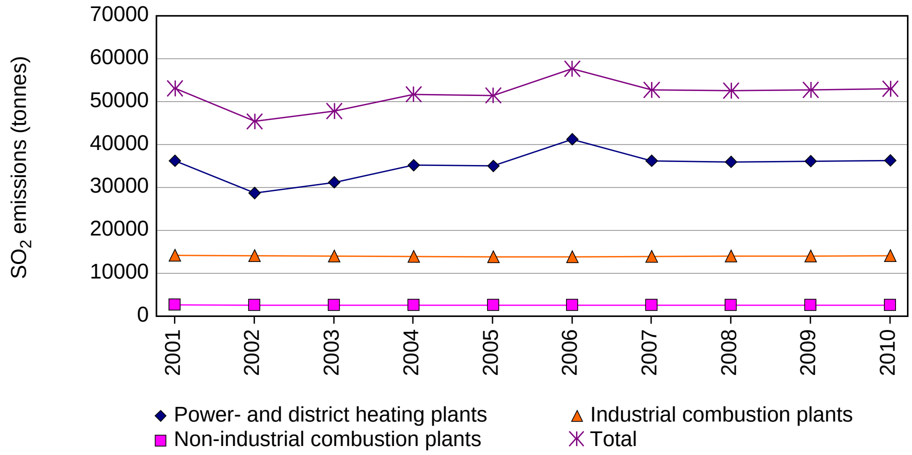


Figure 2.1.3. SO_2 emissions.

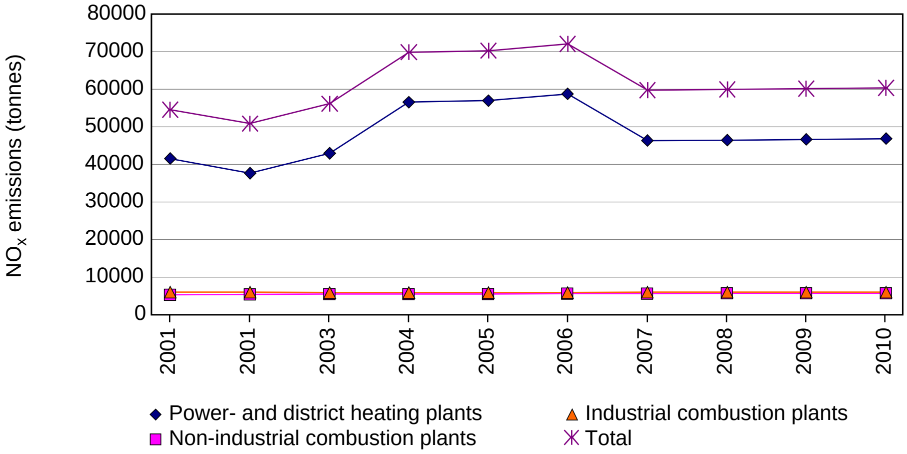


Figure 2.1.4. NO_x emissions.

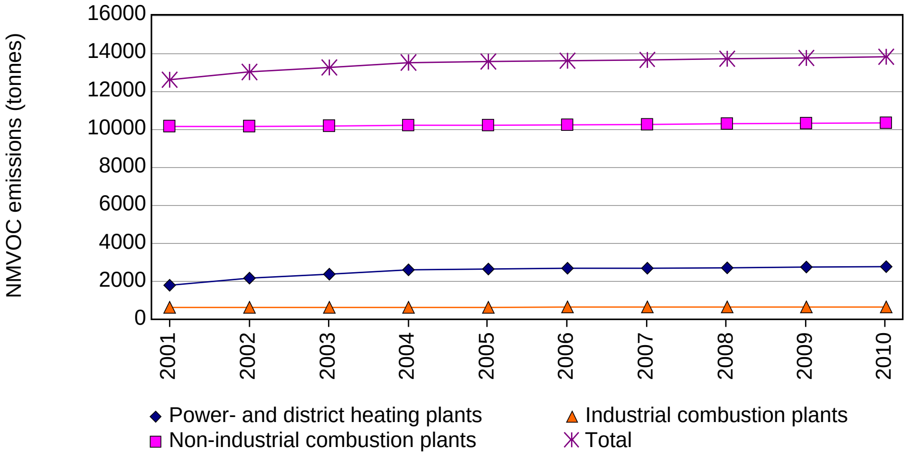


Figure 2.1.5. NMVOC emissions.

Figure 2.1.3 shows that the most important source of SO_2 emission is power- and district heating plants followed by industrial combustion plants and non-industrial combustion plants. The SO_2 emissions from the two latter sources are almost constant in the entire period while the emission from the energy sector reflects the variation in the fuel consumption.

For NO_x as for SO_2 the most important emission sources are power- and district heating plants. In the years up until 2006 the NO_x emission follows the development in the fuel consumption but from 2007 a significant decrease in the emissions is seen. From this year on Selective Catalytic Reactors (SCR) are expected to be installed on two of the large combustion units.

Contrary to what is seen for SO_2 and NO_x the largest source of NMVOC emission is non-industrial combustion plants. Especially combustion of wood in the residential sector contributes to the NMVOC emission.

Table 2.1.10. Projected emissions

SO_2 (tonnes)											
Sector	SNAP -code	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Power- and district heating plants	01	36220	28750	31267	35218	35045	41261	36238	36027	36187	36331
Non-industrial combustion plants	02	2694	2599	2616	2613	2596	2587	2588	2591	2583	2585
Industrial combustion plants	03	14189	14091	13977	13894	13866	13877	13925	13977	14044	14110
Total		53102	45440	47860	51725	51506	57724	52752	52596	52813	53026
NO_x (tonnes)											
		2001	2001	2003	2004	2005	2006	2007	2008	2009	2010
Power- and district heating plants	01	41978	38189	43369	56862	57280	58992	46812	46898	47058	47222
Non-industrial combustion plants	02	6136	6213	6315	6351	6375	6412	6443	6479	6513	6558
Industrial combustion plants	03	6812	6788	6768	6754	6763	6767	6787	6809	6836	6861
Total		54925	51190	56451	69967	70417	72171	60042	60186	60407	60641
NMVOC (tonnes)											
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Power- and district heating plants	01	1790	2150	2359	2589	2635	2667	2677	2696	2722	2749
Non-industrial combustion plants	02	10069	10057	10089	10120	10126	10145	10169	10200	10224	10243
Industrial combustion plants	03	643	641	641	641	643	643	645	647	649	651
Total		12501	12886	13126	13388	13442	13493	13529	13580	13633	13681

Figure 2.1.6 shows the emissions from the large combustion plants. Compared to the projected total emissions for power- and district heating plants it is seen that the emissions from the large combustion plants contribute with about 80% and 60% for SO_2 and NO_x respectively.

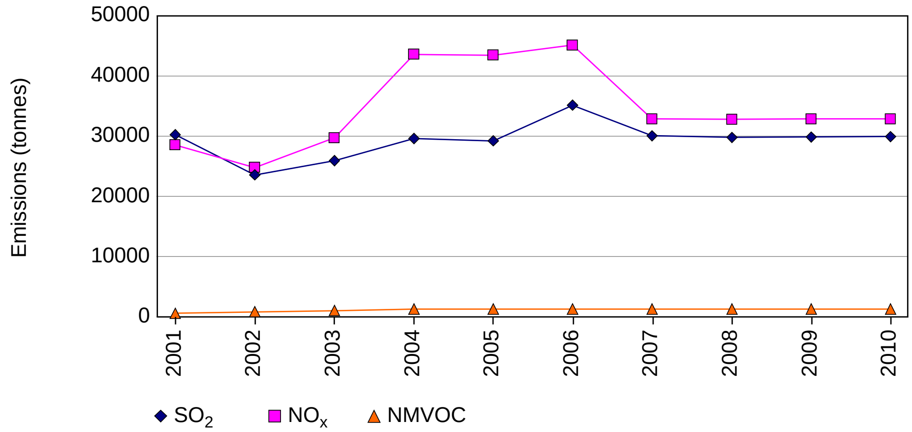


Figure 2.1.6. Emissions for combustion plants larger than 25 MWe.

2.1.6 Model description

The software used for the energy model is Microsoft Access 97, which is a Relational Database Management System (RDBMS) for creating databases. The database is called the 'Energy-model' and the overall construction of the database is shown in Figure 2.1.7.

The model consists of a number of input data collected in tables containing data for fuel consumption and emission factors for combustion plants larger than 25 MWe and combustion plants smaller than 25 MWe. 'Area' and 'Point' in the model refer to small and large combustion plants, respectively. In Table 2.1.11 the names and the content of the tables are listed.

Table 2.1.11. Tables in the 'Energy-model'.

Name	Content
tblEmfAreaTec	Input data for calculating the SO_2 emission factor.
tblEmfArea	Emission factors for other pollutants than SO_2.
tblActArea	Fuel consumption for small combustion plants
tblEmfPointTec	Input data for calculating the SO_2 emission factor.
tblEmfPoint	Emission factors for other pollutants than SO_2.
tblActPoint	Fuel consumption for large combustion plants

From the data in these tables a number of calculations and unions are created be means of queries. The names and the functions of the queries used for calculating the total emissions are shown in Table 2.1.12.

Table 2.1.12. Queries for calculating the total emissions.

Name	Function
qEmfArea_SO_2	Calculation of the SO_2 emission factor for small combustion plants. Input: tblEmfAreaTec
qEmfArea	Union of tblEmfArea and qEmfArea_SO_2
qEmissionArea	Calculation of the emissions from small combustion plants. Input: tblActArea and qEmfArea
qEmfPoint_SO_2	Calculation of the SO_2 emission factor for large combustion plants. Input: tblEmfPointTec
qEmfPoint	Union of tblEmfPoint and qEmfPoint_SO_2
qEmissionPoint	Calculation of the emissions from large combustion plants. Input: tblActPoint and qEmfPoint
qEmissionAll_a	Union of qEmissionArea and qEmissionPoint

Based on some of the queries a number of summation queries are available in the 'Energy-model' (Figure 2.1.8). The outputs from the summation queries are Excel-pivot tables.

Table 2.1.13. Summation queries.

Name	Output
qxlsEmissionAll	Table containing emissions for SNAP groups, Years and Pollutants
qxlsEmissionArea	Table containing emissions for small combustion plants for SNAP groups, Years and Pollutants
qxlsEmissionPoint	Table containing emissions for large combustion plants for SNAP groups, Years and Pollutants
qxlsActivityAll	Table containing fuel consumption for SNAP groups, Years and Pollutants
qxlsActivityPoint	Table containing fuel consumption for large combustion plants for SNAP groups, Years and Pollutants

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

Appendix 2.1.1 contains the database ‘Energy model’ including all the tables and queries.

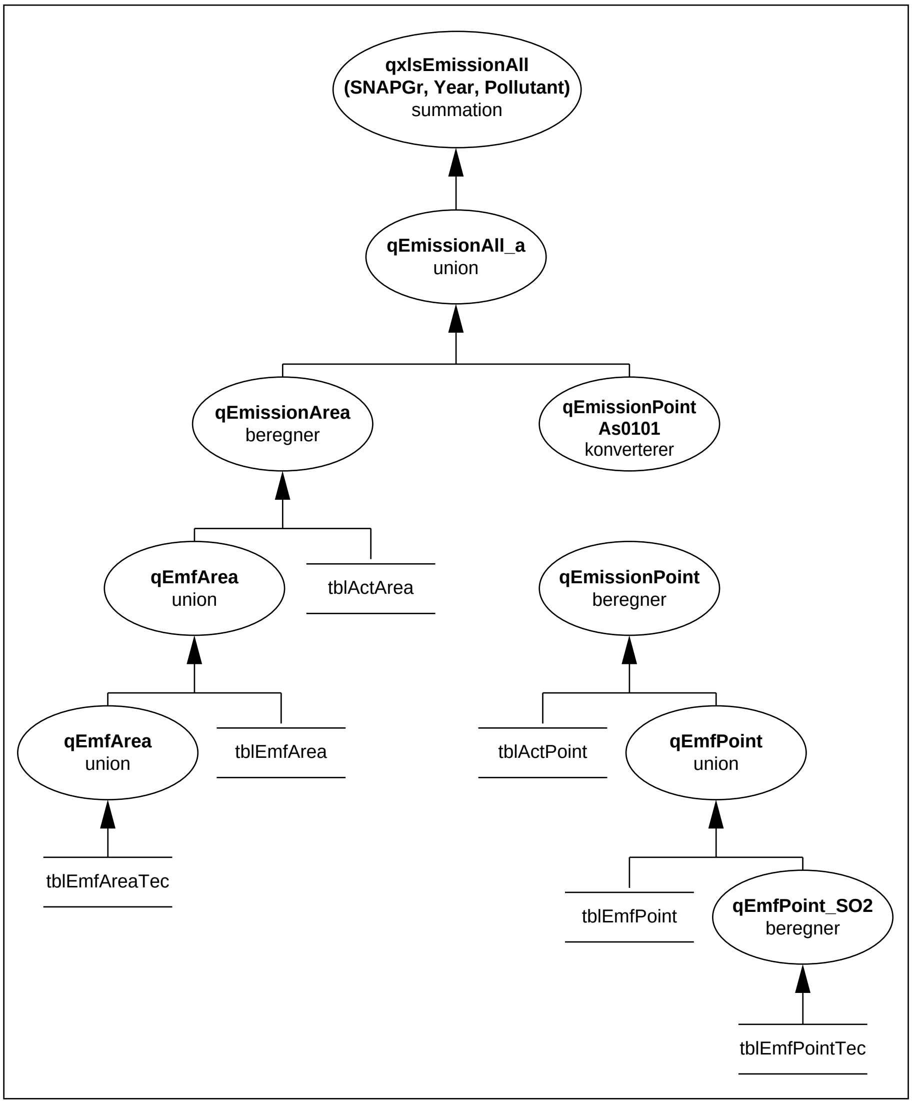


Figure 2.1.7. The overall construction of the database.

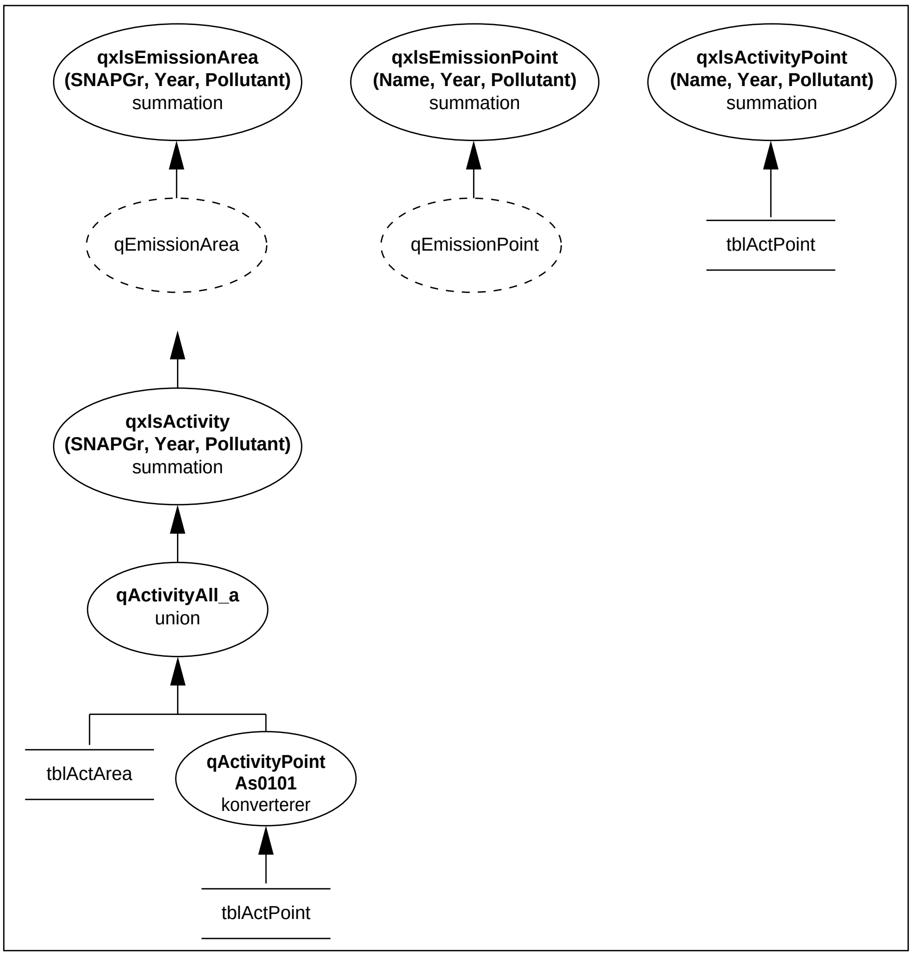


Figure 2.1.8. Summation queries.

2.2 Industry

2.2.1 Oil and gas extraction

2.2.1.1 Processes

The extraction and first treatment of liquid and gaseous fuels involves a number of activities that may cause harmful emissions. The present chapter addresses fugitive emissions and venting/flaring of gas. Emissions from combustion of fossil fuels for generation of heat and electricity are covered by SNAP 0105 (power and heat production in oil/gas extraction). Emissions from refinery activities are covered by 0103 (power and heat production in petroleum refining plants) and 090203 (flaring in oil refinery).

The following parts can be considered for the calculation of emissions from oil and gas activities:

Oil and gas production:
Oil and gas are drawn from underground formations using offshore wells and are often taken simultaneously from the same geological formation and separated. In Denmark the oil and gas activities take place in the North Sea. Emissions of NMVOC are caused by leaks, venting or flaring (SNAP: 050202 (oil) or 050303 (gas)).

Crude oil transportation:
Crude oil is transported by pipelines or ships and stored in tanks on-shore. Leaks, venting and flaring during transport and storage result in emission of NMVOC, particularly from crude oil tanking (SNAP: 050202).

Natural gas processing and transportation:
Transmission facilities are high pressure lines that transport gas from production fields, processing plants, storage facilities and other sources of supplies over long distances to distribution centres or large volume customers. Above-ground facilities supporting the transmission lines use fuel and may emit NMVOC (SNAP: 050303).

Natural gas distribution:
From the storage tanks the gas is distributed to customers. The emission of natural gas stems mainly from damage sections (SNAP: 050603).

In general the emissions can be divided into three different types: fugitive emissions, venting and flaring.

Fugitive emissions are defined as emissions of hydrocarbon vapours from process equipment and evaporation of hydrocarbons from open areas, rather than through stacks or vents. It includes emissions from valves, connectors, flanges, seals, process drains, oil/water separators, storage and transfer operators. Venting is directly controlled release of gas to the atmosphere. Flaring is gas combusted without utilisation of the energy. SNAP 090206 includes all flaring for extraction and first treatment of gaseous and liquid fossil fuels. It also includes emissions from incineration after well testing. Gas is flared on oil and gas production installation for safety. The main reasons are lack of process or transport capacity for gas, a continuos surplus gas flow, start up, maintenance and emergency (need for pressure relief).

2.2.1.2 Facilities and emissions

The previously mentioned processes result in emissions from various facilities used in the oil and gas production industry. The main facilities are combined oil and gas facilities for extraction, gas terminals, ships, pipelines and networks.

The notations for the emission factors and activity rates are explained in Table 2.2.1 and Tables 2.2.2 to 2.2.6.

The total emission can then be expressed as:

$$E_{total} = E_{extraction} + E_{gas\ terminal} + E_{ship} + E_{pipeline} + E_{networks} \qquad (3.2.1.1)$$

Combined oil and gas facilities

The emissions from combined oil and gas facilities for extraction include emissions from facilities for: extraction of oil and gas; separation of gas, crude oil and water; gas treatment; crude oil stabilisation and waste water treatment (SNAP 050202 (oil) or 050303 (gas)). The emissions from these facilities originate from all three types of emissions: venting, fugitive losses and flaring.

$$E_{extraction} = E_{venting} + E_{fugitive} + E_{flaring} \qquad (3.2.1.2)$$

According to the Guidebook the total fugitive emissions of VOCemission of VOC can be estimated by means of equation?

$$E_{VOC,\,fugitive} = 40.2 \cdot N_P + 1.1 \cdot 10^{-2} P_{gas} + 8.5 \cdot 10^{-6} \cdot P_{oil} \qquad (3.2.1.3)$$

It is assumed that the VOC contains 75% methane and 25% NMVOC meaning that the total emission of NMVOC for extraction of oil and gas can be calculated as:

$$\begin{aligned} E_{extraction} &= E_{venting} + E_{fugitive} + E_{flaring} \qquad (3.2.1.4) \\ &= P_{gas} \cdot EMF_V + 0.25(40.2 \cdot N_P + 1.1 \cdot 10^{-2} P_{gas} + 8.5 \cdot 10^{-6} \cdot P_{oil}) + F_P \cdot EMF_{flaring} \end{aligned}$$

Gas terminals

Generally the main emission sources from gas terminals are the flare at the pressure relief system associated with the compression unit. Fugitive losses also contribute to the emissions.

$$E_{GT} = EMF_{fugitive} \cdot N_{GT} + EMF_{flaring} \cdot F_{GT} \qquad (3.2.1.5)$$

Ships

This source includes the transfer of oil or liquefied gas from storage tanks or directly from the well into a ship. This activity also includes losses during transport. When oil is loaded hydrocarbon vapour will be displaced by oil and new vapour will be formed, both leading to emissions.

$$E_{ships} = EMF_{ships} \cdot L_{oil} \qquad (3.2.1.6)$$

Pipelines

Oil and gas are commonly transported from oil and gas facilities to terminals by pipelines. Emissions may originate from connection points, valves and damaged sections.

$$E_{pipelines} = EMF_{pipeline,gas} \cdot T_{gas} + EMF_{pipeline,oil} \cdot T_{oil} \qquad (3.2.1.7)$$

Gas distribution networks

From the terminals the gas is distributed to the customers via pipelines, compressor stations and networks. Emissions from the network could be caused by losses due to leakage and losses due to purging of sections of the pipes and items of equipment during maintenance.

$$E_{networks} = EMF_{network} \cdot C_{gas} \qquad (3.2.1.8)$$

Flaring

Gas is flared on oil and gas production installation for safety. The main reasons are lack of process or transport capacity for gas, a continuos surplus gas flow, start up, maintenance and emergency (need for pressure relief).

2.2.1.3 Activity data

The following statistic activity data are needed to estimate the emissions from off-shore activities: The number of platforms, oil and gas produced, flared gas, the number of gas terminals, the volume of gas processed through a gas terminal, the mass of crude oil loaded into tankers, volume of gas transported by pipelines, volume of oil transported by pipelines and volume of gas consumed.

Table 2.2.1. Activity data for 2000.

Activity	Symbols	Year	
		2000	Ref.
Number of platforms	Np	42	Danish Energy Agency (2001a)
Produced gas (10^6Nm3)	Pgas	11294	Danish Energy Agency (2001a)
Produced oil(10^3m3)	Poil,vol	21111	Danish Energy Agency (2001a)
Produced oil (10^3tonne)	Poil	18155	Danish Energy Agency (2001a)
Number of gas terminals	NGT	1	DONG (2001)
Gas transported by pipelines (10^6Nm3)	Tgas	7111	Danish Energy Agency (2001a)
Oil transported by pipelines (10^3m3)	Toil	16432	DONG (2001)
Oil transported by pipelines (10^3tonne)	Toil	14132	DONG (2001)
Oil loaded (10^3m3)	Loil off-shore	4653	Danish Energy Agency (2001a)
Oil loaded (10^3tonne)	Loil off-shore	4002	Danish Energy Agency (2001a)
Oil loaded (10^3m3)	Loil on-shore	12500	DONG (2001)
Oil loaded (10^3tonne)	Loil on-shore	10750	DONG (2001)
Volume gas consumed (10^6Nm3)	Cgas	4100	Danish Energy Agency (2001b)
Gas flared in oil and gas production (10^6Nm3)	Fp	250	Danish Energy Agency (2001a)
Gas flared in terminals (10^6Nm3)	FGT	0.732	DONG (2001)

Mass weight raw oil = 0.86 tonne / m^3.

The Danish Energy Agency has projected the production of oil and gas in the North Sea as shown in Figure 2.2.1. The other parameters in Table 2.2.1 are projected on the basis of the ratio between the produced oil and gas in 2000 and the projected production in 2001 to 2010. All the projected activity data is shown in Appendix 2.2.1.

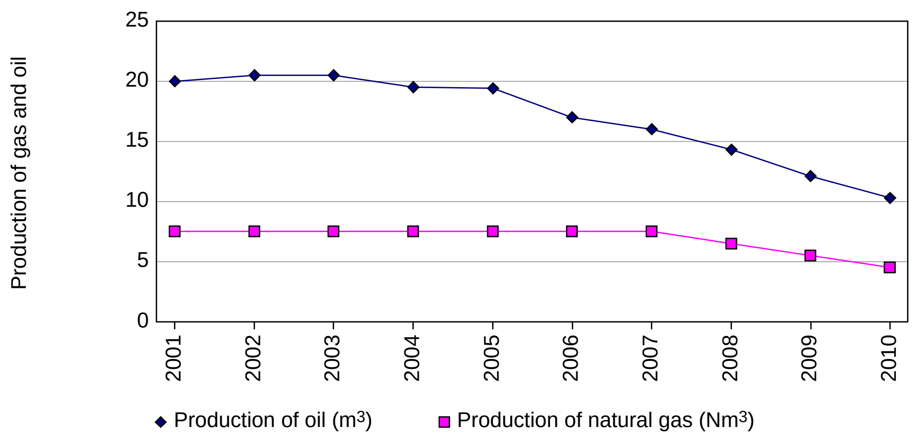


Figure 2.2.1. Projected production of oil and gas (Danish Energy Agency, 2001a).

2.2.1.4 Emission factors

The activities covered by the Atmospheric Emission Guidebook are divided into: Combined oil and gas facilities, gas terminals, oil loading and transport, pipelines, flaring and distribution of gas. The estimated emissions from Danish offshore activities are based on data from the Joint EMEP/EEA Atmospheric Emission Guidebook (Richardson, 1999).

Table 2.2.2. Emission factors for oil and gas facilities.

Activity	Symbol	Emission factor	Unit	Country
Venting	EMF_v	76	kg/ m3 10^6 gas produced	Norway
Flaring	$EMF_{flaring}$	0,1	g/m3gas	Norway
		10	g/m3gas	UK

The venting is higher on older platforms than on newer due to use of lower pressure systems, more recovery of hydrocarbon gases and flaring of the vented gas. The emission factors for flaring from Norway are based on documented measurements. The reason for the low emission factors is that the measurements have shown that unburned hydrocarbons are combusted while leaving the flare.

Table 2.2.3. Emission factors for gas terminals.

Activity	Symbol	Emission factor	Unit	Country
Fugitive	$EMF_{fugitive}$	0,04	Gg/terminal	UK
		0,03	Gg/terminal	Canada
		0,76	Gg/terminal	Norway

Table2.2.4. Emission factors for gas distribution.

Activity	Symbols	Emission factor	Unit	Country
Pipelines	$EMF_{pipeline,gas}$	0.014	g/m3	Denmark, Lithuania
		0.016	g/m3	Italy
		0.003	g/m3	Latvia
Networks	$EMF_{network}$		g/m3	France
		0.88	g/m3	Italy
		0.87	g/m3	Denmark, Lithuania
		0.72	g/m3	Slovak
		0.76	g/m3	Swiss
		0.62	g/m3	UK

For transmission, treatment and storage of natural gas the Danish company DONG (Danish Oil and Natural Gas) has estimated the total emission of NMVOC to be 53 tonnes. In order to match this value as much accuracy as possible the emission factors for gas terminals and gas pipelines are set to be 0,04 Gg/terminal and 0,014 g/m3 respectively.

Table 2.2.5. Emission factors for fugitive losses for oil loading.

Activity	Symbols	Emission factor	Unit	Country
Oil loading	EMF_{ships}	0.1–0.3%	%wt loaded	Norway: Off Shore
		0.02-0.06%	%wt loaded	Norway: On shore
		0.001%	%wt loaded	UK

In estimating the Danish emissions from oil loading the lower range of emission factors suggested by Norway are used.

Table 2.2.6. Emission factors for crude oil distribution.

Activity	Symbols	Emission factor	Unit	Country
Pipelines	$EMF_{pipeline,oil}$	0.02	kg/tonne	Bulgaria, Germany
		0.30	kg/tonne	France, Greece, Italy, Poland, Portugal
		0.023	kg/tonne	Lithuania
		0.27	kg/tonne	Spain
Other handling and storage		0.02	kg/tonne	Bulgaria, Greece, Hungary, Italy, Luxembourg, Poland, Romania, Spain
		1.1	kg/tonne	Norway
		0.18	kg/tonne	Portugal

As the tables illustrate the emission factors for pipelines from different countries vary significantly. DONG has estimated the total emission of NMVOC from distribution and storage of crude oil to be 231 tonnes (Dong, 2001). On the basis of this value an emission factor of 0.02 kg/tonne has been selected.

2.2.1.5 Estimated emissions

As an example the emissions for 2000 are estimated using the activity data and emission factors given above.

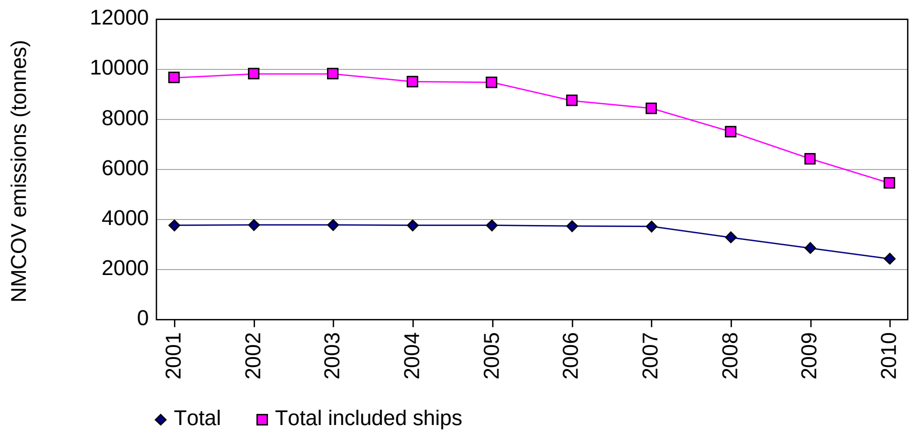
Table 2.2.7. NMVOC emissions for 2000 (tonnes).

Extraction:	
Venting	858
Fugitive	450
Flaring	25
Gas terminals:	
Fugitive	40
Flaring	0,073
Pipelines:	
Gas	99
Oil	282
Network	3567
Total minus ships	**5322**
Ships:	
Off-shore	4002
On-shore	2150
Total	**11475**

2.2.1.6 Projections

Figure 2.2.2 shows the projected emissions of NMVOC for the off-shore activities with and with out loading of oil into ships. It is seen that the emissions from loading contribute substantially to the total emissions. However, it should be stressed that the estimated emissions from loading are quite uncertain.

From 2001 to 2010 the emission is almost halved. Since the emission factors are constant in the period the decreasing emissions are due to an expected smaller extraction of oil and gas as illustrated in Figure 2.2.1.



Figur 2.2.2. Projected emissions of NMVOC from oil and gas production.

Table 2.2.8 shows the emissions aggregated into fugitive emissions (SNAP 05) and flaring (SNAP 09).

Table 2.2.8. Emissions of NMVOC for oil and gas production.

SNAP-code	2001	2002	2203	2004	2005	2006	2007	2008	2009	2010
05	9083	9237	9237	8929	8898	8158	7849	6998	5992	5110
09	587	587	587	587	587	587	587	508	430	352

2.2.1.7 Model description

The model for the offshore industry is created in Microsoft Excel and the worksheets used in the model are collected in the 'Offshore model' (Appendix 2.2.1). The names and content of the tables are listed in Table 2.2.9.

Table 2.2.9. Tables in the 'Offshore model'.

Name	Content
Activity data	Historically data for 2000 (Table 2.2.1) plus estimated activity rates for 2001 to 2010 based on data in table 'Projected production'.
Projected production	Projected production of oil and gas for 2001 to 2010.
EMF	Emission factors for NMVOC for all activities.
Emissions	Projected emissions for 2001 to 2010 based on data in tables 'Activity data' and 'Emission factors'.

Changing of the data in the tables containing input data will automatically update the projected emissions.

2.2.2 Use of solvents

2.2.2.1 Sources

Use of solvents is an important source of evaporation of NMVOC and contributed in 2000 with approximately 26 % of the total NMVOC emission. The most important sectors for industrial use of solvents are: Car repairing and treatment, chemical industry, paint application in iron and steel industry, paint manufacturing, the plastic industry, the foodstuff industry, preservation of wood and the printing industry.

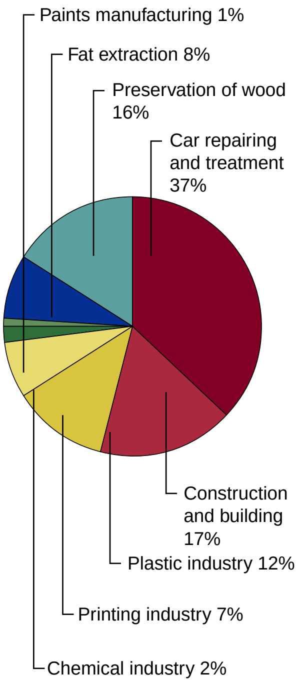


Figure 2.2.3. The Danish NMVOC emissions in 2000 distributed on sectors (Dansk Industri, 2002).

For these sectors the Government and the industries agreed to reduce the emissions of NMVOC by 40 % from 1988 to 2000. The reduction targets for each trade was estimated by trades and companies.

Car repairing and treatment

The two main sources to emissions of NMVOC are vehicles underseal treatment/dewaxing and coating of road vehicles carried out as a part of vehicle repair, conservation or decoration. The number of cars as well as the amount of coatings to the underside of the car bodies is expected to decrease. The amount of paints used for repairing is expected to decrease as a result of a reduction in the amount of paint used per car. The target is a reduction of 46 % from 1988 to 2000 for the area as a whole.

Chemical industry

In the chemical industry NMVOC is used as component or solvent in syntheses processes, for extraction and as a cleaning agent. The application of NMVOC is very specific for each process and the possibility of substitution is very limited. The use of NMVOC is expected to increase while the emissions are expected to decrease by 71 % from 1988 to 2000.

Paint application in the iron and steel industry

The iron and steel industry includes: Constructions and buildings, boat building and other industrial paint application. From 1988 to 2000 the emissions of NMVOC are expected to decrease by 35 % as a result of an increased use of paints with higher content of dry matter, water-based paints, and powdered lacquer.

Paint manufacturing

Organic solvents are used both in water-based paints/lacquers and solvent-based paints/lacquers. For both groups of paints the content of solvents are expected to decrease and consequently the emissions of NMVOC are expected to decrease by 29 % from 1988 to 2000.

The plastic industry

The products contributing most to the emission of NMVOC are expandable polystyrene (EPS), polyester (composite), and polyurethane (PUR). For all three products the production will increase and only a small decrease in the emissions is expected due to decreased content of solvents in the raw material.

The foodstuff industry

Emissions of NMVOC from the food industry come from solvent extraction of fat, edible and non-edible oil. The subsequent drying of the residual may also cause emission of NMVOC. The consumption and the emissions are expected to decrease by 30 % from 1988 to 2000.

Preservation of wood

This area covers impregnation of timber, painting of furniture with organic solvent-based preservation/paints. The main sources of emission of NMVOC are lacquers/paints, glues, impregnation liquids and cleaning agents. The emissions are expected to decrease by 45 % from 1988 to 2000, due to use of products with lower content of organic solvent and altered applying techniques.

Printing industry

Printing processes such as offset, rotogravure, flexography, letter-press and screen-printing contributes to emission of NMVOC-emissions. Based on information on emissions in 1988 the emissions in 2000 are expected to decrease by 58 % as a consequence of an increase in the use of water-based products.

Domestic use of solvents

Domestic use of solvents and solvent containing products are also an important source of NMVOC emissions. Many of the products used in households are also used in the industry and it is difficult to separate the two sectors. Domestic use of solvent covers: Paint application, cosmetics, household products, construction and car care products. No detailed Danish inventory exists for domestic use of solvents. The recommended emissions factor in the Guidebook is therefore used for projection of the emissions (Richardson, 1999). The emission is estimated by multiplying the emission factor by the population.

2.2.2.2 Emissions

As a part of the agreement the industry trades have collected activity and emission data for the sectors. A model for calculating industrial emissions of NMVOC is based on these data and the emission can be calculated by means of equation 3.2.2.1.

$$E = \sum_{s} A_s(t) \cdot \bar{e}_s(t) \qquad (3.2.2.1)$$

where As is the activity for subsector s for the year t and es(t) is the related aggregated emission factor. The average emission factor expresses the emission for all sources for the given subsector.

Based on the SNAP groups for solvent and the data reported by the industries an emission model has been developed. In Appendix 2.2.2 the subsectors and the related SNAP code are listed along with the reported activities and emissions for 1988, 1990 and 2000. From this information emission factors have been estimated for each subsector and by means of interpolation time series from 1985 to 2000 has been created. Aggregated emission factors are shown in Table 2.2.10.

Table 2.2.10. Aggregated data for industrial use of solvents for 2000.

Source	Emission factor (kg/tonnes)	Activity rate (tonnes)	Emissions (tonnes)
Car repairing and treatment	27	178138	4888
Construction and building	207	10405	2156
Plastic industry	69	22476	1560
Printing industry	247	3524	872
Chemical industry	1	268000	266
Paints manufacturing	5	36300	166
Fat extraction	500	2042	1021
Preservation of wood	538	3900	2100
Totale			13029

Table 2.2.11. Data for domestic use of solvents for 2000.

Source	Emission factor (kg/person/year)	Actively rate (population)	Emission (tonnes)
Domestic use	2,59	5330020	13805

No detailed Danish inventory exists for domestic use of solvents. The recommended emissions factor in the Joint EMEP/EEA Atmospheric Emission Guidebook is therefore used in the projections. The emission is estimated multiplying the emission factor by the population size. As shown in Table 2.2.10 and 2.2.11 the emissions of NMVOC from industrial and domestic use of solvents are almost equal. However, it should be stressed that the estimated emissions are very uncertain.

2.2.2.3 Projections

At present no projection of Danish activity and emission data for industrial use of solvent is available. However, in connection with the EU Council Directive (1999/13/EC) on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations the French-German Institute for Environmental Research, University of Karlsruhe, has estimated that the implementation of the directive will result in a reduction of 57 % on a European level compared to the emissions in 1990. In the calculation a certain economic growth in the implementation period is assumed. From 1990 to 2000 the Danish emissions of NMVOC have decreased by 30 %. It is possible that the emissions will decrease further from 2000 to 2007 where the directive is fully implemented. In the emission projection it is assumed that the emission will decrease by 57 % from 1990 to 2010.

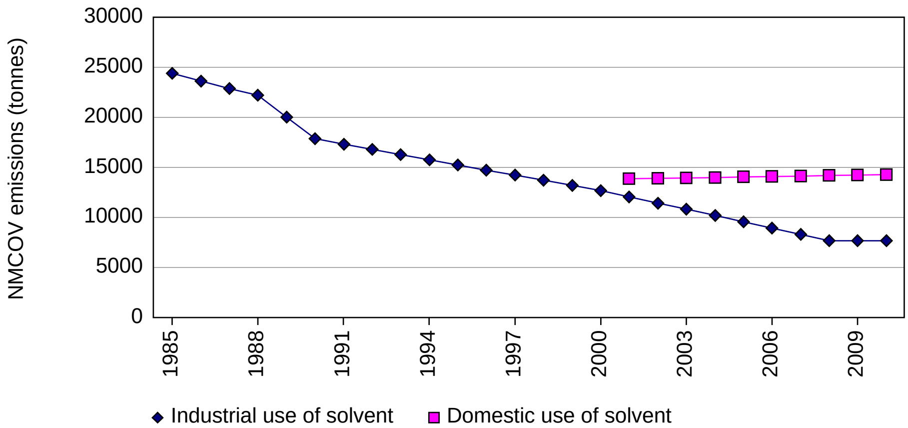


Figure 2.2.4. Projected emissions for NMVOC from industrial and domestic use of solvents.

2.2.2.4 Model description

The model for use of solvents is created in Microsoft Excel and the worksheets used in the model are collected in the 'Use of solvents' (Appendix 2.2.2). The names and content of the tables are listed in Table 2.2.12.

Table 2.2.12. Tables in the 'Use of solvent' model.

Name	Content
Domestic	Activity data and emission factor for domestic use of solvents.
Figure	Figure with projected emissions for industrial and domestic use of solvents.
Sum emission	The total emission for industrial use of solvents
'The name of the sector'	10 tables with the emissions for each sector

Changing the data in the tables containing input data will automatically update the projected emissions.

2.2.3 Other Industries

Other industries causing harmful emissions are petroleum refineries, breweries and nitric acid plants. This chapter only covers fugitive emissions and other emissions not related to combustion of fuels for energy production.

2.2.3.1 Petroleum refineries

In the production process at the refineries a part of the volatile hydrocarbons (VOC) is emitted to the atmosphere. It is assumed that NMVOC accounts for 99 % of the emission. The NMVOC-emission from petroleum refinery processes cover non-combustion emissions from feed stock handling/storage, petroleum products processing, and product storage/handling. SO_2 is also emitted from the non-combustion processes and includes emissions from products processing and sulphur recovery plants. The projected emissions are calculated, based on the information on emissions in 2000 and the projection for the processing of crude on Danish refineries. In the energy projection it is assumed that the processing of crude oil is constant from 2001 to 2010.

2.2.3.2 Beer production

When making beer the cereals are germinated, roasted and boiled before fermentation. In the fermentation process the sugar in the processed cereals is converted into ethanol by yeast. Emissions of alcohol and other NMVOC may occur during any stage of the production. The projection is based on the information on beer production in 2000.

2.2.3.3 Flaring in oil refinery

Flaring is gas combustion without utilisation of the energy. Flares are commonly used during petroleum refining for the safe disposal of waste gases during process upsets, maintenance and emergency. The emission of NMVOC from flaring offshore is calculated using the amount of gas flared and an emission factor.

2.2.3.4 Nitric acid production

For the production of nitric acid ammonia is oxidised catalytically and nitrous gases (NO and NO_2) are obtained. These gases are converted to nitric acid, oxygen and water. For NO_x emissions the relevant process units are the absorption tower and the tail gas cleaning units. The projected emissions are based on the amount of nitric acid produced in 2000.

2.2.3.5 Projections

For the sectors considered in this chapter the projected activity rate and the emission factors are the same in the entire period 2001 to 2010, and the emissions are therefore constant.

Table 2.2.13. Activity rates.

SNAP	Activity	Activity rate	Unit	Reference
0401	Processes in petroleum industries	8068837	tonne	Energy projection
040402	Nitric acid production	433000	tonne	2000-inventory
040607	Beer production	746030	tonne	2000-inventory
090203	Flaring in oil refinery	336541	GJ	2000-inventory

Table 2.2.14. Emission factors.

SNAP	Activity	SO_2	NO_x	NMVOC	Unit	Reference
0401	Processes in petroleum in-dustries	103	0	524	g/tonne raw oil	2000-inventory
040402	Nitric acid pro-duction	0	954	0	g/tonne HNO3	2000-inventory
040607	Beer production	0	0	625	g/tonne beer	2000-inventory
090203	Flaring in oil refinery	0	299	2,5	g/GJ	Guidebook, Norway

Table 2.2.15. Projected emissions.

SNAP	Activity	SO_2	NO_x	NMVOC	Unit
0401	Processes in petroleum indu-tries	831	0	4228	tonne
040402	Nitric acid pro-duction	0	413	0	tonne
040607	Beer production	0	0	466	tonne
090203	Flaring in oil refinery	0	101	1	tonne

Table 2.2.16. Projected emissions on SNAP 1 level.

SNAP	Activity	SO_2	NO_x	NMVOC	Unit
04	Production pro-cesses	831	413	4694	tonne
09	Waste treatment and disposal	0	101	1	tonne

2.3 Transport

2.3.1 Road Transport

In this project a detailed model has been developed in order to forecast the emissions from road transportation vehicles. In the model fuel use, emission factors, data for vehicle stock and the amount of traffic are made available on a detailed level. This enables the simulation of fuel use and emissions 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.

Table 2.3.1. Model vehicle classes, trip speeds and mileage split.

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

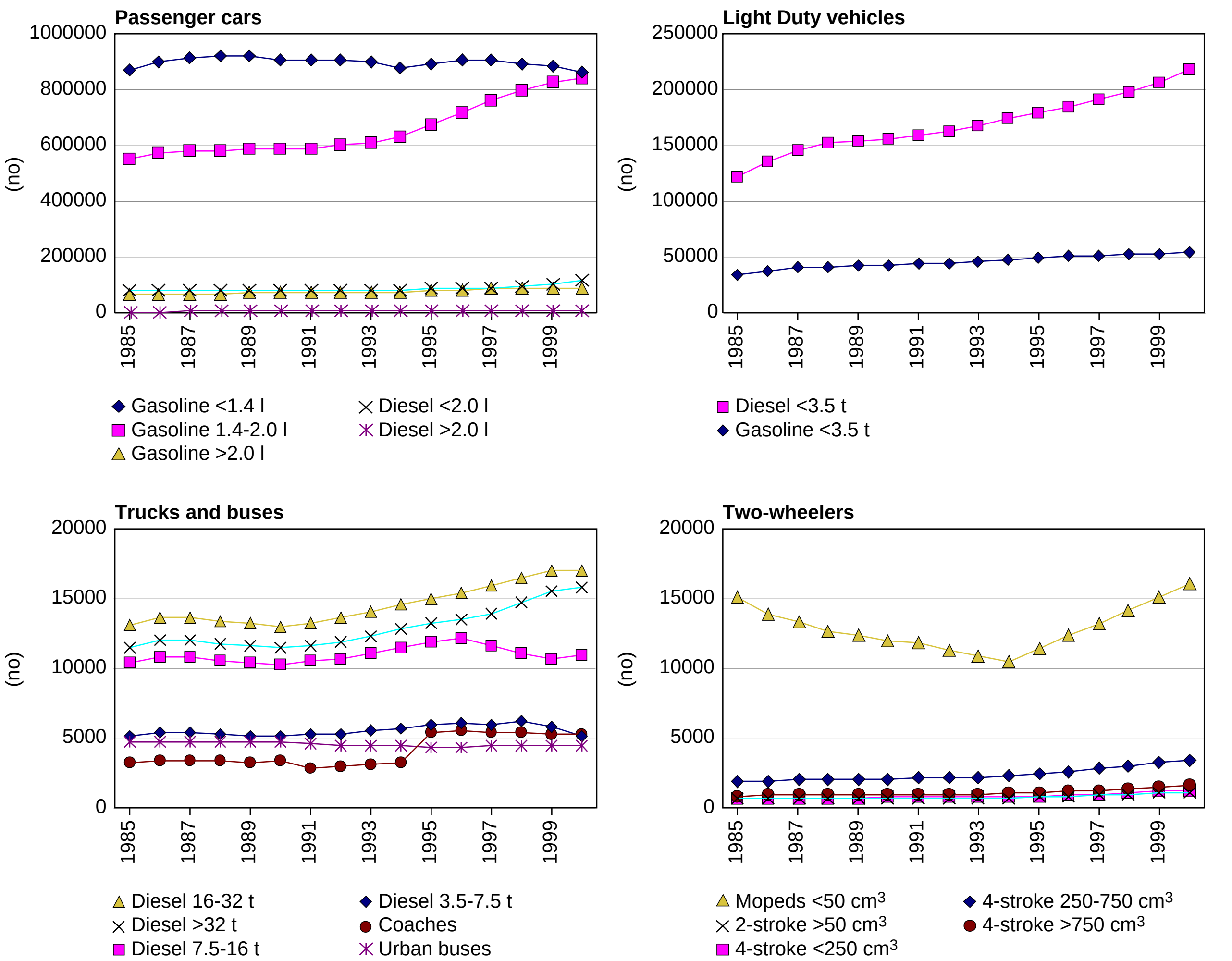


Figure 2.3.1. No. of vehicles in sub-classes in 1985-2000.

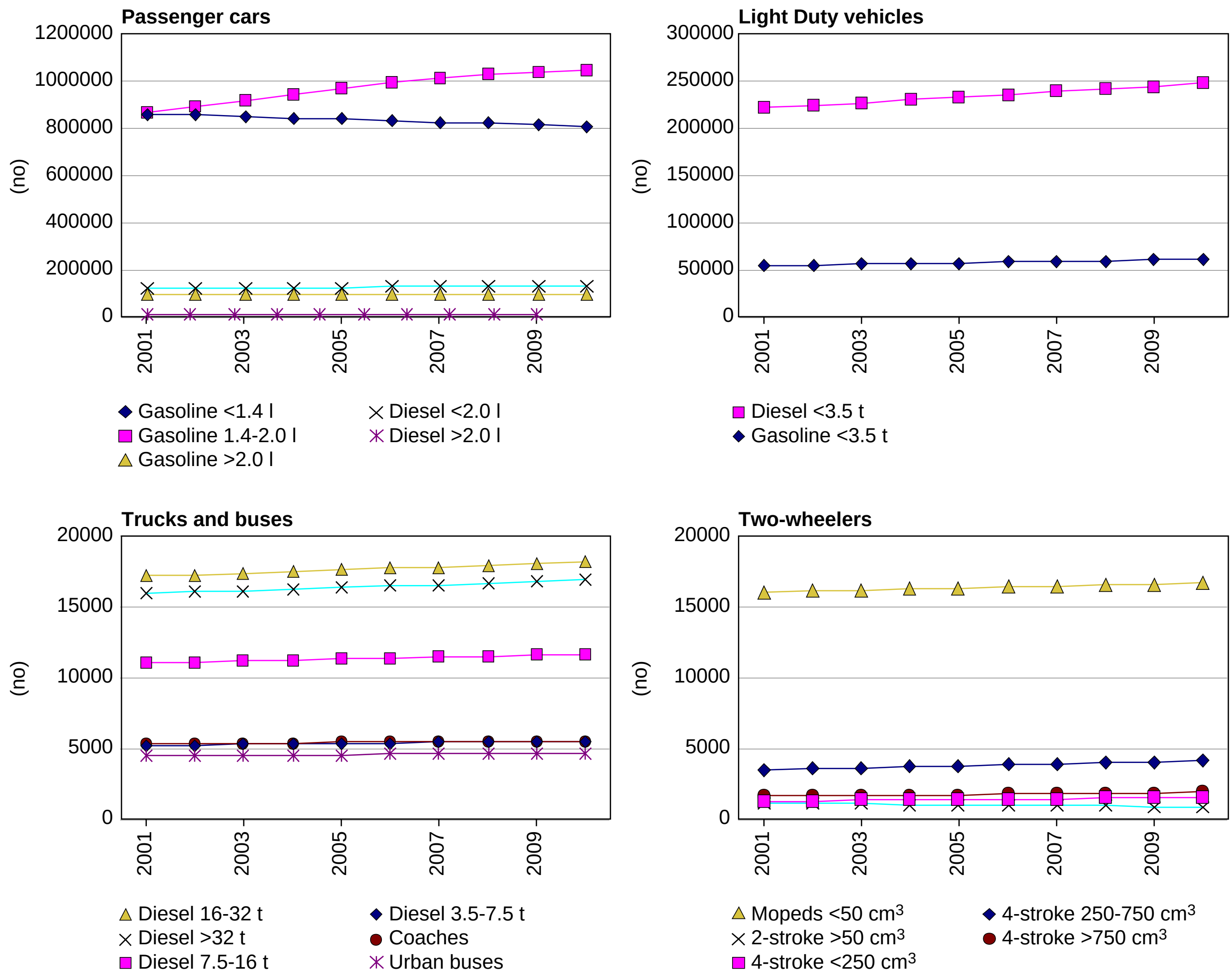


Figure 2.3.2. No. of vehicles in sub-classes in 2001-2010.

In the model all present and future vehicles in the Danish traffic are grouped into vehicle layers. This is a sub-division of all vehicle classes into groups of vehicles with the same average fuel use and emission behaviour. The grouping is identical with the one used by the European COPERT model (Ntziachristos et al., 2000). An overview of the different layers with years of implementation is given in Appendix 2.3.1.

Information on the vehicle stock and annual mileage is obtained from the Danish Road Directorate. This information covers data for the number of vehicles, annual mileage, mileage split between urban, rural and highway driving and the respective average speeds. In forecast of the future vehicle stock and mileage the Danish Road Directorate has used historical data as background information. By making historical data analyses and using economical parameters, assumptions have been made for new sales of vehicle and of the mean vehicle life span in the years during the forecast period.

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

$$N_{j,y} = \sum_{i=FYear(j)}^{LYear(j)} N_{i,y} \quad (2.3.1)$$

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

$$M_{j,y} = \frac{\sum_{i=FYear(j)}^{LYear(j)} N_{i,y} \cdot M_{i,y}}{\sum_{i=FYear(j)}^{LYear(j)} N_{i,y}} \quad (2.3.2)$$

For the remaining vehicle classes only total vehicle numbers and annual mileages per forecast year are provided by the Danish Road Directorate. The vehicle numbers are distributed into first registration years with the age distribution table given in Appendix 2.3.3 and are subsequently grouped in layers. No variation of annual mileage is given in the data from the Danish Road Directorate. In Appendix 2.3.2 the vehicle numbers and annual mileage are shown per layer.

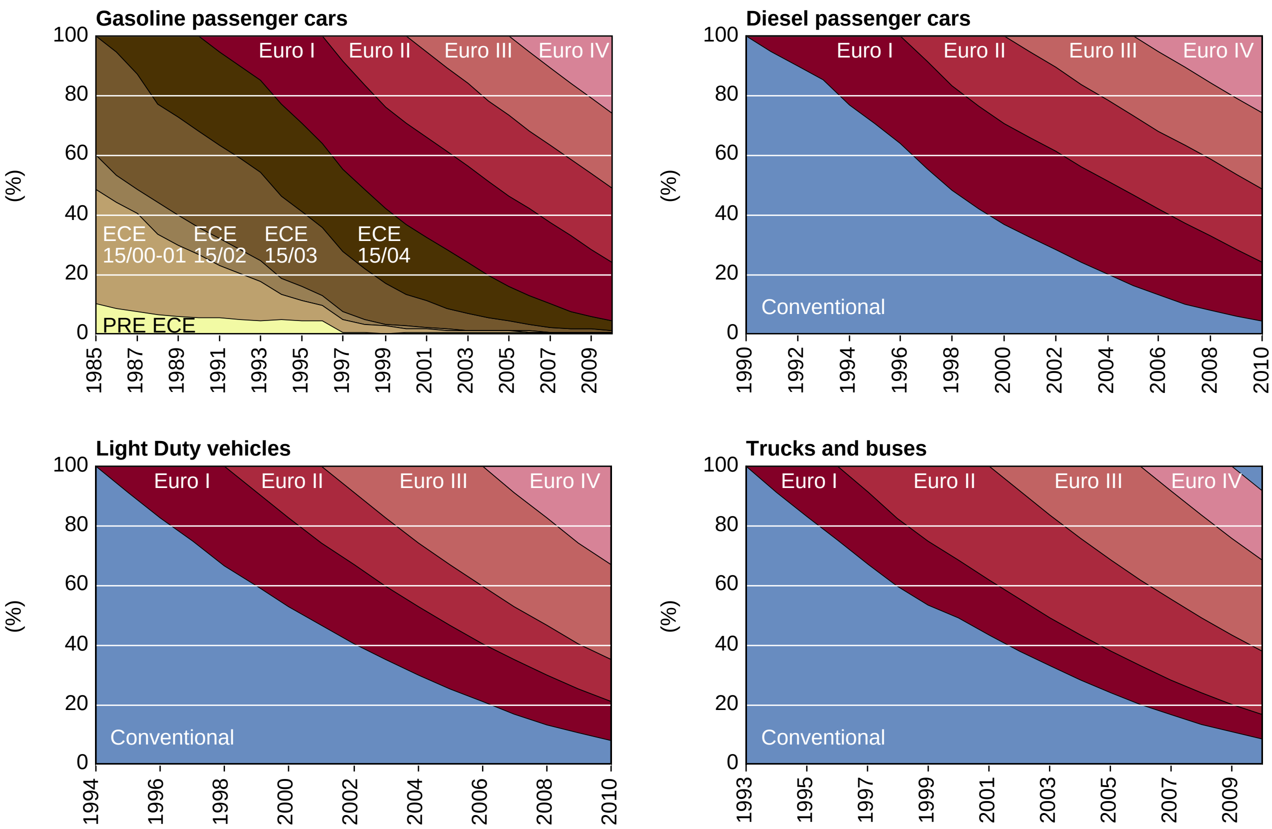


Figure 2.3.3. Layer distribution of vehicle numbers per vehicle type in 1985-2010.

Trip speed dependent fuel use and emission factors are taken from the COPERT model using trip speeds as shown in Table 2.3.1. The factors are listed in Appendix 2.3.4. For new layers not represented by actual data, the emission factors are scaled according to the percentages given in Appendix 2.3.5.

2.3.1.1 Deteoriation factors

For three-way catalyst cars the emissions of NO_x and NMVOC (and CO) gradually increase due to catalyst wear and are therefore modified as a function of total mileage by the so-called deteoriation factors. Even though the emission curves may be serrated for the individual vehicles, on average the emissions from catalyst cars stabilise after a given cut-off mileage is reached due to OBD (On Board Diagnostics) and the Danish inspection and maintenance programme. For each forecast year the deteoriation factors are calculated per first registration year by using deteoriation coefficients and cut-off mileage as given in Appendix 2.3.6 for the corresponding layer. The deteoriation coefficients are given for the two driving cycles ”Urban driving Cycle” and ”Extra Urban driving Cycle” (urban and rural), with trip speeds of 19 and 63 km / h, respectively.

In step one the deteoriation factors UDF (U: urban) and EUDF (EU: extra urban) are calculated for the corresponding trip speeds of 19 and 63 km / h. Two formulas are applied in each case determined by the total cumulated mileage, MTC, less than or exceeding the cut-off mileage U_{MAX} and E_{MAX}, respectively.

$$UDF = U_A \cdot MTC + U_B \text{, MTC < } U_{MAX} \quad (2.3.3)$$

$$UDF = U_A \cdot U_{MAX} + U_B \text{, MTC >= } U_{MAX} \quad (2.3.4)$$

$$EUDF = E_A \cdot MTC + E_B \text{, MTC < } E_{MAX} \quad (2.3.5)$$

$$EUDF = E_A \cdot E_{MAX} + E_B \text{, MTC >= } E_{MAX} \quad (2.3.6)$$

The next step is to find the deteoriation factors, DF, for the actual trip speeds, V, used in the model.

$$DF = UDF \text{, V<=19 km / h} \quad (2.3.7)$$

$$DF = UDF + \frac{(V-19)\cdot(EUDF-UDF)}{44} \text{, 19<V<63 km / h} \quad (2.3.8)$$

$$DF = EUDF \text{ V>=63 km / h} \quad (2.3.9)$$

The final deteoriation factors per first registration year for catalyst vehicles in urban, rural and highway driving is found by inserting the trip speeds given in Table 2.3.1 in the formulas 7 to 9. Subsequently the deteoriation factors are aggregated into layers by taking into account each forecast year's vehicle numbers and annual mileage per first registration year.

$$DF_{j,y} = \frac{\sum_{i=FYear(j)}^{LYear(j)} DF_{i,y} \cdot N_{i,y} \cdot M_{i,y}}{\sum_{i=FYear(j)}^{LYear(j)} DF_{i,y} \cdot N_{i,y}} \quad (2.3.10)$$

2.3.1.2 Emissions and fuel use for hot engines

Emissions and fuel use results, E, for operationally hot engines are calculated for each year and layer, and urban, rural and highway driving. The procedure is to combine fuel use and emission factors, EF (and deteoriation factors for catalyst vehicles), number of vehicles, N, annual mileage numbers, M, and their urban, rural and highway shares given in Table 2.3.1. For non-catalyst vehicles this yields:

$$E_{U,j,y} = EF_{U,j,y} \cdot U_{share} \cdot N_{j,y} \cdot M_{j,y} \quad (2.3.11)$$

$$E_{R,j,y} = EF_{R,j,y} \cdot R_{share} \cdot N_{j,y} \cdot M_{j,y} \quad (2.3.12)$$

$$E_{H,j,y} = EF_{H,j,y} \cdot H_{share} \cdot N_{j,y} \cdot M_{j,y} \quad (2.3.13)$$

For catalyst vehicles the calculations becomes:

$$E_{U,j,y} = DF_{j,y} \cdot EF_{U,j,y} \cdot U_{share} \cdot N_{j,y} \cdot M_{j,y} \quad (2.3.14)$$

$$E_{R,j,y} = DF_{j,y} \cdot EF_{R,j,y} \cdot R_{share} \cdot N_{j,y} \cdot M_{j,y} \quad (2.3.15)$$

$$E_{H,j,y} = DF_{j,y} \cdot EF_{H,j,y} \cdot H_{share} \cdot N_{j,y} \cdot M_{j,y} \quad (2.3.16)$$

Subsequently the contributions from each vehicle layer and road class can be summarised in order to attain the total emissions.

2.3.1.3 Extra emissions and fuel use for cold engines

Extra emissions of SO_2, NO_x and NMVOC (as well as CO, PM, CH_4, CO_2 and FC) from cold start are simulated separately. In the model each trip is associated with an amount of cold start emission and is assumed to take place under urban driving conditions. The numbers of trips are distributed evenly on months. Firstly cold emission factors are calculated by multiplying the hot emission factor by the cold:hot emission ratio. Secondly the extra emission factor during cold start is found by subtracting the hot emission factor from the cold emission factor. Finally this extra factor is applied to the fraction of the total mileage driven with a cold engine (the β-factor) for all vehicles in the specific layer.

The cold:hot ratios depend on the average trip length and the monthly ambient temperature distribution, and are equivalent for gasoline fuelled conventional passenger cars and vans, and for diesel passenger cars and vans, respectively. An average of the temperature distribution for the years 1990-1999 is used to calculate the cold:hot emission ratios, which are displayed in Appendix 2.3.7. In the case of conventional gasoline and all diesel vehicles the cold extra emissions, CE, become:

$$CE_{j,y} = \beta \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr - 1) \quad (2.3.17)$$

For catalyst cars the cold:hot ratio is also trip speed dependent, though unaffected by catalyst wear. The EURO I ratio is used for all future catalyst technologies. However, in order to comply with gradually stricter emission standards the catalyst light-off temperature must be reached in even shorter time periods for future EURO standards. Correspondingly the β-factor for gasoline vehicles is stepwise reduced for EURO II onwards in the model. The β-factors are shown in Appendix 2.3.8.

For catalyst vehicles the cold extra emissions are found from:

$$CE_{j,y} = \beta_{red} \cdot \beta_{EUROI} \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr_{EUROI} - 1) \quad (2.3.18)$$

To end up with the total emissions per forecast year the emissions from each vehicle layer are summarised.

2.3.1.4 Evaporative emissions from gasoline vehicles

For each year in the forecast period evaporative emissions of hydrocarbons are simulated in the forecast model as hot and warm running loss, hot and warm soak, and diurnal emissions. All emission types are influenced by RVP (Reid Vapour Pressure) and ambient temperature. The emission factors are shown in Appendix 2.3.9.

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

$$R_{j,y} = N_{j,y} \cdot M_{j,y} \cdot ((1-\beta) \cdot HR + \beta \cdot WR \quad (2.3.19)$$

In the model hot and warm soak emissions for carburettor vehicles also occurs for hot and cold engines, respectively. These emissions are calculated as number of trips – broken down into cold and hot trip numbers using the β-factor - times respective emission factors:

$$S_{j,y}^{C} = N_{j,y} \cdot \frac{M_{j,y}}{l_{trip}} \cdot ((1-\beta)\cdot HS + \beta \cdot WS) \quad (2.3.20)$$

For catalyst vehicles the soak emissions are given by:

$$S_{j,y}^{fi} = N_{j,y} \cdot \frac{M_{j,y}}{l_{trip}} \cdot WHS \quad (2.3.21)$$

In the model the emissions from (20) effectively become zero since all catalyst vehicles are assumed to be carbon canister controlled. Average maximum and minimum temperatures per month are used in combination with diurnal emission factors to estimate the diurnal emissions from uncontrolled vehicles $E^{d}(U)$:

$$E_{j,y}^{d}(U) = 365 \cdot N_{j,y} \cdot e^{d}(U) \quad (2.3.22)$$

Each forecast year's total is the sum of each layers running loss, soak and diurnal emissions.

2.3.1.5 Fuel use balance

The calculated fuel use in the model must equal the statistical fuel sale totals from the Danish Energy Agency (DEA). The standard approach to achieve a fuel balance in annual emission inventories is to multiply the annual mileage by a fuel balance factor derived as the ratio between simulated and statistical fuel figures for gasoline and diesel, respectively. This method is also used in the present model.

The mileage figures for all gasoline vehicles and diesel passenger cars are multiplied by the gasoline fuel balance factor. The reason for using this factor also for diesel passenger cars is that in general the mileage information for passenger cars is considered to be fairly precise. This is reflected by the gasoline fuel balance factor, which is close to 1.00 for all forecast years in the model. The annual mileage for all other diesel vehicles is multiplied by the diesel fuel balance factor.

The final fuel use and emissions are shown in Appendix 2.3.10, along with the historical results from 1985-2000. The derived emission factors are also given In Appendix 2.3.10.

2.3.2 Other mobile sources

The emissions from other mobile sources come from the activities in multiple sectors. The emission results for 1990-2000 are taken from the annual Danish emission inventories. For military aircraft, railways, national sea traffic, fishing and aviation the emissions for 2001-2010 are calculated using fuel related emission factors for the latest historical year and fuel use from the DEA forecast. For military ground material aggregated emission factors for diesel and gasoline are derived from the road traffic emission simulations. For all sectors emission factors and fuel use figures are given in Appendix 2.3.11 for the years 2001-2010.

Table 2.3.2. Other mobile source categories.

SNAP codes	Other mobile sources
08 01	Military (ground material and aviation)
08 02	Railways
08 03	Inland waterways
08 04 02	National sea traffic
08 04 03	National fishing
08 05 01	Domestic airport traffic (LTO cycles < 1000 m)
08 05 03	Domestic cruise traffic (> 1000 m)
08 06	Agriculture
08 07	Forestry
08 08	Industry
08 09	Household and gardening

The historical emissions and derived emission factors are calculated in most detail for civil aviation. For this sector the estimations must be made separately for Landing and Take Offs (LTOs < 3000 ft) and cruise (> 3000 ft). The overall calculation scheme is firstly to estimate the fuel use and emissions for LTO. Secondly the total cruise fuel use is found as the statistical fuel use total minus the calculated fuel use for LTO. The final step is to combine this cruise fuel use with fuel related emission factors for cruise. Behind the annual estimates are relevant aircraft type/LTO statistics and energy use and emission factors for a number of representative aircraft types (Winther 1999b, 2001a and 2001b). For cruise the background data has been improved by using the results from a Danish city pair emission inventory, see Winther (2001b).

Off road working machines and equipment are grouped in the sectors: Inland waterways, agriculture, forestry, industri and household and gardening. The emission contributions from these sectors are calculated with a new model developed in the present project. In general the emissions are calculated by combining information on the number of different machine types and their respective load factors, engine sizes, annual working hours and emission factor (Winther et al., 1999). Relevant parts of the DEA statistics are used as input to the model in terms of the fuel consumption of diesel oil, gasoline and LPG. Further the statistical amount of diesel consumed determines the model activity with regard to annual working hours. The fuel use balance for gasoline and LPG is made by adjusting the amount of fuel used in the simulations for road traffic and household. The new model takes into account the implementation of a two stage emission legislation directive depending on engine size for relevant types of diesel fuelled machinery. Stage I and II of the directive become effective for new machinery in use in 1999-2001 and 1999-2003 respectively.

2.3.3 NMVOC emissions from gasoline distribution

Evaporative NMVOC emissions from gasoline stations occur during the transfer of gasoline from road tankers to storage tanks and from storage tanks to petrol vehicles.

Table 2.3.3. NMVOC emission factors for gasoline distribution in kg per tonne of gasoline.

Years	Emission factor
1985-1990	2.800
1991	2.160
1992-1995	1.597
1996	1.384
1997	1.171
1998	0.959
1999	0.746
2000-2010	0.533

The reason for the emission decline from 1985 to 2000 is the implementation of a two-stage reduction of the emission factor. In 1991-1995 the first stage was introduced to ensure the returning of the fuel vapour to the road tanker by a separate pipe. The second stage from 1996 to 2000 established a demand on the equipment that 70 % of the evaporative emissions must be recycled under practical fuelling conditions for gasoline cars. Stage II was introduced rapidly due to an economic incentive to the fuelling stations where the equipment was installed.

Table 2.3.4. NMVOC emissions from gasoline distribution in tonnes from 1985 to 2010.

Year	NMVOC	Year	NMVOC
1985	4177	1998	1947
1986	3987	1999	1527
1987	3970	2000	1067
1988	4004	2001	1131
1989	3889	2002	1143
1990	4222	2003	1149
1991	3629	2004	1158
1992	2907	2005	1166
1993	3074	2006	1169
1994	3000	2007	1172
1995	3211	2008	1172
1996	2778	2009	1171
1997	2350	2010	1168

The emissions from 1985 to 2000 are taken from the historical Danish emission inventories, while the emission forecast is produced by combining the gasoline fuel sales figures from the DEA forecast with the emission factors in Table 2.3.3.

2.3.4 Emission results

Annual emission results from COPERT III for 1985-2000 are used to achieve a full consistency in the emission time series. The use of energy by road transportation vehicles has increased in the historical time period. However, the step-wise lowering of the sulphur content in diesel fuel has brought along a substantial decrease in the emissions of SO_2. In 1999 the sulphur content was reduced from 500 ppm to the present level of 50 ppm. Historically the emission totals of NO_x and especially NMVOC have been very dominated by the contributions coming from private cars. However, the emissions from the latter types of vehicles

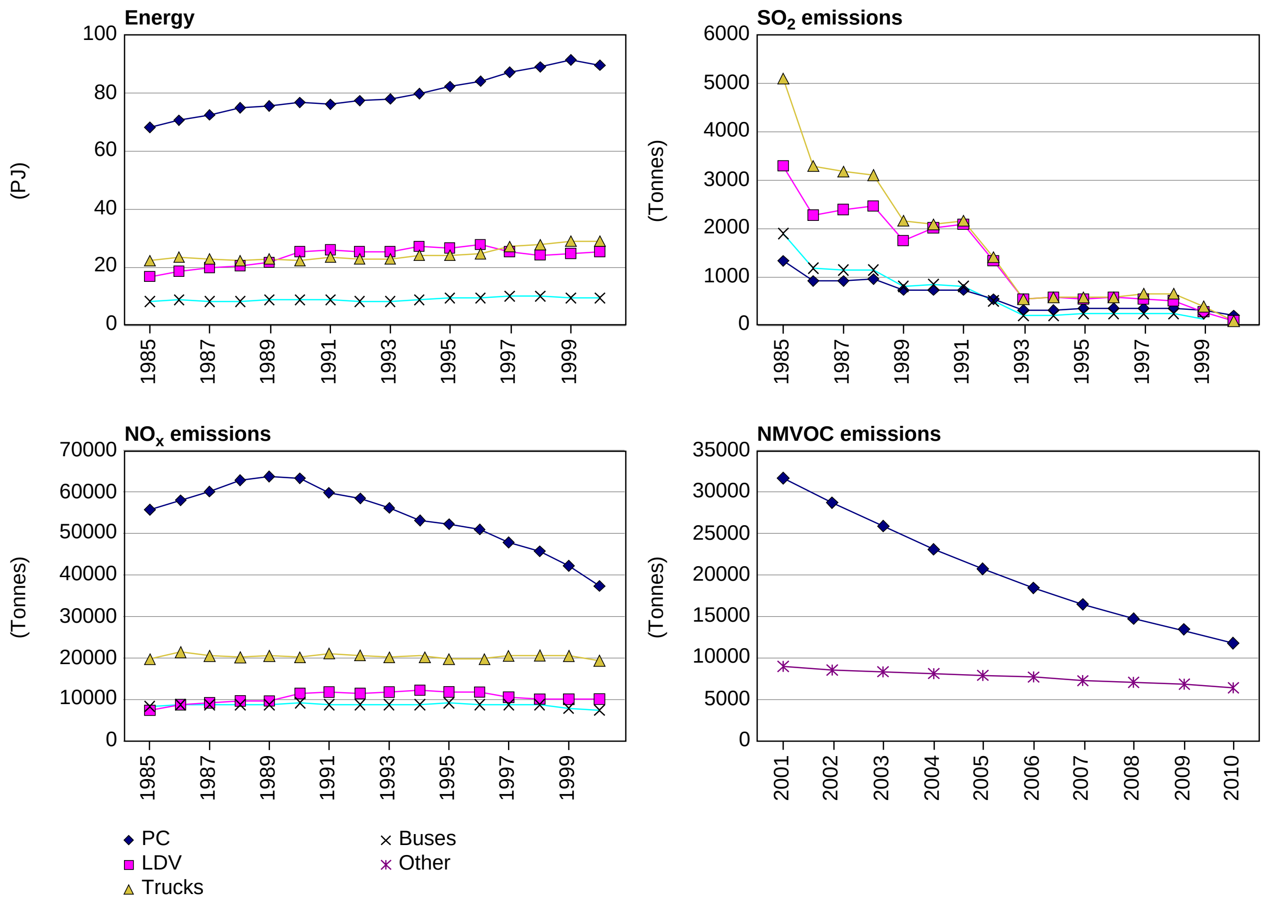


Figure 2.3.4. Fuel use and emissions for the most dominant road traffic sources in 1985-2000.

have shown a constant lowering trend since the introduction of catalyst private cars in 1990. As a side effect the same technology has given a dramatic increase in the emissions of NH_3, however still small compared with the agricultural NH_3 share. The total emission reductions of NO_x and NMVOC are fortified by the introduction of new gradually stricter EURO emission standards for all other vehicle classes, see Figure 2.3.3.

The EU emission legislation has not been as strict as for road transportation vehicles with regard to the other mobile sources and this is reflected in the emission totals. In order to explain the emission development in the following figures, the energy use in internal marine is taken as the sum of energy used by small boats and pleasure crafts, fishing vessels and ships leaving Danish ports with domestic destinations. The offroad category comprises the working equipment and machines in the agriculture, forestry, industry and household and gardening.

The overall energy use remained more or less constant throughout the whole period. However, the offroad energy use increased from the mid-1990s. The same increase is seen for the offroad NMVOC emissions due to this machinery's high NMVOC emission factors. The NMVOC emissions from small boats also increase due to an increase in fuel use for these vessels, thus causing the internal marine sector emission totals to rise. The SO_2 emissions show a remarkable decrease from 1985 to 2000. The lowering is due to the reduction of the sulphur content for marine diesel fuel and diesel fuel used by among others offroad machinery.

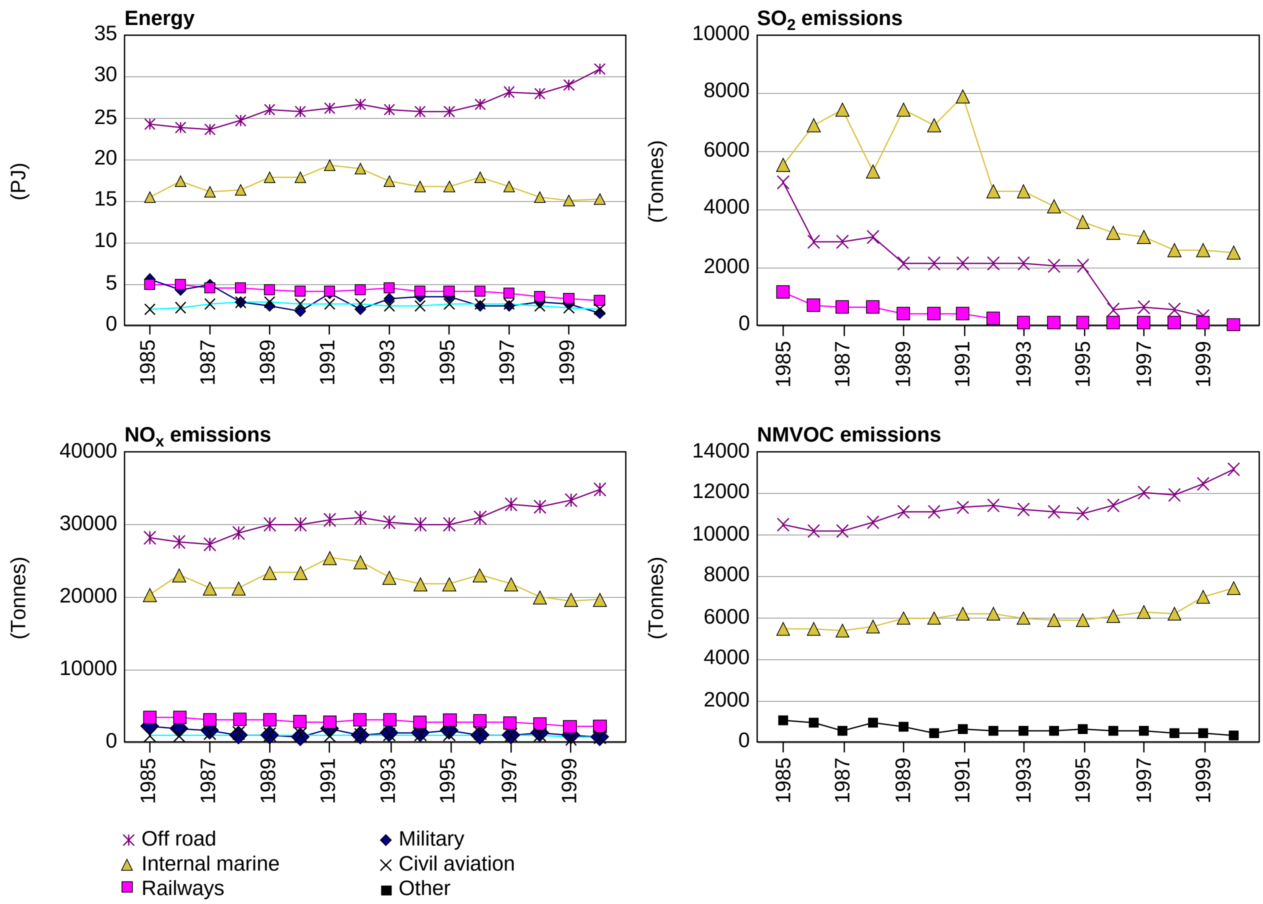


Figure 2.3.5. Fuel use and emissions for the most dominant other mobile sectors in 1985-2000.

Road traffic emissions of NO_x and NMVOC have decreased substantially since the beginning of the 1990's. Still in 2000, this sector has very dominant shares of the emission totals for all mobile sources. The shares are more than one half and two third respectively, for NO_x and NMVOC. However, these shares are smaller than the road traffic energy use share of 75 %. Off road emissions of NO_x and NMVOC are also relatively high; around one fourth and one fifth of the overall mobile totals. Their relative importance become even stronger considering the smaller energy use share of 15 %. Even though the NO_x and NMVOC emissions from internal marine are also relatively high, it is the SO_2 emissions from this sector which cause concern. This sector's emission share has made a sudden increase since the lowering of the sulphur content for all other diesel fuel types in 1999.

The emissions in the period 2001-2010 are calculated with the forecasting model described previously. Even though the road transport activities continue their increase during the forecast period the emissions of NO_x and NMVOC decrease even further. The penetration of new and lower emitting vehicles into the Danish vehicle fleet (as seen in Figure 2.3.3) more than compensate for the increase in energy use by road transportation vehicles. A strengthening of the standard for the fuel sulphur content gives a substantial SO_2 emissions decline from 2005.

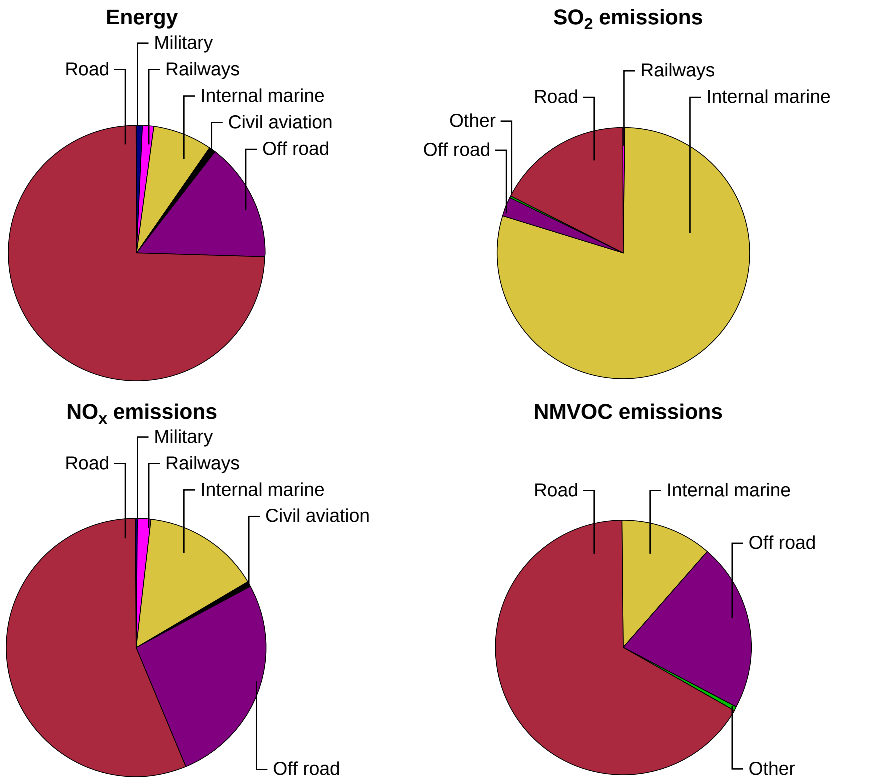


Figure 2.3.6. Fuel use and emissions in 2000 for major contributing mobile sectors.

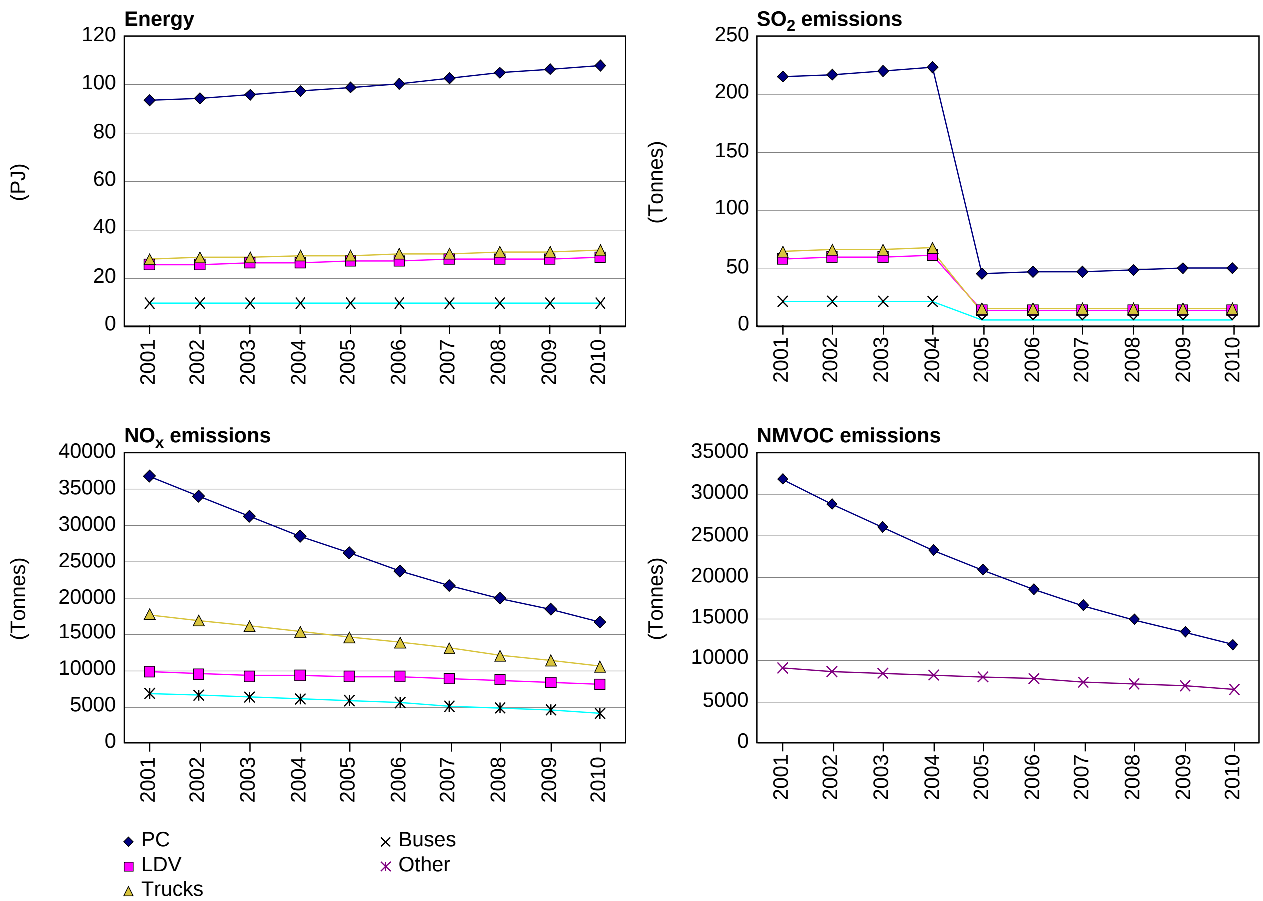


Figure 2.3.7. Fuel use and emissions for the most dominant road traffic sources in 2001-2010.

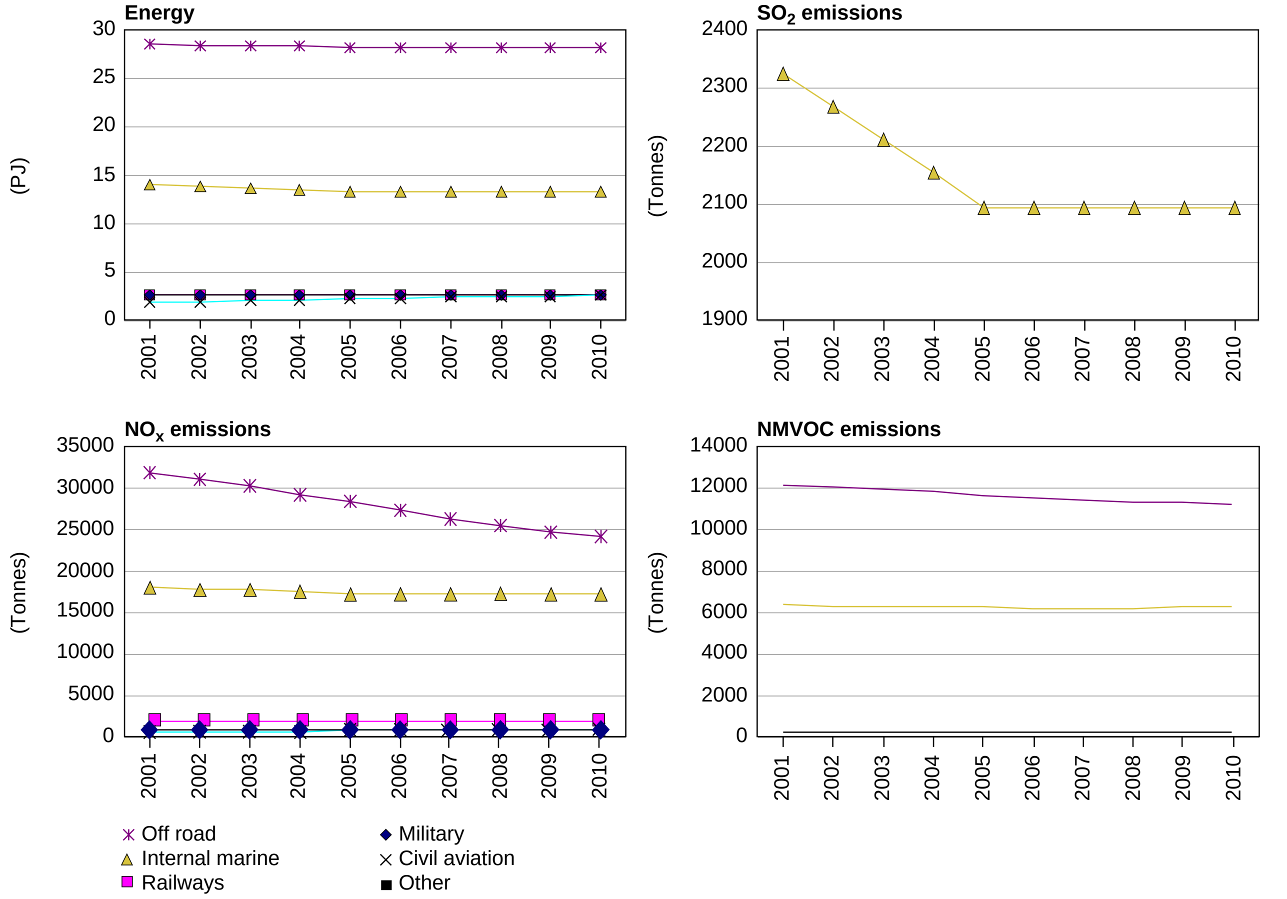


Figure 2.3.8. Fuel use and emissions for the most dominant other mobile sectors in 2001-2010.

Table 2.3.5. Emissions in 2001-2010 summarised per SNAP category.

	Year	SNAP	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
SO_2	Road traffic	07	359	363	368	374	76	77	78	80	81	82
	Other mobile	08	2404	2347	2290	2233	2114	2114	2114	2114	2115	2115
NO_x	Road traffic	07	71029	67042	63011	59194	55643	52167	48687	45556	42616	39481
	Other mobile	08	53257	52247	51217	49954	48677	47711	46789	45878	45212	44534
NMVOC	Road traffic	07	40714	37507	34382	31437	28735	26112	23846	21877	20093	18405
	Other mobile	08	18729	18564	18466	18298	18118	17995	17900	17811	17740	17663
	Gasoline dist.	05	1131	1143	1149	1158	1166	1169	1172	1172	1171	1168
NH_3	Road traffic	07	2473	2608	2762	2917	3064	3212	3343	3467	3575	3651
	Other mobile	08	6	6	6	6	6	6	6	6	6	6

In the forecasting period the energy use for other mobile sources also remains rather constant. The small decline in the derived SO_2 emissions is due to a slight decrease in the fuel use for internal marine. The offroad emissions of NO_x and NMVOC show a decline due to the implementation of the two-stage emission legislation directive for diesel fuelled machinery in 1999-2001 and 1999-2003 respectively.

As seen in Table 2.3.5 the reductions of NO_x and NMVOC emissions from road traffic are more significant from 2001 to 2010 compared to the other mobile sources. This is due to the increasingly stricter automobile emission legislation directives step-wise coming into force in the period. From 2001 to 2010 the NO_x and NMVOC shares go from 57 and 68% respectively, to 47 and 51%. The pace in which the NH_3 emissions increase slows down at the end of the 2001-2010 period depending on the catalyst vehicle penetration rate.

2.3.5 Model structure for road traffic

The software for the road traffic emission model is a database which consist of four main areas covering hot emissions simulation, calculation of extra cold emissions, estimation of evaporative emissions, and lastly a fuel balance to equal model values and statistical sale figures. In the hot emission calculation section the actual traffic data is given as input ready to use and for further processing. The following text explains how the software is organised starting with input data in tables and through data processing queries in order to end up with the final fuel use and emissions results. The model flow is also visualised in diagrams in the end of this paragraph.

Simulation of hot emissions

The table “TrafficFirstRegYear<2000” consist of the number of vehicles and annual mileage (fleet / mileage) per first registration year for all vehicle types and the historical years 1990-1999.The table “TrafficFirstRegYear2000+” consist of fleet / mileage data for passenger cars per first registration year and the forecast years 2000-2030. Informations of fleet / mileage per first registration year for the remaining vehicle types are added to the table by running the query “qATrafficFirstRegYear2000+”. The latter query use information from the tables “tblTrafficBasis” and “tblVDistribution” already prepared. The table “tblTrafficBasis” contains fleet / mileage data per vehicle type, while the “tblVDistribution” table consists of the corresponding vehicle age distribution keys.

The fleet / mileage data per first registration year and the years 1990-2030 is gathered in the query “qTrafficFirstRegYear”. In order to make the final emissions calculations the fleet / mileage data must be grouped into layers, which are classes of first registration years for individual vehicle types with the same average fuel use and emissions behaviour. This grouping is made in the “TrafficLayer” query by joining the query “qTrafficFirstRegYear” with information from the “Layer” table. However, in parallel the model has to go through an additional series of queries in order to simulate the emission effect of catalyst wear.

The initial step in this extra procedure is to create the “tblTrafficRegYearLayer” table from the query “qM_TrafficRegYearLayer”. Attached to this table is also the layer dimension. The two succesive queries “qMileage_Acc_a” and “qMileage_Acc_b” sums up the cumulated mileage per first registration year in each forecast year. The cumulated mileages are used in the “qDeg_EF_a” query along with the mileage degradation coefficients given in the “tblMilDegCoef” table. As a result the degradation factors are calculated. The latter factors are trip speed dependent and are interpolated in the query “qDeg_EF_b” to reflect the urban, rural and highway trip speeds as given in “tblCircData”. The final aggregation of degradation factors into layers is made in the “qDeg_EF_Layer” query.

The baseline emission factors per layer from COPERT III are given as input in the table “tblHotfactOldNew”. Here, the EURO I factors are repeated for vehicle layers corresponding to EURO II and onwards. The emission reduction for post EURO I layers is incorporated in the “qHotfactBasis” query by using the reduction factors listed in the "tblRedfact" table. The factors from "qHotfactBasis" are multiplied by the degradation factors from "qDeg_EF_Layer" in the query "qHotfactFinal".

In "qHotEmissions" the end calculations of hot emissions are made. They are given as the product of emission factors from "qHotfactFinal", the number of vehicles and annual mileages from "Traffic Layer" and the mileage split between urban, rural and highway driving from "tblCircData". At this stage SO_2 emissions are also estimated by incorporating information regarding fuel types per vehicle layer from the "FuelType" table. In the "qHotEmissions_Sector" query, basically the same information is given as in "qColdEmissionsYear".

Finally the hot emission results must be scaled in order to obtain a valid fuel balance which equals model results and statistical sale figures. In "qHotEmissions_Scaled" the scaling factors found in "Fuel_ScaleFactor" are multiplied by the unscaled hot emissions results from "qHotEmissions_Sector". The fuel type information from "FuelType" is also used. The scaling procedure is explained later in this section.

Calculation of extra cold emissions
In the queries "qColdEmissions_Gasoline" and "qColdEmissions_Diesel" each month's extra cold emissions are calculated for gasoline and diesel passenger cars and light duty vehicles. Both queries use information of average cold:hot ratios for the years 1990-1999 given in the tables "tblEEfact1_90_99" and "tblEEfact2_90_99". Average monthly β-factors for the years 1990-1999 in "tblBeta90_99", the future reductions in cold start periods in "tblEECoef", and fleet/mileage data per layer in "TrafficLayer" are also used. Hot baseline emission factors from "tblHotfactOldNew" are used in the case of gasoline vehicles, and for diesel vehicles hot factors from "qHotfactBasis".

All the extra cold emissions contributions are summed up in the "qColdEmissions" query, and further summed up per year in "qColdEmissionsYear". At this stage CO_2 and SO_2 emissions are also estimated using fuel type information per vehicle layer from the "FuelType" table. In the "qColdEmissions_Sector" query, basically the same information is given as in "qColdEmissionsYear".

The extra cold emission results must also be scaled in order to obtain a valid fuel balance. In "qColdEmissions_Scaled" the scaling factors found in "Fuel_ScaleFactor" are multiplied by the unscaled extra cold emissions results from "qColdEmissions_Sector". The fuel type information from "FuelType" is also used. The scaling procedure is explained later in this section.

Estimation of evaporative emissions
To estimate the evaporative emissions for gasoline vehicles fleet/mileage data per layer is used from "TrafficLayer" along with each month's emission factors from "tbEVfactNew", data for the emission distribution per road type in "tblCircData" and average monthly β-factors for the years 1990-1999 in "tblBeta90_99". The evaporative emissions are calculated in "qEvapEmissions", and are

further summarised in "qEvapEmissionsSum". The running loss emissions are scaled with the fuel scale factors from "Fuel_ScaleFactor" also using the fuel type information from the "FuelType" table. The scaling is made in the query "qEvapEmissions_Scaled", and is explained later in this section.

Fuel balance

A table "FuelType" is created which contains information of fuel type per layer and fuel scale type. The fuel type and scale type are identical except for diesel passenger cars which should be scaled as gasoline. The next step is to sum up all fuel use calculated by the model in the query "qFuel_Cal_Types". The statistical fuel sale figures are given in the "FuelTotals" table and for gasoline the total is compared with the model fuel use in "qFuel_Scalefactor_Gasoline_MakeTbl". The latter query makes the table "Fuel_ScaleFactor" with computed scaling factors; at this stage only for gasoline vehicles.

In the query "qFuel_Diesel_Scaled_As_Gasoline" the modelled diesel fuel is taken from "qFuel_Cal_Types" and for diesel passenger cars the fuel use is scaled according to the gasoline fuel scale factor given in "Fuel_ScaleFactor". In a final step the diesel fuel scale factors are found in "qFuel_Scalefactor_Diesel_Append". And at the same time these factors are appended to the "Fuel_ScaleFactor" table.

Changing basic scenario run

If new input data becomes available or if there is a need to investigate the emission impact of changing some of the model parameters it is possible to make alternative basic scenario runs. A way to establish a new scenario is 1) to input new emission and fuel use factors, 2) to make changes in the vehicle composition with respect to absolute vehicle numbers or the relative distribution in layers or 3) to change the annual mileage driven for individual vehicle layers (or per first registration year).

In the model emission and fuel use factors can be changed by feeding new data to the table "tblHotfactOldNew". Changes to the vehicle composition and mileage can be made by entering own values per first registration year for passenger cars in the table "TrafficFirstRegYear2000". The total vehicle number (and mileage per vehicle class) for other vehicle categories can be altered in the table "tblTrafficBasis", while the distributions into first vehicle numbers per registration year can be changed in the table "tblVdistribution".

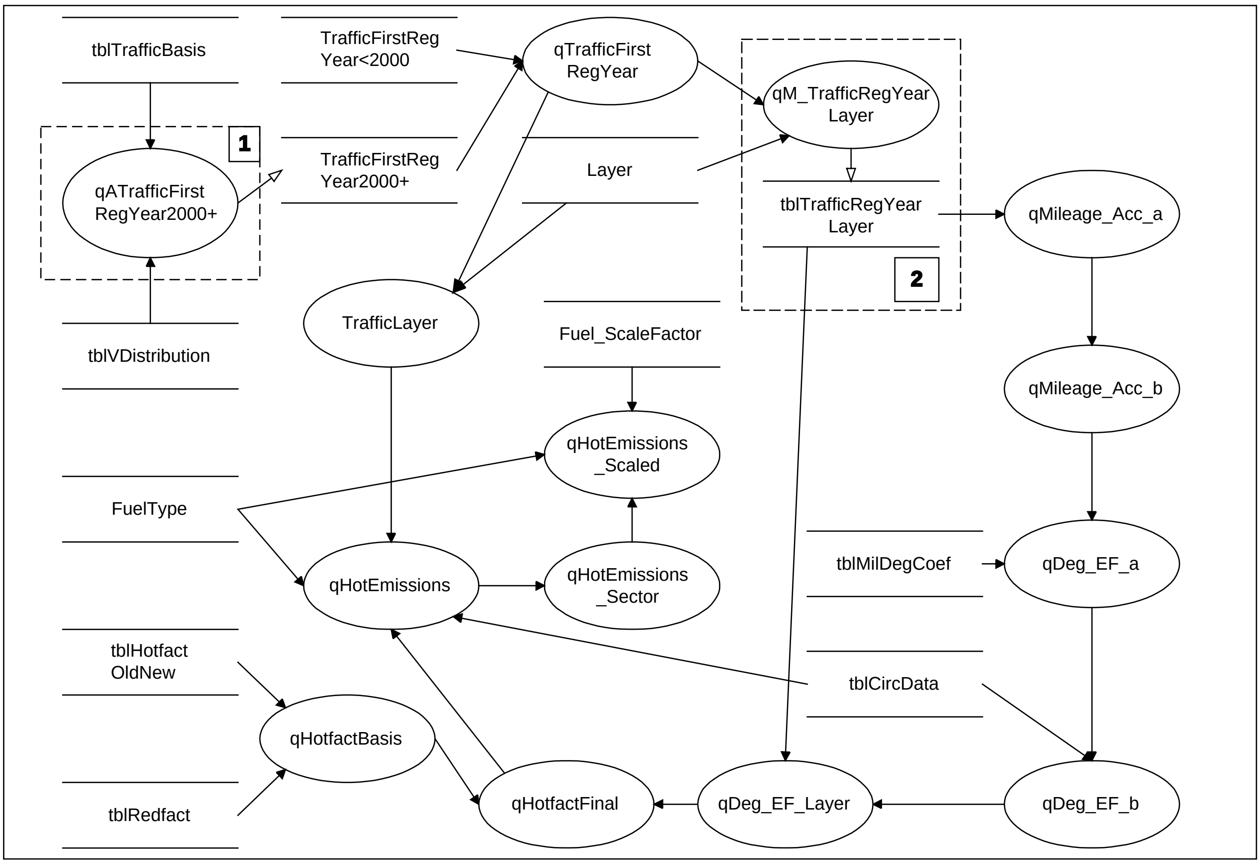


Figure 2.3.9. Flow chart: hot emissions calculation.

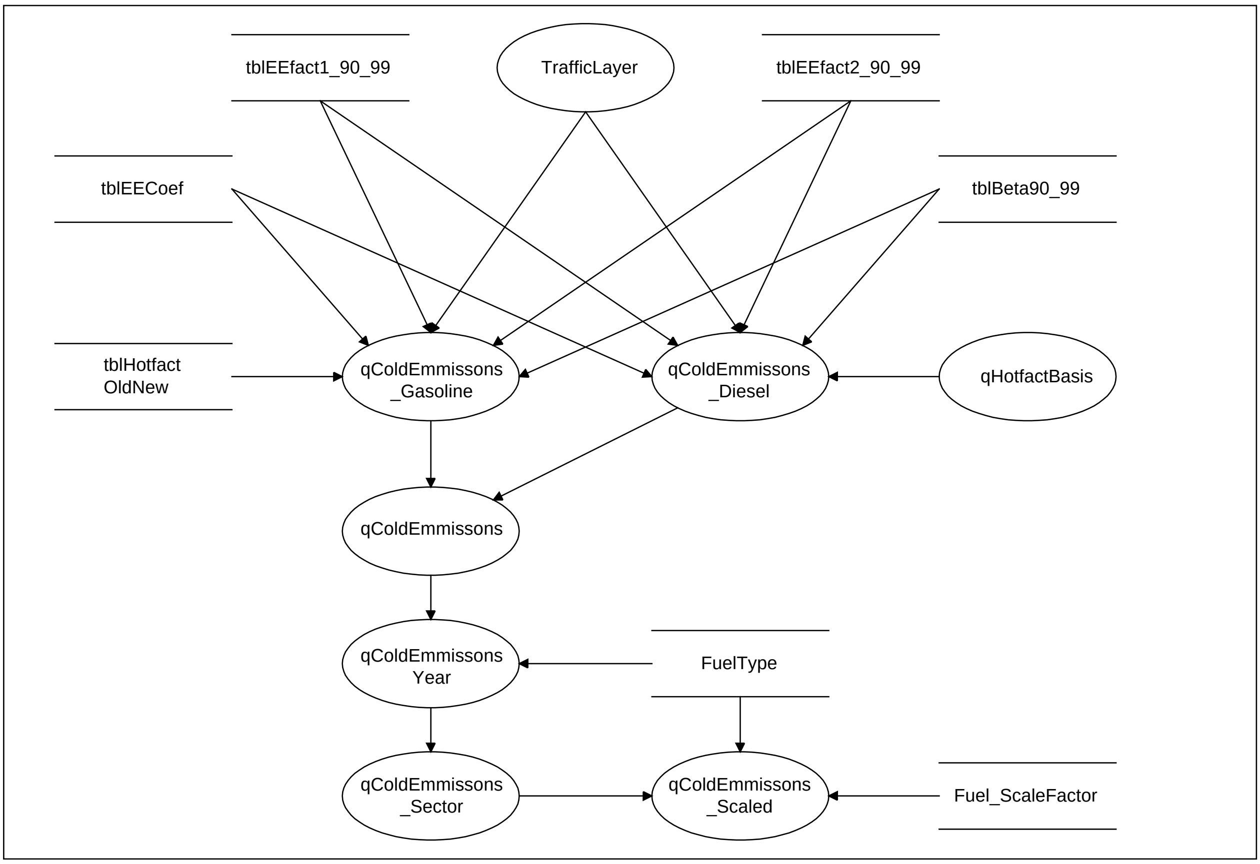


Figure 2.3.10. Flow chart: cold emissions calculation.

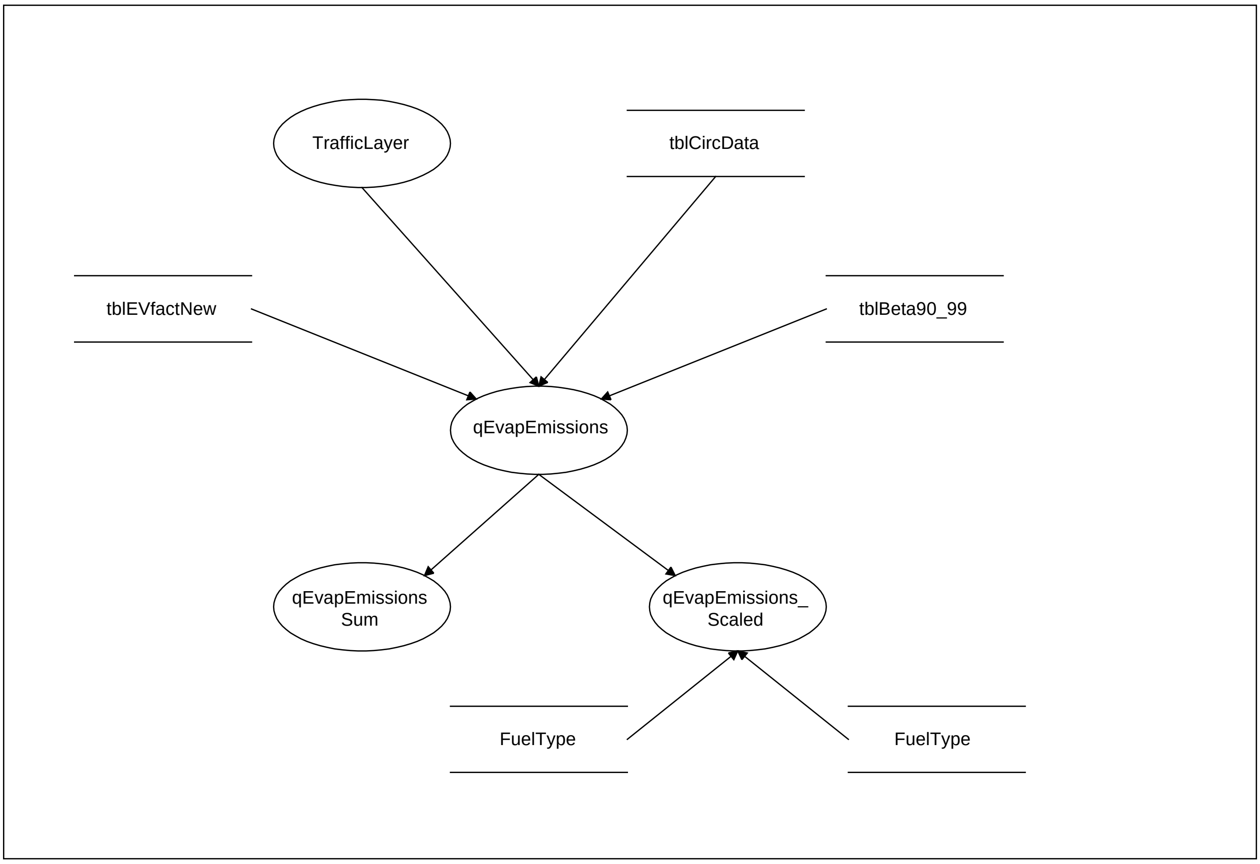


Figure 2.3.11. Flow chart: evaporation emissions calculation.

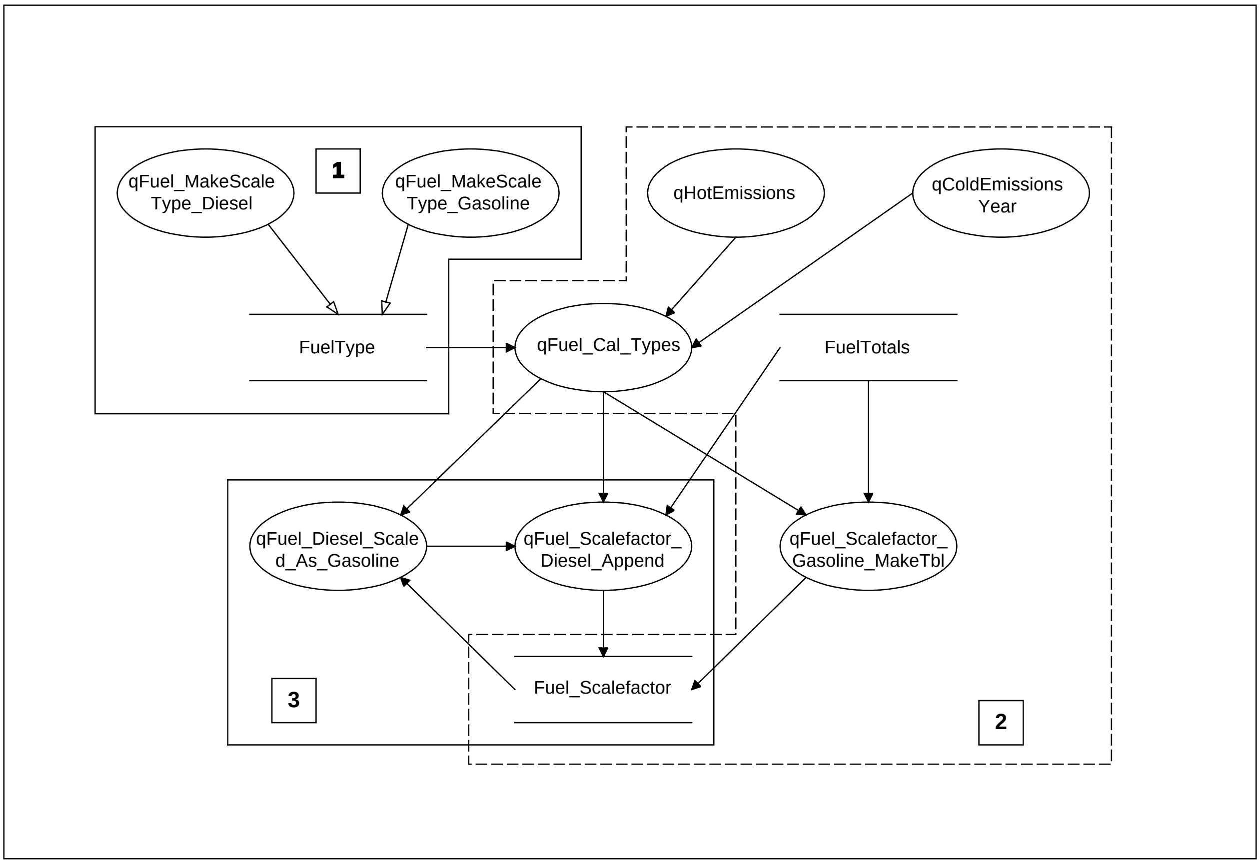


Figure 2.3.12. Flow chart: fuel balance module.

2.4 Agriculture

The ammonia emission in Denmark is primarily caused by agricultural activities. Danish agriculture contributes with 98% of the total emission. The remaining 2% are emitted from traffic (year 2000). The emission from agricultural activities is estimated based on emission from livestock manure, artificial fertilisers, emission from crops, enteric fermentation of straw and other small sources (Eq. 2.4.1).

$$E_{\text{NH3, total}} = E_{\text{NH3, livestock manure}} + E_{\text{NH3, artificial fertilizer}} + E_{\text{NH3, crops}} + E_{\text{NH3, enteric fermentation}} + E_{\text{NH3, others}} \quad (2.4.1)$$

The amount is to a large extent influenced by the number of livestock, because manure contributes with 78 % of the total ammonia emission (Fig. 2.4.1). The ammonia emission from crops and artificial fertilisers contribute to the total emission with 13 % and 7 % respectively, meanwhile emission from sewage sludge on agricultural soils and straw treated with ammonia (for feeding) amounts to less than 3 %.

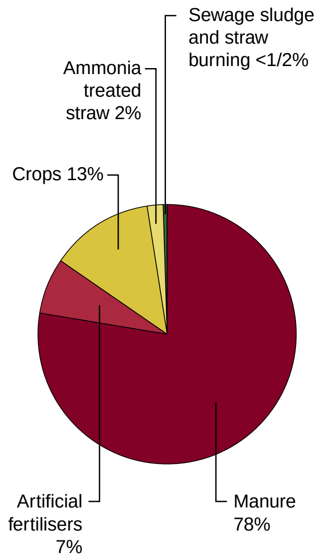


Figure 2.4.1. Ammonia emission from agricultural activities (2000).

About one third of the total loss of nitrogen from agricultural activities is lost as ammonia. The main part of the ammonia will be deposited within a short distance from the source. A small part will react with particles in the air. These particles can be transported over long distances.

Ammonia emission is seen as the main source to air pollution in the countryside. Ammonia adds to the acidification of the soil, increased growth of algae in lakes and coastal waters and changes in the ecosystem in nitrogen poor natural areas such as heaths, raised bogs, common fringes and some wood lands. An unintentional high supply of nitrogen as in the case of ammonia deposition may result in more nitrogen tolerant plants ousting other plants and thereby reducing the number and variation in habitats and the biodiversity.

As ammonia moves across frontiers international focus has been put on the reduction of the ammonia emission. In connection with the NEC Directive (Directive 2001/81/EC – 23 Oct. 2001) and the Gothenburg Protocol, Denmark has agreed on an emission target of 69000 tonnes ammonium (NH_3) (56800 tonnes NH_3-N) in 2010. The emission target does, however, not include ammonia emission from crops and ammonia treated straw for feeding.

In year 2000 the ammonia emission from agriculture exclusive emission from crops and treated straw has been estimated to 85900 tonnes NH_3, which means that the emission should be reduced within the next ten years (Fig. 2.4.2). In connection with the Action Plan on the Aquatic Environment II from 1998 and the preparation of an ammonia reduction plan from agriculture from 2001 some actions have been taken to reduce the ammonia emission.

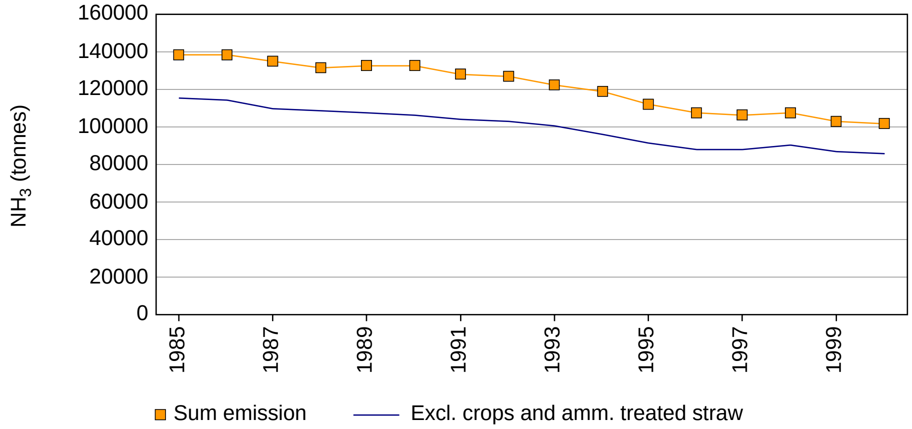


Figure 2.4.2. Ammonia emission (NH_3) from the agricultural sector 1985 - 2000.

A model has been developed in this project to estimate the emission from the agricultural sector in year 2010. The projection is based on the past development in Danish agriculture and expectations to the future.

The projection is based on the method used in the emission inventory. It is however important to note that the emissions in this projection are larger than earlier ones. The reason for this is that new knowledge has led to a revision of previos calculations. The consequense of the revised calculations is that the overall emission from agricultural sector are estimated to be 9% higher in 1999 compared to earliere estimates (NERI, 2002). There are several reasons for the revised calculations. The most important reason is due to changes in the estimate of manure handling. In Appendix 2.4.1 the results of both old and new emissions are listed.

2.4.1 Assumptions

This is a brief description of the assumptions used for the basic scenario. For detailed information about nitrogen-turnover, emission factors, stable types, methods of storing etc. (Poulsen et al., 2001 and Andersen et al., 2001).

In the assumptions all major important factors affecting ammonia emission have been included, however, it has not been possible to include all details.

In recent years focus has been on the reduction of the ammonia evaporation by means of technical measures in both stables and by storage of the manure. A number of examinations of possible steps and effects for the emission have been initiated but knowledge and experience in the area is still insufficient. Therfore a decision has been made not to include the technological development in the projection. However, it is pointed out that technical solutions will have an essential importance for the reduction of the total ammonia evaporation provided that the costs measures up to the reduction of the emission.

The development in the agricultural sector does not only depend on the legislation on the national level, but especially on the agricultural policy in the EU. In this forecast it is assumed that today's policy will continue although modifications to the subsidiaries known today may occur when the enlargement of the EU to the east comes into effect in 2006. Therefore no attempts are made to incorporate possible changes in the agricultural production based on changes in the subsidiaries. Furthermore it is assumed that the EU will continue to cover 50% of the costs on forestation on agricultural soils, a continued subsidiary to environmental friendly agricultural growing and conversion to organic farming.

2.4.2 Husbandry manure

The turnover and excretion of nitrogen and ammonium from livestock are based on published Danish standard data for nitrogen turnover in animals and storage (Poulsen et al., 2001) combined with personal information from The Danish Institue of Agricultural Sciences, Danish Agricultural Advisory Centre, The Danish Poultry Council, Copenhagen Fur Centre and Statistics Denmark. In cases where a higher nitrogen-efficacy in the fodder is estimated, this may lower the free ammonium content in the faeces and urine. The lower ammonium content may reduce the emission rates. The effect of this is unknown and therefore the same emission coefficients from manure and slurry is used in all years.

The total emission per livestock category is calculated as follows:

$$E_{total} = E_{stable} + E_{stock} + E_{spreading} + E_{\mathrm{grassing}} \qquad (2.4.2)$$

Where E_{total} = *Total Emission (tonnes year^{-1})*
E_{stable} = *Emission from stables and barns (tonnes year^{-1})*
E_{stock} = *Emission from storage and tanks (tonnes year^{-1})*
$E_{spreading}$ = *Emission from manure spread in the field (tonnes year^{-1})*
$E_{grassing}$ = Emission from manure left in the field (tonnes year^{-1})

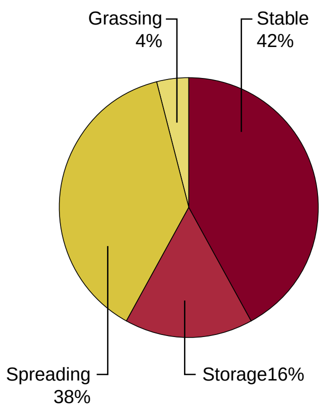


Figure 2.4.3 Ammonia emission from manure, 2000.

Figure 2.4.3 shows the allocation of the ammonia emission from manure for the year 2000. The evaporation from stables make up 42% of the total emission. 16 % of the evaporation occurs in connection with the storage, 38 % from manure spread in the field and the remaining 4 % from manure left in the field.

The emission from livestock manure is divided into the different husbandry categories. For every livestock category an evaluation has been made in the earlier development and expectations for the future. This includes the overall production (produced numbers), nitrogen efficacy in the fodder, genetically improvement in milk production or number of offspring, export possibilities, environmental regulations, market development, development in stabling, grazing days, time of spreading and spreading method of the manure.

Appendix 2.4.2 – 2.4.5 shows a detailed view of the husbandry production, stable type allocation, method and time of spreading and the emission coefficients used in the projection.

2.4.2.1 Cattle

In 2000 there were 636000 dairy cows and 125000 cows were kept for suckling. The Danish milk quota of 4454-mio kg milk EKM (Energy Corrected Milk) limits the number of dairy cows. The average milk production per cow is still increasing due to breeding and improved feeding. Figure 2.4.4.A shows the milk production per cow since 1985. The milk production has on average increased by 90.3 litre per cow per year from 1985 to 2000. It is assumed that the Danish milk quota will remain on the same level until 2010. From 2000 to 2010 the amount of milk per cow is expected to continue with an increase of 100 litre per cow per year. In 2010 the annual production is thus expected to be 8318 kg per cow. At the same time excretion of ammonium per cow will increase due to the increased demand for milk production. The increase in milk production may be underestimated because of the very fast structural development in the milk production at the moment.

Consequently the herd of dairy cows will decrease from 636000 in 2000 to 559100 in 2010 (Fig. 2.4.4.B) (it is assumed that 12% of cows is Jersey). The number of offspring will decrease to the same extent as the number of dairy cows.

For suckling cattle a small reduction from 125000 to 115000 cows is assumed because of low market prices on meat.

The ongoing structural reorganisation is at the moment very fast and intensive. E.g. in 2001 20% of the Danish milk quota were offered for sale on the milk stock exchange of which only half were sold. The development is especially due to poor economy in the primary production, which increases the rationalisation. As an effect old tied-up stables in which 46% of the cows were kept in 2000 are outdated and replaced by larger loose-holdings. Within the last few years a very high number of new stables have been built and these stables will be the dominating stable types in the future. In 2000 nine out of ten new stables were loose housing stables (Danish Agricultural Advisory Centre). In 2010 almost all dairy cows are expected to be in loose-holdings.

In loose-holdings the cows have more space and this will increase the ammonia emission per cow compared to the old tied-up stables (Table 2.4.1).

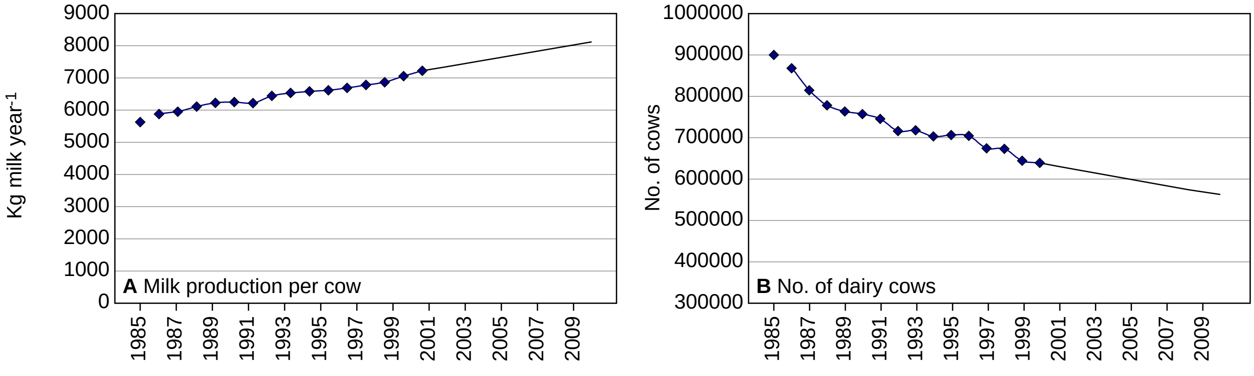


Figure 2.4.4.A. and 2.4.4.B. Development in milkproduction, number of dairy cows 1985-2000 and the expected development until year 2010.

Table 2.4.1. Estimated ammonia emission from different stable types, kg NH_3-N per cow per year.

Dairy cows	Stable type (2000) pct.	Ammonia emission kg NH_3-N per cow per year	Average emission kg NH_3-N per cow per year[1]
Tied-up with liquid and solid manure	18	20.59	21.30
Tied-up with slurry	28	21.76	
Loose-holding with beds and slatted floor	34	26.33	26.45
Loose-holding with beds, solid floor and scrapers	6	28.16	
Deep litter, slatted floor	7	26.22	26.35
Deep litter, solid floor and scrapers	3	26.95	

[1] weighted average ammonia loss throughout the production period (stable, storage, spreading and grassing).

Because the number of cows in loose-holdings with beds is expected to be very high in 2010 slurry will then be the main manure type in 2010. The number of loose-housing cows on deep litter is expected to be constant on 10% of the total number of cows. This is primarily due to the costs of managing the straw in the field and in the stable.

Figure 2.4.5 shows the development in number of dairy cows per farm. In 2000 the average herd size is 61.5 and in 2010 the average herd size is estimated to 100-110 dairy cows indicating that the source point pollution will be higher.

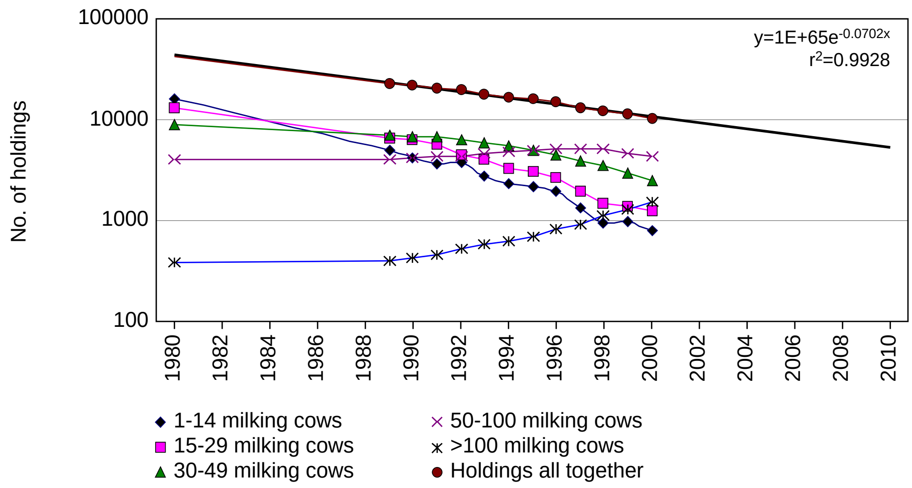


Figure 2.4.5. The number of holdings with dairy cows 1985-2000.

2.4.2.2 Pigs

The amount of the pork production depends on the actual world market prices on pork meat and export possibilities. Since 1985 the pork production (incl. exported and dead animals) has increased from 15.1 mio pigs to 22.7 mio per year in 2000 or an annual increase of 2.5%. The increase has been favoured by the fact that Denmark has had no outbreaks of swine fever or foot-and-mouth disease as has been the case in other European countries. This has resulted in an improved market in

Europe, USA and Japan. In 2001 the prices on pork meat were very high which should increase the pork production further.

However, the forecast for prices on pork meat in 2002 is very low - approx. 1.2 EURO per kg (Danish Bacon and Meat Council). This will prevent the farmers from continuing a rapid increase in pig production. Furthermore only a restricted amount of manure applied per hectare is allowed making it more and more difficult to increase the production in areas where pork production traditionally takes place. Therefore an increase in pork production of 3.6 mio pigs or 1.5 % per year until 2010 is assumed ending up with 26.3 mio produced pigs in 2010. It is assumed that export of 1.1 mio. piglets per year will continue till 2010 and the mortality rate is assumed to be at the same level for both piglets (3.6 %) and slaughter pigs (3.6 %).

The number of sows to produce the piglets for meat production is a function of the number of pigs per litter and how fast the piglets are weaned and mortality rates. From 1985 to 2000 the number of pigs weaned per litter has increased from 18.2 to 22.3 (Fig. 2.4.6) or 0.34 piglets per year. From 2000 to 2010 an increase in the production of piglets per sow is estimated to 0.3 per year or slightly lower than in the previous period because the number of pigs per litter is biologically limited and because time of weaning is difficult to reduce further. The number of year sows is expected to increase by approximately 3000 annually, corresponding to the increase in the number of slaughter pigs.

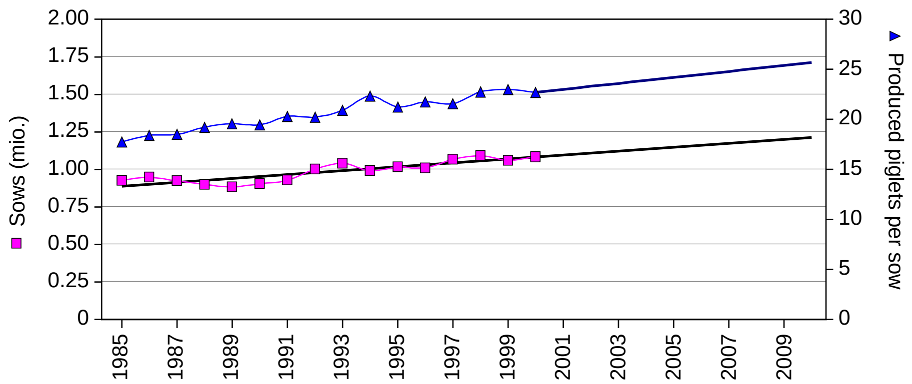


Figure 2.4.6. Number of Sows and Piglets per sow, 1985-2000 and estimation for 2000-2010 (Statistics Denmark).

An improved nitrogen-efficacy in the fodder of 10 % is expected for sows and piglets and 8% for slaughter pigs in 2010 compared to 2000. This efficacy level is achieved today by 25 % of the farmers.

The stable types in 2010 are only expected to differ marginally from now. Two acts are coming into force that may affect the ammonia emission. EU directive concerning housings of sows (Council Directive 2001/88/EC of 23 October 2001), which has to be implemented in all new buildings from 2003 and a Danish act about housing of piglets and slaughter pigs (Act no. 104 of 14 February 2000), which says that in new-built stables at least one third of the floor for slaughter pigs and half of the floor in piglet stables has to be solid or drained.

Furthermore the pigs must have access to straw or other types of bedding material. The act must be fully implemented in 2015.

Because the existing buildings are quite new the acts will only have limited effects on the ammonia emission. The consequences of the acts are incorporated in the scenario. The use of deep litter especially in combination with slatted floor is expected to become more common in new stables. Changes in stable types for pigs will not have the same consequences in the estimated ammonia emission as for cattle (Table 2.4.2).

Table 2.4.2. Estimated ammonia emission from different stable types, kg NH_3-N per pig per year.

Pigs	Stable type (2000) pct.	Average emission kg NH_3-N per pig per year[1]
Full slatted floor	58	0.95
Partly slatted floor	31	0.85
Solid floor	5	1.16
Deep litter	6	1.19

[1] weighted average ammonia loss throughout the production period (stable, storage, spreading and grassing).

2.4.2.3 Remaining animal husbandry

Sheep and Goats

Statistics Denmark registered 68000 mother sheep in Denmark in 2000. However, the number is expected to be higher because the Statistics Denmark count only includes farms larger than 5 ha and thus the number has increased by 20 %. An unchanged number is expected in 2010. For goats the number is estimated to be 10000 mother goats in 2000 which is expected to increase by 500 per year until 2010 (Danish Agricultural Advisory Centre). No changes in fodder efficacy and stabling are assumed.

Poultry

The number of egg laying hens is expected to increase by 6% from 2.86 mio to 3.04 mio (The Danish Poultry Council). A small increase is expected in both organic farmed hens and in the number of caged hens but with changed manure handling. The chicken production (incl. exported and dead chickens) is expected to increase from 139 mio to 162 mio in 2010. The production is expected solely to be conventional production. The number of broodings is increasing in accordance with the increase in poultry. The nitrogen efficacy in the fodder is increasing with approximately 12 % for egg laying hens and 6% for broilers (The Danish Poultry Council).

For turkeys, ducks and geese an unaltered production and nitrogen efficacy in the fodder is assumed.

Fur farming

For mink and foxes an unchanged number of 2.1 mio female mink and 11000 vixen is expected in 2010. An increased number of whelps per litter may be expected in the future which may increase the fodder efficacy. In the period from 1995 to 1999 the nitrogen excretion per mink was constant despite of an increased number of whelps per litter (Møller et al., 2001) and this is assumed to continue in the future.

92 % of the nitrogen in the fodder is excreted again. Of this 84 % can be found in urine and the remaining in faeces (Børsting, 2001). The nitrogen in the urine is primarily ammonium, and consequently emission from fur farming is high. It is possible to reduce the nitrogen content in the fodder without effects on numbers of offspring and fur quality (Børsting, 2001). However, no economical incitements exists to reduce the nitrogen content in fodder, as in the case of pigs, because the fodder is primarily trash fish and offal from the slaughterhouses. Because of the lack of incitements no improved nitrogen-efficacy is incorporated in the scenario.

On the basis of the present revision of the Statutory Order on Fur Animals it is expected that in 2010 all mink are housed in cages with underlying manure collectors to reduce the emission.

Horses

Statistics Denmark registered 40000 horses in 2000 but this count only includes farms larger than 5 ha. According to the Danish Agricultural Advisory Centre, the total number of horses is 150000 and it is expected to increase by 10% or to 165000 horses in 2010. No changes in stabling and fodder are expected.

2.4.2.4 Annual production

Table 2.4.3 shows the number of produced animals per year in 2000 and the expected production in year 2010 in the various livestock categories. Appendix 2.4.2 lists the annual production of all livestock categories and for all the years in the projection period.

Table 2.4.3. The annual production for 2000 and the expected annual production for 2010.

Annual production	2000 Number of animals per year	2010 Number of animals per year	Change pct. per cent
Livestock categories			
Dairy cows	635500	559100	- 12
Remaining cattle categories	2359100	2072400	- 12
Slaugther pigs	22682200	26323600	16
Sows	1083200	1113100	3
Piglets	24142300	28018100	16
Sheep and goats	91300	96300	6
Horses	150000	165000	10
Hens and Pullets 100 produced units)	76400	77000	1
Broilers (1000 produced units)	139200	162400	17
Turkeys, ducks, geese (100 produced units)	25800	25800	0
Mink	2187900	2187900	0
Foxes	11000	11000	0
Total number of animal	53583900	60811700	14

2.4.2.5 Grazing

The amount of grassing is expected to be unaltered. E.g. the amount of manure deposited in the field is 15 % (average 55 days per year) from dairy cows, 55 % for young stock more than a half year old, 61% for suckling cows, 73 % for sheep and goats and 50 % for horses.

7 % of the nitrogen in faeces and urine deposited in the field is expected to emit as ammonia (Andersen et al., 1999).

2.4.2.6 Emission from stables

The ammonia emission from stables is closely related to the ammonium (NH_4^+) content in faeces and urine. NH_4^+ is in an equilibrium state with NH_3 and NH_3 is extremely volatile and may emit into the air. The volatilisation rate primarily depends on the surface area and pH of the manure or slurry and the ventilation and temperature in the stable. The emission from stables are thus determined by a number of different conditions that strongly depend on the type of stable and the different kinds of manure disposal systems placed in these stables. A systematic statement of the stabling of husbandry does not exist and the stabling is therefore based on estimates (Rasmussen, J.B. and Lundgaard, N.H., pers. comm.). See Appendix 2.4.3.

The Danish Institute of Agricultural Sciences (DIAS) has estimated emission coefficients for different types of stables in Denmark (Poulsen et al., 2001). However, big differences in the evaporation exist within the same stable types because of variations in the contruction of the floor, temperature, ventilation system and bedding amounts etc. Therefore the coefficients are subject to some uncertainty. The estimated emission coefficients are listed in Appendix 2.4.4 along with the remaining emission coefficients for storage, spreading and in connection with grazing.

Emission factors are maintained during the entire projection period, which means that the possibility of a development towards technical improvements with ammonia reducing effects in stables have not been taken into consideration.

2.4.2.7 Storage of solid manure and slurry

Livestock manure is collected either as solid manure or as slurry depending on type of stable. In the future the storing of solid manure is expected to be unaltered. E.g. that the part of solid manure taken directly from the stable into the field is expected to comprise 80 % from cattle, 25 % from pigs, 50 % from sows, 15 % from poultry and 5 % from hens. The remaining part of the solid manure is spread in stack piles in the field.

By law (BEK no. 877 of 10-12-1998) all slurry tanks have to be covered by floating manure in order to reduce ammonia emission from the tanks. In 2000 5% of the tanks with cattle slurry and 20 % with pig slurry were incompletely covered (COWI, 2000). The projection takes the lack of covering into account and in 2010 incomplete covered tanks are expected to be reduced to 5 % for cattle and 10 % for pigs. The emission coefficients for the year 2000 in slurry tanks with cattle slurry have been estimated to 2.2 % and for pig slurry to 3.4 %. Improvements of the cover capacity means that the emission coefficients are expected to reduce to 2.2 % for cattle slurry and 2.7 % for pig slurry.

The used emission factors by storage is shown in Table 2.4.4 and is based on information from DIAS (Poulsen et al., 2001). It should be noted that no survey has been made on the emission from manure from poultry, horses, sheep, goats and furred animals and the losses are therefore estimated on the basis of knowledge on loss from the rest of the husbandry groups. With the exception of the emission coefficients from slurry tanks the coefficients remain unchanged in the entire projection period.

Table 2.4.4. Emission factors on storage of livestock manure.

	Solid manure	Liquid manure	Slurry	Deep litter	
	NH_3-N in percent of total N ab stable				
Cattle	5	2	2,2[1]	8,8	
Pigs	25	2	3,4[2]	12,5	Year sows
	25	2	3,4[2]	25	Piglets
	25	2	3,4[2]	18,8	Slaugther pigs
Poultry	5	-	2 (hens)	9,5	Hens + Pullets
	-	-	5 (pullets)	12,8	Broilers
	-	-	-	15	Turkeys, ducks + geese
Furred animals	15	0	2	-	
Sheep/goats	-	-	-	5	
Horses	-	-	-	5	

[1] Reduced to 2.0 % in 2010 due to improvement of the covering of slurry tanks.
[2] Reduced to 2.7 % in 2010 due to improvement of the covering of slurry tanks.

2.4.2.8 Spreading of Manure

The ammonia emission in connection with the spreading of manure depends among other things on the time of spreading, the spreading method and whether the manure is spread on bare soil or on growing crops. There is no statistical information on how the farmer handles the manure in practice and it is therefore based on estimate (Andersen et al., 1999). On the basis of this estimate an aggregated emission coefficient is calculated for solid manure and slurry respectively. The aggregated emission coefficient will thus vary from year to year depending on changes in the practice of spreading.

During the last few years a number of changes have taken place in manure handling (BEK no. 877 of 10-12-1998 and later alterations). In connection with the coming revision of the Statutory Order of Livestock further steps are being initiated to reduce the ammonia evaporation. It is thus expected that:

- a prohibition on broadspreeding of manure is stipulated from 2002
- the manure spread on bare soil must be ploughed within 6 hours. It is reduced from the present 12 hours.

The proposals have the consequence that nitrogen in manure has become more precious as fertiliser in the crop production. It is therefore expected that a greater part of the field-applied slurry will be directly incorporated in the soil. In 2000 only 7 % of the slurry is incorporated in the soil, 56 % spread by trailing hoses and 37 % broad spread. In 2010 it is assumed that 35 % of the slurry will be incorporated in the soil and 65 % spread by trailing hoses (Fig. 2.4.7). No changes in the proportion applied in the autumn and in the spring until 2010 is expected.

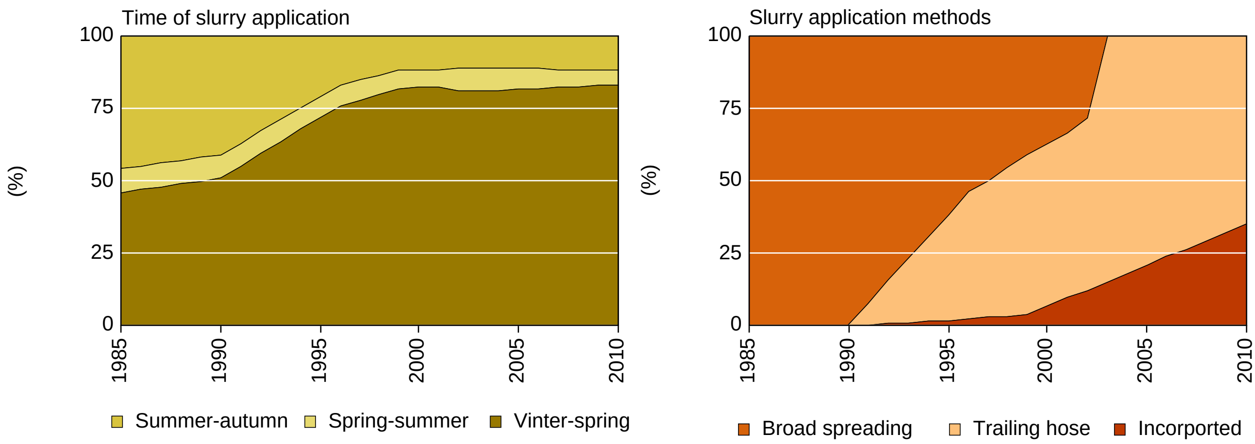


Figure 2.4.7 Time and methods for slurry application.

All slurry applied to spring cereals, beets and silage maize is expected to be incorporated into the soil, because calculations have shown that it is economically feasible today (Danish Agricultural Advisory Centre). In total 83 % of the slurry is expected to be applied during spring and the remaining part in summer/autumn (before 15 October). Of solid manure 65 % is expected to be applied in the spring and the remaining part in the autumn.

Appendix 2.4.5 shows the estimated spreading practice until the year 2010 and the calculation of the aggregated emission coefficients. When calculating the ammonia emission from spreading of manure an aggregated emission coefficient for solid manure on 6.8 % is used in 2000 and for slurry the number is 14.1 %. This means that on the basis of the spreading practice in 2000 it is estimated that 6.8 % of N storage of solid manure will be lost in the shape of ammonia evaporation. In 2010 the emission coefficients for solid manure are expected to be reduced by 11.7 % and 3.7 % for slurry, which is due to the prohibition on broadspreeding of liquid manure, introduction of the statutory requirement to reduce the period before the manure is incorporated into the soil from 12 hours to 6 hours and increased demand to the N-explotation in livestock manure.

2.4.3 Crops

Ammonia emission may occur from green plants and especially from fertilised crops. The amount of the emission from different crop types and even between fields with the same crop differs significantly and is not well understood. Variations from ½ to 15 kg NH_3-N per hectare can be found in literature (Andersen et al., 2001). Because of lack of well-documented figures for difference between crop types an average emission of 5 kg NH_3-N per hectare per year for cash crops and 3 kg NH_3-N per hectare for grass within rotation is used. The emission from organic grown fields is estimated to 2½ kg NH_3-N per hectare per year from cash crops and 1½ kg NH_3-N per hectare per year for grass (Andersen et al., 2001).

2.4.3.1 Farmed area

Today the farmed area covers two thirds of the total area of Denmark or 2647 mio hectares. In the future the farmed area is expected to decrease further and be replaced by forest, semi-natural areas, roads and buildings. From 1995 to 2000 the agricultural area has been reduced relatively more than in previous years (Table 2.4.5). The reduction is mainly caused by the general structural development in the agriculture where smaller areas are taken out of rotation and by an increased focus on environmental issues in the landscape.

Implementation of the Action Plan on Aquatic Environment II and the EU Water Resource directive indicates that environmental issues will still have a high priority.

Table 2.4.5. Average reduction in the agricultural area per period (Statistics Denmark).

Period	Reduction in the agricultural area	
	hectare per year	percent per year
1985 – 1990	9165	0.33 %
1990 – 1995	12445	0.45 %
1995 – 2000	15813	0.59 %

Until 2010 an annual decrease in the farmed area of 13400 hectares or 0.52 % is assumed, corresponding the development from 1990 to 2000 (Fig. 2.4.8).

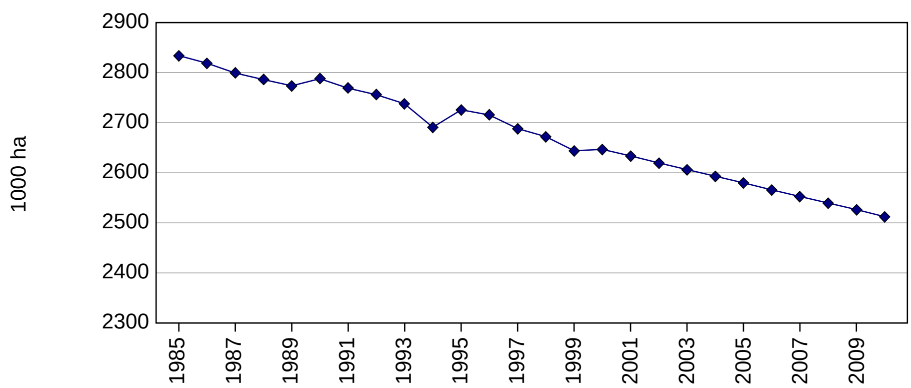


Figure 2.4.8. The estimated agricultural area until 2010.

The estimated development is close to the figures estimated by Groth et al. (1998). They estimate an annual decrease in the farmed area of 0.46 % pro annum until 2025 when high priorities will be given to environmental issues. They estimate an annual decrease on 0.59 % pro annum when high priorities is given to growth in urban development and infrastructure.

2.4.3.2 Organic farming

From the mid-1990s the organic grown area has increased (Fig. 2.4.9). In year 2000 the organic farmed area was 6 % of the total farmed area or approximately 160000 hectares (The Danish Plant Directorate, 2000). In 1999 the Ministry of Food, Agriculture and Fisheries proposed a plan to increase the organic grown area to 230000 hectares in 2003. The Danish Plant Directorate expects a conversion of 9-10000 hectares per year in 2001 and 2002. Figures from the Danish Agricultural Advisory Centre (2001) shows however, a decline in the conversion rate of approximately 6000 hectares per year because several farmers have given up organic farming. The expected goal in 2003 is not expected to be reached. In this project an increase in the organic grown area with 6000 hectares until 2010 is assumed, which means that the organic grown area covers 217000 hectares in 2010.

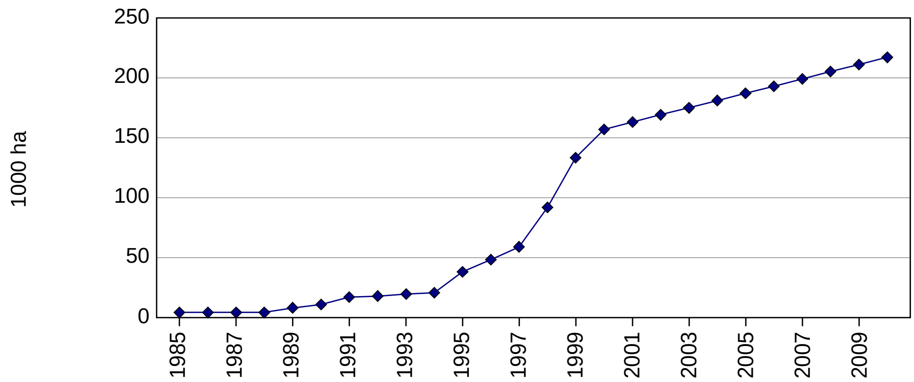


Figure 2.4.9. Development in the organic farmed area.

The set-a-side rule was implemented in 1992. Until now between 5 and 8 % of the total farmed area has been used for set-a-side. Until 2010 the average set-a-side area is estimated to 7 % of the farmed area.

The ratio between cash crops, fodder crops, grass in rotation and permanent grass areas in 2010 is assumed to be the same as in 2000.

Based on the above assumptions the farmed area is used as shown in Table 2.4.6.

Table 2.4.6. The estimated development in the farmed area in 2000 and 2010 (1000 hectares).

Year	**Hectares** (1000 ha)	**Conventional** (1000 ha)				**Organic grown** (1000 ha)			
		Cash crops, beets and silage maize	Grass/ Clover in rotation	Permanent pastures	Set-a side	Cash crops, beets and silage maize	Grass/ Clover in rotation	Perma-nent grass	Set-a-side
2000	2647	1959	202	146	183	84	44	20	8
2010	2513	1806	186	135	169	116	61	28	11

2.4.4 Artificial fertilisers

Since the beginning of the 1990s there has been a reduction in the use of nitrogen in artificial fertilisers. This reduction is expected to continue because of an increased demand of utilising nitrogen in manure and slurry as outlined in Action Plan on Aquatic Environment II. In Table 2.4.7 the utilization ratio for different types of manure in 2001/02 is shown. These figures will be increased by 5 % from 2003.

Table 2.4.7. Utilization ratios for nitrogen in manure (The Danish Plant Directive 2001).

	2001/02			From 2003		
	1st year %	2nd year %	Total %	1st year %	2nd year %	Total %
Pig slurry	60	10	70	65	10	75
Cattle slurry	55	10	65	60	10	70
Solid manure	50	10	60	50	10	60
Liquid manure	50	10	60	50	10	60
Deep Litter	25	15	40	25	15	40
Other types	50	10	60	50	10	60

The total amount of nitrogen in livestock manure, which is to be incorporated in the nitrogen account in 2000, is estimated to 122500 tonnes of nitrogen. Due to the increased demand for efficacy and the increased amount of manure the total amount of nitrogen which has to be used in the nitrogen budget in manure in 2010 is estimated to 130700 tonnes.

The total nitrogen quota for crop production is based on standards outlined by the Danish Plant Directorate. The standards may vary between years if the precipitation during the winter is different from normal. The total nitrogen quota for the crops in 2000 has been estimated to 341000 tonnes (Grant et al., 2001). The agricultural area is expected to be reduced by 134000 hectares in 2010 (Table 2.4.6). Making the condition that the crop type composition is unchanged the nitrogen quota will be reduced to 324000 tonnes in 2010.

In 2010 the use of nitrogen in artificial fertilisers is assumed to decrease by 17300 tonnes due to the decreased agricultural area and another 8200 tonnes because of the increased utility of the manure. Altogether 25500 tonnes N. In 2000 the use of nitrogen in artificial fertilisers was 245700 tonnes of N and the use in 2010 is estimated by 220200 tonnes N (Fig. 2.4.8).

Table 2.4.8. Estimated nitrogen quota, nitrogen in manures which shall be incorporated in the nitrogen budget and the estimated use of and ammonia emission from artificial fertilisers.

	Unit (tonnes)	**2000**	**2010**	**Difference**
Estimated N-quota	N	341000	323700	17300
N in livestock manure	N	122500	130700	8200
				25500
N in art. fertiliser	N	245700	**220200**	

The emission from artificial fertiliser depends on the type of fertiliser. In 2000 the average emission rate was estimated to 2.2 % of the nitrogen content in artificial fertilisers. No changes in the composition of the different fertiliser types are assumed.

2.4.5 Ammonia treated Straw

Ammonia is used for conservation of straw and to improve the nitrogen content of the fodder. In 2000 3800 tonnes were used for this purpose of which 2030 tonnes NH_3-N was estimated to disappear into the air. In the ammonia action plan a ban on the treating of straw was proposed. In the future a decreased demand for treated straw is assumed because of changed feeding strategy in the dairy production. From 2004 it is assumed that no straw will be treated except in years with high precipitation rates when the straw is harvested for preservation.

2.4.6 Sewage sludge

Approximately half of the sewage sludge from Danish sewage treatment plants is deposited on agricultural soil. From 1985 and until 1995 the deposits increased but from 1995 and until now the deposits have decreased (Fig 2.4.10). In 2000 85800 tonnes of sewage sludge were deposited on agricultural land (Bielecki, 2001).

The deposit of sludge on agricultural soils is the cheapest solution for the municipals because there is no tax on the depositing. In urban areas however, it is difficult to get rid of the sludge and more and more municipalities consider establishing incineration plants or carbonisation plants. Furthermore the industry has shown increased interest in using sewage sludge for cement production (Bielecki, 2001, Pers. comm.). It is therefore assumed that depositing of sewage sludge will decrease in the future with 2000 tonnes per year, corresponding to the development within the last three years. In 2010 65800 tonnes of sewage sludge is expected to be deposited on agricultural soils.

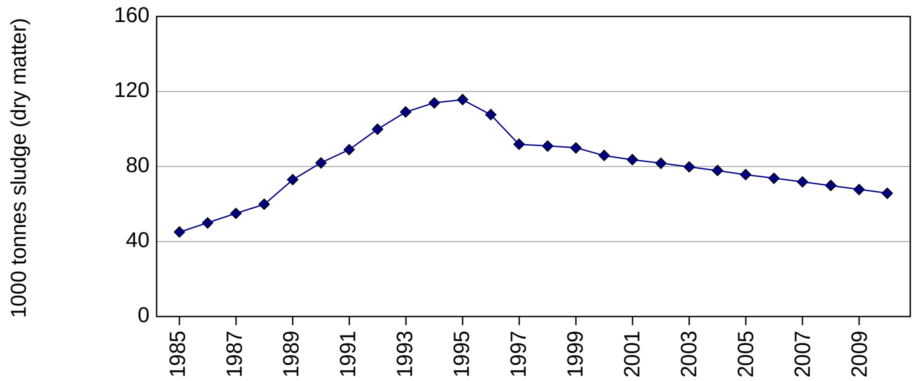


Figure 2.4 10. Sewage sludge deposited on agricultural soil 1985-2000.

The nitrogen content in the sludge varies between 4 and 4.5 % of the dry matter content. In 1999 the average was 4.3 %. This value will be used until 2010. The ammonia emission depends on the time it takes before the sludge is ploughed in the soil. It is assumed that 1.5 % of the nitrogen content is emitted into the air if the sludge is incorporated within 12 hours. This is assumed for 75 % of the sludge. The remaining part is assumed to have an emission of 3 % of the nitrogen content (Andersen et al., 2001).

2.4.7 Projections

The total ammonia emission in NH_3-N from Danish agriculture is expected to decrease from 83900 tonnes to 75600 tonnes in 2010 equivalent to 10 %. Appendix 2.4.6 indicates the emission from each year in the period 2000-2010 allocated on the different sources.

The emission from husbandry manure is expected to be reduced by 8 % (Table 2.4.9). The ammonia emission from artificial fertilisers will be reduced by 11 % due to a decline in the agricultural area, an increased production of manure and an increased demand on nitrogen-efficacy in the manure. The reduction of 7 % from crops is due to a decreased agricultural area and the expected increase in organic farming. Emission from ammonia treated straw is expected to be reduced to zero. Exceptions may be made in some years when bad weather conditions make the harvest of straw for fodder troublesome. In these occasions it may be necessary to add ammonia to straw for preservation. The emission from sewage slurry is expected to be reduced from 69 to 53 tonnes NH_3-N because of an improved interest of sewage slurry from the industry.

Table 2.4.9. Estimated ammonia emission (NH_3-N and NH_3) from agriculture in 2000 and in 2010.

Ammonia emission	2000 tonnes NH_3-N	2010 tonnes NH_3-N	2000 tonnes NH_3	2010 tonnes NH_3	Change percentage
Manure	65227	60261	79205	73174	- 8
Artificial fertilisers	5466	4844	6638	5882	- 11
Crops	11146	10418	13534	12650	- 7
Ammonia treated straw	2031	0	2467	0	- 100
Sewage slugde	69	53	84	64	- 24
Sum emission	83940	75575	101927	91770	- 10

The percentage distribution of the emission from the different sources does not differ significantly in 2010 compared to 2000. The amount from livestock manure and slurry is expected to increase from 78 % to 80 % of the total ammonia emission from the agricultural sector. Of this 90 % of the emission comes from cattle and pigs.

2.4.7.1 Livestock manure

The emission caused by the different livestock categories is shown in Figure 2.4.11.

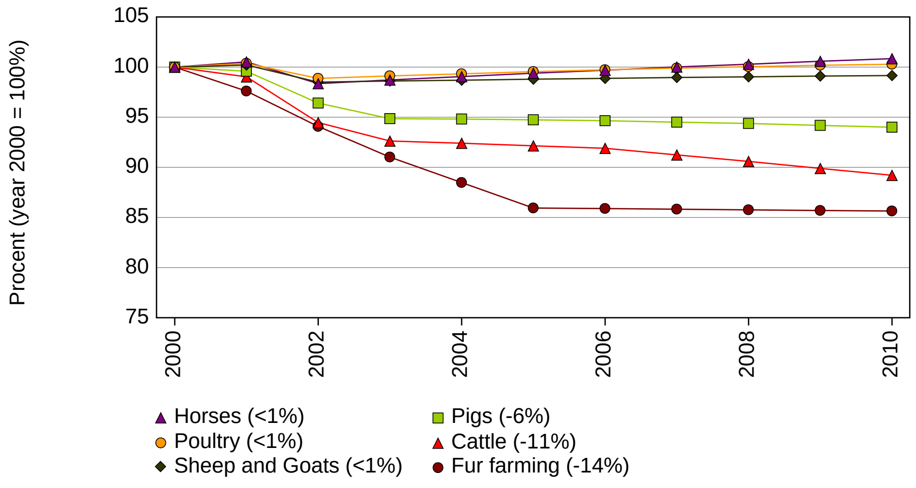


Figure 2.4.11. Ammonia emission 2000-2010 from different livestock categories.

The reduction of emission from cattle is estimated to be 11 %. The decrease is mainly due to an increased efficacy in the milk production. The scenario is provided by an increase in milkproduction of 100 kg milk per year. The vast increase in the last three years may argue for an increase at 150 kg milk per year. The number of dairy cows will then be 526000 in 2010 and the emission from cattle manure will be reduced by another 1100 tonnes NH_3-N.

As mention earliere the emission from cattle is increased because of changes in stabletypes from tied-up stables to loose-holding stables. Given no changes in stabling the emission from cattle will be lowered by 1700 tonnes NH_3-N compared with the estimations in the basic scenario.

An increase in the number of grazing days for cattle will contribute to a reduction of the ammonia emission. In the basic scenario it is assumed that dairy cows on average are grazing 55 days a year. If this grazing period is increased to 150 days in 2010 the total emission will be reduced by 2700 tonnes NH_3-N. However, it can not be expected that all dairy herds has the possibility of extending the grazing period to 150 days in practice. It would call for changes of the crop rotation, of the feed formula and in the planning of work.

The overall emission from the pig production is expected to decrease by 6% (Figure 2.4.11) despite the estimated 16 % increase in the pork production. This happens, among other things, because the emission from the stable per producted pig for slaughtering is expected to decrease by 7 % due to an increase in fodder efficacy. If the number of pigs is unchanged with a production of 22.7 mio pigs (for slaugthering) the expected development in fodder, stabling, spreading and increase in the nitrogen-efficacy in manure and slurry, the ammonia emission from pig production would be reduced by further 3600 tonnes NH_3-N.

If no changes in nitrogen-efficacy in the fodder and in the manure and slurry handling will take place the ammonia emission is expected to increase with further 2400 tonnes NH_3-N.

In the basic scenario the Danish pig production is increased by 1.5% per year. From 1990 to 1999 the figure was 2.7 %. If the scenario is changed to 2.5 % the pork production will be 28 mio per year in 2010. The ammonia emission from pigs is then 2000 tonnes NH_3-N more than estimated in the basic scenario.

Compared with the basic scenario the emission will be reduced by another 700 tonnes NH_3-N Provided that the distrubution among types of pigstables remains unchanged. The emission is thus less influenced by changes in stabletypes for pigs than for cattle.

Changes in the ammonia emission from the other domestic animals (i.e. horses and poultry) do not effect the total emission from the agricultural sector as much as the production of pigs and cattle does. It should be noted that changes in stabling on fur farm are expected to reduce the ammonia emission by 14 %.

Table 2.4.10 The influence of actions in the overall emission from animal manure.

	Basic scenario 2010	*Alternative* 2010	*Consequence*
	Action	Action	Emission compared to Basic scenario Tonnes NH_3-N
Production			
Cattle	100 kg milk per year/cow	150 kg milk per year/cow	- 500
		unchanged milkproduction	1900
Pigs	year prod. = 26.3 mio	unchanged - 22.7 mio/yaer	- 3600
		decreased - 28 mio/year	2000
Grassing			
Cattle	Average 55 days per year	Average 150 days per year	- 2700
Fodder efficacy			
Pigs	increased fodder efficacy	unchanged fodder efficacy	2300
Stable types			
Cattle	change stable types	unchanged stabletypes	- 1800
Pigs	change stable types	unchanged stabletypes	700

Table 2.4.10 lists the different altenatives to the basic scenario described in the text. The last column states what importance the alternatives have for the total ammonia emission.

Figure 2.4.12 shows the emission from stables, storages, spreading and grazing. The emission from the stables is expected to increase by 2 %, which can be explained by the increased production. The reduction in the emission from grazing depends on the lower number of cattle. The reduction from storages is mainly due to increased expectations in covering of slurry tanks and solid manure. It is assumed in the projection that an improvement in the lack of covering of the slurry tanks for pigs from 20 % in 2000 to 10 % in 2010 will take place, which means that the emission will be reduced by 700 tonnes NH_3-N. An improvement with full covering or well established floating layers on all slurry tanks (98 %) would mean that the emission would be further reduced by 600 tonnes NH_3-N.

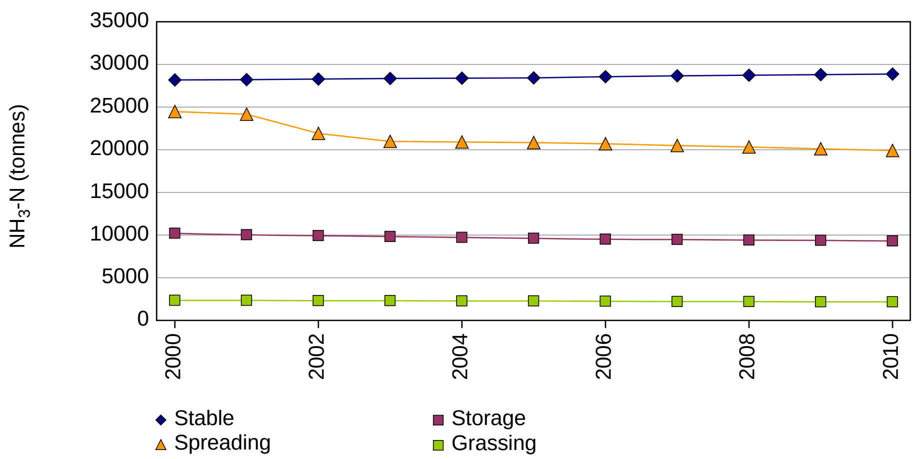


Figure 2.4.12. The ammonia emission from different sources.

It can clearly be seen at Figure 2.4.12 that the overall reduction can be related to the spreading of slurry. The largest difference is seen in 2001-2002 because the time before the manure is ploughed in the soil is reduced from 12 to 6 hours. From 2006 a tendency for further reduction in the emission can be seen, which is caused by the decline in N ab storage – i.e. the decline in the total amount of nitrogen in the storage.

If the maximum hours before incorporation continued to be 12 hours in 2010 the emission from livestock manure would be 900 tonnes bigger than stated in the basic scenario. It does not sound of much. Only 5 % of the slurry are expected to be spread on bare soil in 2010. The remaining part of the slurry is incorporated directly or is spread in growing crops in which the slurry cannot be incorporated with the present technical possibilities.

If no changes in manure and slurry handling will take place the ammonia emission is expected to increase by further 5000 tonnes NH_3-N in 2010. This means that the emission from livestock manure in 2010 corresponds to the level in 2000 and thus the total reduction will only be reduced by 3000 tonnes NH_3-N. Table 2.4.11 lists the different altenatives to the basic scenario described in the text.

The basic scenario unambiguously illustrates that the reduction of emission is determined by changes in spreading and handling of manure and it is therefore dependent on these changes taking place.

The change in the manure practice is - among other things - based on the statutory requirements expected to be initiated in connection with the resolution of the Ammonia Action Plan and the revision of the the Statutory Order of Livestock. Despite the fact that these have not yet been determined it is assumed to be incorporated in praxis anyway. This is mainly because of the limitations in the maximum nitrogen supply to the agricultural crops in combination with a minimum utilisation rate of nitrogen in slurry and manure and that nitrogen in the nitrogen budget is calculated ab storage. Under these circumstances it is economically favourable for the farmers to minimise the loss of ammonium.

The Danish farmers' Union has likewise worked out a projection of the agricultural sector until 2010 and has estimated the evaportion of NH_3-N to be 3300 tonnes lower than the basic scenario in this report (Danish farmers' Union, 2002). The difference is mainly due to the fact that the Danish farmers' Union presumes a larger increase in the milk yield and thus projects with a lower number of dairy cows.

Table 2.4.11. Manure and slurry handling influence of the overall emissions.

	Basic scenario 2010	**Alternative 2010**	**Consequence**
	Action	Action	Emission compared to Basic scenario
Manure and slurry handling			Tonnes NH_3-N
	6 hours (incorporated)	12 hours (incorporated)	900
		unchanged	5000
Covering of tanks			
	Improved covering	Unchanged	700
		total cover (98%)	-600

2.4.7.2 Emission 2010

The projection shows that the estimated emission for year 2010 is 79100 tonnes NH_3 (excl. crops and ammonia treated straw (Fig. 2.4.13)). This emission even without the emssion from traffic is higher than aimed for in the NEC Directive and the Gothenborg Protocol.

It is important to point out that the presumption is that the emission will become lower than estimated in the projection. Firstly, it does not take into account that the amount of ammonia in the manure is decreasing. Secondly, the importance of tecnological develoment is not taken into account.

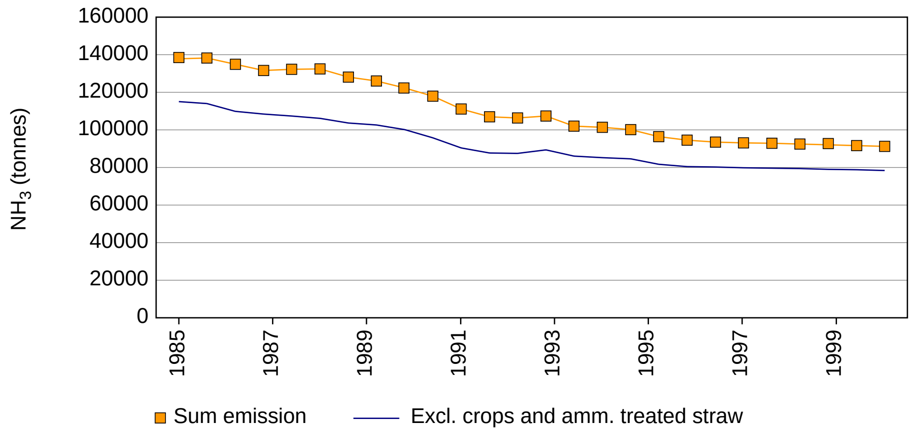


Figure 2.4.13. Ammonia emission from agricultural activities 1985- 2000 and the estimated emission until 2010.

In the future an improvement in the feed formula will take place in order to - to a higher degree - adjust the animals' need of essential amino acid. The ammonia evaporation is calculated as the percentage loss of the total amount of nitrogen. An improvement of the feed formula means that the share of organically fixed nitrogen will increase while the share of ammonium will be reduced and thus the emission will be reduced too. In practice it is expected that the emission coefficient will decline more than stated in the projection, but it is not possible to estimate the reduction of the total ammonia emission.

The technological development determines the possibilities available to limit the ammonia evaporation. A reduction in the ammonia emission can be achieved by a number of methods (see the box below). Some of them are easy to implement while others are more complicated technically or have high economical costs. Some methods are very costly and are only expected to be implemented to a minor extent.

- reducing the temperature and the ventilation speed in the stables,
- reduce areas in the stables where urinating takes place,
- frequent clearing of the manure from the stables,
- adding sulphuric acid to the slurry. The pH value is lowered and the most of the ammonia is transformed to ammonium,
- incorporation of manure into the soil also with spreading in crops,
- slurry seperation will reduce the ammonia emission. The seperated slurry improve the infiltration in the soil.

There is no doubt that the technological development in agriculture will result in an additional reduction of ammonia evaporation than estimated in the basic scenario. The trend is towards added environmental requirements to the agricultural production and especially for the livestock production. The biggest farmholders do have an interest in extending the production. For several of the biggest farmholders investment in new tecnology can become nessecary. For that reason the odds for tecnological development are good. At present it is hard to assess how changes in the tecnological development will effect the total amount of emission from the agricultural sector.

The projections show that the estimated emission in 2010 is larger than aimed at in the assumption that is given. The tecnologial measurements will reduce the ammonia emission. In present it is difficult to estimate the effect for the overall emission from agriculture. In the following years it is assumed that knowledge on the effects is avaible. It is then necessary to prepare another projection acounting for the tecnological possibility. It is thus suggested that the future projection will be used to assess the need for additional initiatives to reduce ammonia emissions.

2.5 Pollutants summary

2.5.1 SO_2

The largest contribution to the SO_2 emission comes from public power and district heating plants. About 80 % of the emissions from this sector alone come from combustion plants larger than 25 MWe. As seen from Figure 2.5.1 and Table 2.5.1 the emission ceiling of 55,000 tonnes is almost reached. The parameters, which have the largest influence on the projected emissions, are the sulphur content in the fuel and the amount of electricity exported. In the projection of the fuel consumption it is assumed that the electricity export will make a sudden increase of 90 PJ from 2004. The projected SO_2 emissions are slightly higher than the emissions estimated in 2000, due to a low content of sulphur in the coal consumed for the latest historical year.

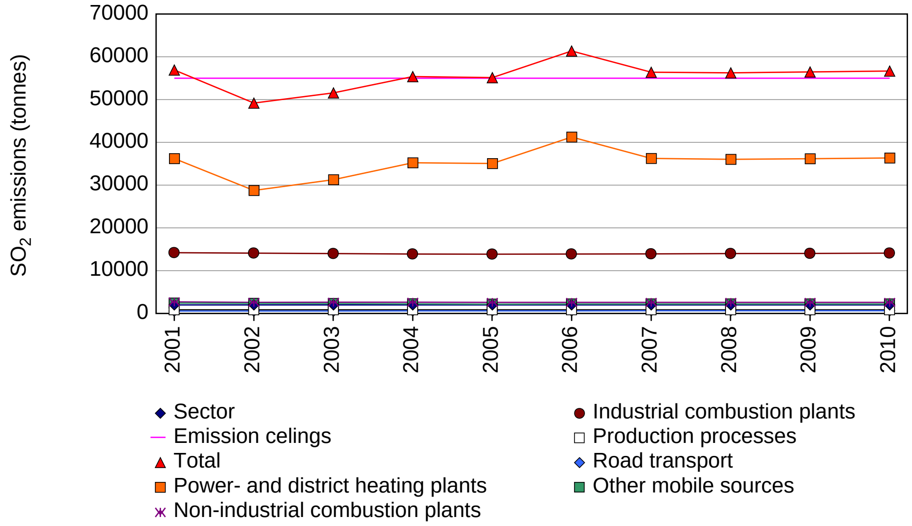


Figure 2.5.1. Projected SO_2 emissions.

2.5.2 NO_x

The projected NO_x emission in 2010 is slightly higher than the emission ceiling as shown in Figure 2.5.2 and Table 2.5.2. The three largest - and almost equivalently sized – sources are power and district heating plants, road transport and other mobile sources. The emissions from both road transport and other mobile sources decrease from 2001 to 2010 due to new gradually stricter emission standards. For public power plants the emissions are almost constant since the emission reduction achieved by introduction of SCR-units in 2007 is outbalanced by the large increase in the electricity export from 2004.

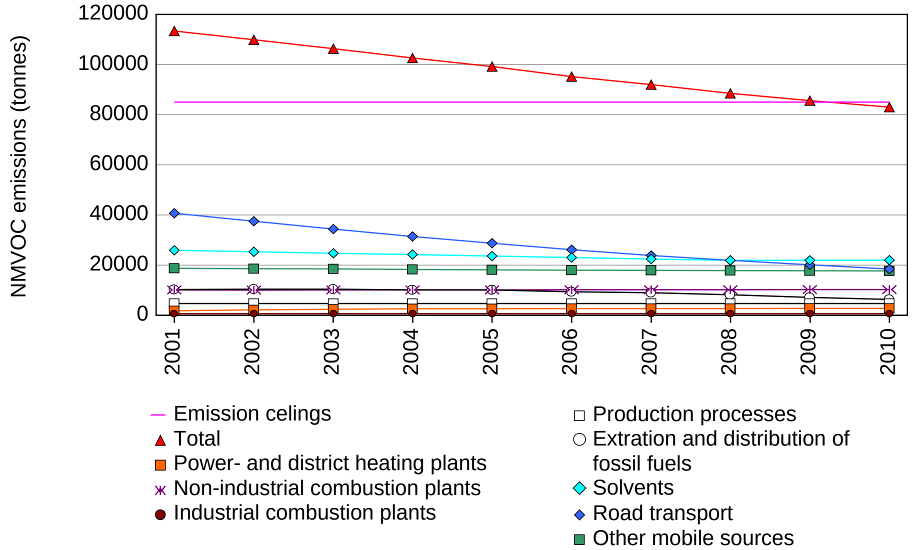


Figure 2.5.2 Projected NO_x emissions.

2.5.3 NMVOC

The largest emission sources of NMVOC are road traffic, other mobile sources, solvents and non-industrial combustion plants. Offshore activities and refineries are also important sources. Due to a significant decrease of the NMVOC emissions from road traffic the projected emissions in 2010 will be just below the emission ceiling. The emission from other mobile sources and non-industrial combustion plants are almost constant in the period while a decline is expected for the emissions from use of solvents. It should be stressed that the projected emissions for NMVOC are very uncertain. Especially the emission estimates from use of solvent and offshore activities are attached with large uncertainties.

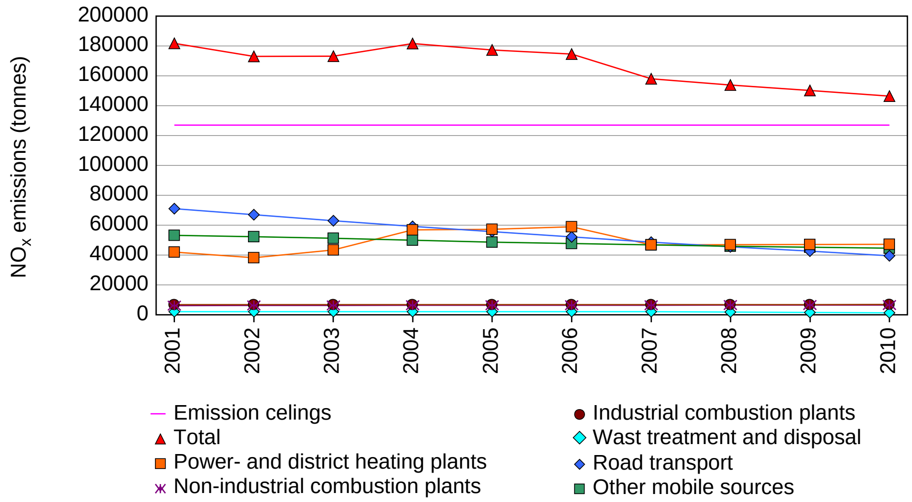


Figure 2.5.3. Projected NMVOC emissions.

2.5.4 NH_3

Almost all emissions of NH_3 result from agricultural activity; in 2010 only 4 % of the emissions are expected to come from road traffic. The major part of the emission from agriculture comes from livestock manure (80 %) when the manure is handled in stables and during spreading. Since the NH_3 emission ceiling excludes the emissions from crops and straw treatment with NH_3 the emissions in Tables 2.5.4 and 2.5.5 show the total emissions in both situations. The projected emissions in 2010 are estimated to be 95,427 tonnes and 82,777 tonnes, respectively. Compared to the limit of 69,000 tonnes the emission ceiling is exceeded with more than 10,000 tonnes.

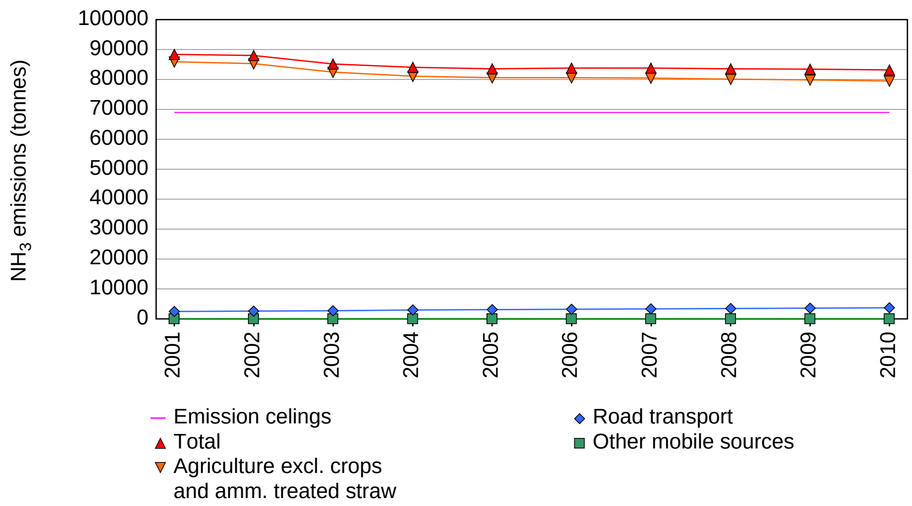


Figure 2.5.4. Projected NH_3 emissions.

Table 2.5.1. Projected emissions for SO_2.

	SO_2 (tonnes)										
SNAP-code	Sector	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
	Emission ceilings	55000	55000	55000	55000	55000	55000	55000	55000	55000	55000
	Total	56697	48981	51349	55163	54528	60747	55774	55620	55841	56054
1	Power- and district heating plants	36220	28750	31267	35218	35045	41261	36238	36027	36187	36331
2	Non-industrial combustion plants	2694	2599	2616	2613	2596	2587	2588	2591	2583	2585
3	Industrial combustion plants	14189	14091	13977	13894	13866	13877	13925	13977	14044	14110
4	Production processes	831	831	831	831	831	831	831	831	831	831
5	Extraction and distribution of fossil fuels										
6	Solvents										
7	Road transport	359	363	368	374	76	77	78	80	81	82
8	Other mobile sources	2404	2347	2290	2233	2114	2114	2114	2114	2115	2115
9	Waste treatment and disposal										
10	Agriculture										

Table 2.5.2. Projected emissions for NO_x.

	NO_x (tonnes)	2001	2001	2003	2004	2005	2006	2007	2008	2009	2010
	Emission ceilings	127000	127000	127000	127000	127000	127000	127000	127000	127000	127000
	Total	181723	172992	173192	181627	177249	174561	158030	153865	150214	146369
1	Power- and district heating plants	41978	38189	43369	56862	57280	58992	46812	46898	47058	47222
2	Non-industrial combustion plants	6136	6213	6315	6351	6375	6412	6443	6479	6513	6558
3	Industrial combustion plants	6812	6788	6768	6754	6763	6767	6787	6809	6836	6861
4	Production processes	413	413	413	413	413	413	413	413	413	413
5	Extraction and distribution of fossil fuels										
6	Solvents										
7	Road transport	71029	67042	63011	59194	55643	52167	48687	45556	42616	39481
8	Other mobile sources	53257	52247	51217	49954	48677	47711	46789	45878	45212	44534
9	Waste treatment and disposal	2099	2099	2099	2099	2099	2099	2099	1833	1566	1300
10	Agriculture										

Table 2.5.3. Projected emissions for NMVOC.

	NMVOC (tonnes)	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
	Emission ceilings	85000	85000	85000	85000	85000	85000	85000	85000	85000	85000
	Total	113356	109920	106367	102640	99211	95204	91995	88483	85644	83012
1	Power- and district heating plants	1790	2150	2359	2589	2635	2667	2677	2696	2722	2749
2	Non-industrial combustion plants	10069	10057	10089	10120	10126	10145	10169	10200	10224	10243
3	Industrial combustion plants	643	641	641	641	643	643	645	647	649	651
4	Production processes	4694	4694	4694	4694	4694	4694	4694	4694	4694	4694
5	Extraction and distribution of fossil fuels	10214	10380	10386	10087	10064	9327	9021	8170	7163	6278
6	Solvents	25916	25339	24762	24186	23609	23032	22455	21878	21927	21975
7	Road transport	40714	37507	34382	31437	28735	26112	23846	21877	20093	18405
8	Other mobile sources	18729	18564	18466	18298	18118	17995	17900	17811	17740	17663
9	Waste treatment and disposal	588	588	588	588	588	588	588	509	431	353
10	Agriculture										

Table 2.5.4. Projected emissions for NH_3.

	NH_3 (tonnes)	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
	Emission ceilings	69000	69000	69000	69000	69000	69000	69000	69000	69000	69000
	Total	103108	99650	97763	96956	96732	96622	96361	96091	95776	95427
1	Power- and district heating plants										
2	Non-industrial combustion plants										
3	Industrial combustion plants										
4	Production processes										
5	Extraction and distribution of fossil fuels										
6	Solvents										
7	Road transport	2473	2608	2762	2917	3064	3212	3343	3467	3575	3651
8	Other mobile sources	6	6	6	6	6	6	6	6	6	6
9	Waste treatment and disposal										
10	Agriculture (all sources)	100629	97036	94995	94033	93662	93404	93012	92618	92195	91770

Table 2.5.5. Projected emissions for NH_3.

	NH_3 (tonnes)	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
	Emission ceilings	69000	69000	69000	69000	69000	69000	69000	69000	69000	69000
	Total	87812	85060	83877	83776	83640	83618	83446	83264	83037	82777
1	Power- and district heating plants										
2	Non-industrial combustion plants										
3	Industrial combustion plants										
4	Production processes										
5	Extraction and distribution of fossil fuels										
6	Solvents										
7	Road transport	2473	2608	2762	2917	3064	3212	3343	3467	3575	3651
8	Other mobile sources	6	6	6	6	6	6	6	6	6	6
9	Waste treatment and disposal										
10	Agriculture (excl. crops and amm. treated straw)	85333	82446	81109	80853	80570	80400	80097	79791	79456	79120

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3 Financial and welfare economic analysis of emission reduction measures

3.1 Introduction

The UNECE Convention on Long-Range Transboundary Air Pollution requires the reduction of SO_2, NO_x, NMVOC and NH_3 emissions up to certain maximum ceilings in the year 2010. Projections of these emissions described in the previous chapters have shown that the respective emission ceilings for Denmark will not necessarily be reached in all cases. In addition to the already implemented and planned measures included in the baseline calculations it might therefore be necessary to introduce further emission reduction initiatives in different sectors. These additional measures, however, are likely to result in extra costs to the entities implementing them (e.g. companies, private consumers, energy producing utilities, etc.) and to society as a whole. Given that society's resources are scarce and should therefore be allocated in the most optimal way, the question remains, how emission ceilings can be met in the most cost-effective way.

The following chapters analyse different suggested measures in the industry, agriculture, energy and transport sector, with regard to their cost-effectiveness in reducing the emissions included in the UNECE Convention. The cost-effectiveness methodology has been chosen because of the lack of reliable benefit estimates for units of the different emissions reduced. However, in order to give the reader an idea about the possible relation between benefits and costs, including a potential effect on the ranking of the emission reducing measures analysed in this report, monetary estimates for the foregone damages associated with the different emissions have been included in Chapter 3.8. As described in that chapter, estimates have been taken from a recently published report in Denmark (Ministerierne, 2001). The monetary values suggested in that report are only applied in the following calculations for illustrative purposes. Given the limited resources available for the cost-effectivness analyses of this report, NERI has neither had the opportunity to review the literature on benefit valuation of air pollution, nor to produce an update of the physical damage estimates in Denmark. The authors of this report therefore do not recommend an application of either benefit estimates or the results of Chapter 3.8 for policy decisions.

The report contains both, financial and welfare economic analyses of eight different measures. The selected measures include the substitution of solvent based paint with a water based alternative in all Danish car-painting workshops for the industry sector and the building of an offshore wind turbine farm and installation of De-NO_x and desulphurisation units at large power plants for the energy sector. For the transport sector the introduction of electrical vehicles and

EGR-filter installations for heavy-duty vehicles were selected as potential future emission reduction measures. Increasing grazing days for dairy cows and changes in the application of manure were included as two scenarios for the agricultural sector. The financial calculations are based on the actual expenses of the different entities involved in implementation. Prices applied here reflect the costs to companies, utilities and the private consumer. The welfare economic analyses of the costs to society resulting from an implementation of the suggested measures are based on the so-called "accounting-price"-method (Møller et al., 2000). For easy reference and in order to avoid repetition of methodological explanations in each chapter the basic theory behind the accounting-price method is explained in the next chapter.

Each analysis starts with a description of the baseline scenario and the proposed measure and its physical consequences. The costs associated with those physical consequences are than analysed using financial prices and the welfare economic method described above. Sensitivity analyses are included in these cases in which specific assumptions on effects and costs are likely to change the results of the analysis. Indirect environmental effects, e.g. emissions resulting from the production of operation and maintenance equipment, are not included in the analyses.

All costs are calculated using 2001 prices. A financial or economic investment rate of 6% is used for the financial analysis, while a social time preference rate of 3% is applied in the welfare economic calculations. The return on investment factor[1] is calculated using both the economic investment rate of 6% and the social time preference rate of 3%.

The resulting cost-effectiveness measures for each emission reduction initiative (in terms of MDKK/tonne) are compared in Chapter 3.7 and a basic ranking of initiatives is presented. Chapter 3.8 analyses the implications of including a monetary value for emission reductions on the costs per tonne calculated and the final ranking of measures.

3.2 The accounting-price method

Financial and welfare economic analyses differ primarily with regard to their perspectives. The financial (or budgetary) cost-benefit analysis calculates the financial costs and benefits from the point of view of single actors or sub-groups of the population in an economy: the state, the private investor, or the consumer. The prices used are the "buyer" prices either paid on the market for inputs in the form of producer or consumer goods or obtained on the market for selling outputs, including all non-refundable taxes and subsidies.[2]

[1] See explanation in the following chapter.
[2] In the case of consumer goods all taxes are non-refundable and should therefore be included in the price.

While the financial analysis measures financial flows for the specific sub-group or individual the idea behind a welfare economic evaluation is to determine the improvement in welfare for a country's population. Measuring the benefits and costs from the point of view of the country as a whole is based on so-called applied welfare economics. Here it should be taken into consideration that society's resources are limited and using these resources in one application causes opportunity costs for an alternative usage.

In former analyses of similar character (Fenhann et al., 1997) GHG emission reduction measures were analysed using two different socio-economic evaluation methods, the so-called factor-price method and the accounting-price method. The factor-price method entails that buyer prices are corrected by subtracting taxes and adding any subsidies paid to the producer. While this method is the preferred method in many EU countries it does - strictly speaking - not adhere to the principles of welfare economics, but rather represents an attempt to measure the direct contribution of the project or measure analysed to the income generation in an economy (Møller, 1989). The accounting-price method, on the other hand, is in agreement with welfare economic principles. Recently, therefore, this method (which is explained in detail in Møller et al. (2000)) has been declared the preferred method by the Danish Ministry for Environment and the Danish Finance Ministry. It is the only welfare economic method employed in this report.

The Accounting-price method uses consumers' willingness to pay for goods and services *given existing taxes and subsidies* in a market. In the easiest case, when the input or output is a consumer good, the prevailing buyer (consumer) price, including all taxes and subsidies, is assumed to reflect the marginal benefit the consumer derives from the respective good or service.

In order to derive at accounting prices for inputs, the preferred method would be to calculate the welfare economic costs of producing that input factor, since these costs reflect the foregone consumption possibilities from using resources for this particular production. However, in many cases this approach would be too time-consuming and costly in itself. Therefore, the buyer price of a producer good is often simply adjusted to reflect the increase in value to the final consumer when the good is used in the production of consumer goods. The price the next producer in line is willing to pay for the specific producer good only reflects the marginal value of the good for the producer. It does not include the total value for the consumer, who will also be willing to pay sales tax and maybe other product specific taxes levied on the producer and consumer good during the production process towards the final consumer good.

Two different cases of producer goods need to be distinguished: domestically traded producer goods (the so-called "non-tradables") and exported or internationally traded producer goods ("tradables"). The calculation of welfare economic prices for those two types is explained in more detail below.

Domestically Traded Producer Goods ("Non-tradables")
When domestically traded resources and intermediate goods are used as inputs in a production process these are taken away from the potential use in other projects or investments. The opportunity costs of inputs used (or more specifically the change in consumption possibilities for the consumers) should therefore be calculated using the foregone value of these resources to the consumer (measured in their willingness to pay) when used in those alternative production processes.

Møller et al. (2000) suggests increasing producer prices of domestically traded goods and services (net of refundable taxes) with a so-called "net-tax-factor". This net-tax factor is calculated as the proportion between gross domestic product (GDP) at buyer-prices and gross domestic income (GDP at factor prices), measured as the sum of income earned by those providing the factors of production (i.e. wages, salaries, rent, interest and profit).[3] For Denmark this net-tax-factor is at 1.17 for domestically traded goods (Møller et al., 2000).

Exported producer goods (" Tradables")
A tradable output represents foreign exchange earnings to an economy, which in turn increases the consumption possibilities to the consumer. The foreign exchange earnings can either be used to increase imports or to decrease the amount of goods exported, thereby releasing resources applied in the production process to other consumption possibilities. The net-tax factor therefore needs to reflect the relationship between the domestic prices of these producer goods and their world market prices.

In the case of internationally traded goods the net-tax factor is calculated as the proportion between the domestic value of the sum of all international trade and the value of this trade as it can be found in the country's current account. This current account value is equal to the sum of all foreign currency income and expenditures caused by export and import of goods and services. The domestic value of the current account balance can be derived by adding indirect tax (VAT) and export subsidies to the foreign currency income and import duty and tax, import VAT, registration duty for cars and other special taxes (on energy products, alcoholic beverages, tobacco etc.) to the foreign currency expenditures. For Denmark this net-tax factor for internationally traded goods is calculated as 1.25.

A tradable input used in the production of goods and services, on the other hand, decreases the amount of foreign exchange available for use in other private projects, because it either needs to be imported or decreases the amount of that particular good to be exported. Again, the opportunity costs of inputs used (or more specifically the change in consumption possibilities for the consumers) should therefore be calculated using the foregone value of these resources to the consumer (measured in their willingness to pay) when used in those alternative production processes.

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[3] Gross domestic income is equal to gross domestic product minus all taxes plus subsidies paid on all levels of production.

Transfer Payments

Some financial inputs or costs represent transfers between different sectors and should not be included as costs to the economy as a whole. This refers mainly to the payment of interest to financial institutions and the payments of taxes on the local or national level.

Labour input

Similar to the use of other resources in the production process the use of labour in a project means that these skilled or un-skilled workers are not available in other production processes. Again it is the loss of consumption possibilities from these alternative projects that should be captured in the economic price of labour, which is equal to the wage multiplied by the net-tax factor for domestically traded goods and services of 1.17. If it is assumed that a project is using otherwise unemployed labour the economic costs of employment are equal to zero.

Capital goods

The annual costs associated with the inputs of capital goods (i.e. equipment, machines, buildings) normally enter a financial cost-benefit analysis in the form of annual depreciation, e.g. the assumed annual loss of value associated with the use of these capital goods in the production process. In a welfare economic cost-benefit analysis (CBA), on the other hand the total investment amount[4] increased by the respective net-tax factor is divided up over the assumed period of operation with the help of a capital recovery factor.

Investing in capital goods in one project causes opportunity costs to an economy in the form of foregone returns from either investing that sum of money in alternative investment projects or in the form of foregone consumption. In financial calculations these foregone returns are reflected in the discount rate chosen to derive the net present value of the annual cash flows.[5] In the case of an economic analysis of benefits and costs increasing the annual investment amount with a “return on investment factor for capital” is suggested[6]. This return on investment factor is equal to the present value of one DKK invested in the next best alternative project and is calculated using an (economic) investment rate and the social time preference rate for discounting.

In the calculations in this report an economic investment rate of 6 percent is used in accordance with the recommendations for socio-economic cost-benefit analysis of the Danish Finance Ministry (Ministerierne, 2001). This economic investment rate reflects the income foregone from investing the respective amount in alternative projects before tax but after reduction of depreciation, i.e. the value of investments is kept constant by reinvesting part of the original yield (which can be expected to be higher than 6%) in reinvestments.

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[4]Here again it would be preferable to calculate the welfare economic investment amount first by summing up the costs of producing the capital good (in accounting prices) (see explanation under tradable and non-tradable inputs). However, in most cases the analyst will only have the market price or investment amount to base his calculations upon.

[5] In financial calculations it is assumed that the entire investment amount would otherwise be invested and not spent on consumption.

[6] Often this factor is also referred to as “shadow price on capital”.

Box 1

Capital Recovery Factor **Return on Investment Factor**

$$a(r,T) = \frac{r*(1+r)^T}{(1+r)^T - 1}$$

where r = social time preference rate

T = time horizon / operation period

$$f_K = \frac{q}{r}*(1-\frac{1}{(1+r)^T}) + \frac{1}{(1+r)^T}$$

where q = economic investment rate

r = social time preference rate

T = time horizon

Therefore the return on investment factor described in box 1 includes an additional term at the end, which reflects the present value of the maintained investment capital at the end of its lifetime.

After calculating the annual investment amount by using a capital recovery factor and taking into consideration the opportunity costs from foregone investments by multiplying the annual amount by the return on investment factor, the resulting amount is then increased by the net-tax factor for either domestically or internationally traded goods. The formulas for the capital recovery factor and the return on investment factor for capital are described in box 1.

Accounting prices for renewable and non-renewable resources

The correct way of calculating the accounting price for the services rendered by for example farm and woodland areas and fishing grounds consists of calculating the resource rent received by either the owner of the resource or the owner of the machinery and tools used to extract the resource (e.g. fishery). The welfare economic resource rent of these renewable resources is equal to the accounting price of the products produced (agricultural products, wood, fish etc.) minus the costs (in accounting prices) for labour, real capital, intermediate goods and other resources employed in the production process. The same calculation rule applies to the case of non-renewable resources. Possible pitfalls and problems associated with determining the right welfare economic resource rent, e.g. in the case of non-sustainable use of renewable resources are discussed in further detail in Møller et al. (2000) and will therefore not be repeated here.

3.3 Emission reduction measures in the industrial sector

3.3.1 Reduction of NMVOCs from car painting workshops

3.3.1.1 Description of proposed measure and consequences

In the reference projection in this report, the NMVOC emissions from the different sectors in 2010 are the same as the emissions in 2000. The total emissions in 2000 are not measured values but the revised reduction goals in Foreningen af Auto-og Industrilakerere (1999). The total NMVOC emissions in 2010 are therefore 35816 tonnes NMVOC, of which 1875 tonnes NMVOC originates from car painting workshops.

According to Miljøstyrelsen (1995) the emission of the 1875 t NMVOC was calculated in the following way:

Number of private cars painted (average 2.1 m^2):	680000
This is equivalent to whole private cars painted (15 m^2):	100000
Number of used private cars painted:	35000
Equivalent to number of whole used private cars painted:	25000
Total number of whole private cars painted:	125000

If the painting of one personal car emits 9 kg NMVOC then the total emission from 125000 is 1125 t NMVOC.

There is no information on the number of trucks painted, but 60% of the sale of car paint is for private cars and 40% for trucks. The NMVOC emission from personal cars above is therefore upscaled with the factor 100/60, resulting in total annual emission of 1875 tonnes NMVOC.

According to Miljøstyrelsen (1995) a realistic option is to reduce the emission from the painting of one car from 9 kg NMVOC to 5.5 kg NMVOC. This emission level can be reached using a water based basis paint and High Solid (HS) main paint and filler. HS products have a high content of dry matter, i.e. smaller amounts of solvents are needed. To carry this through, the following investments have do be made at the workshop:[7]

Infrared dryers	150000 DKK
New ventilation system	10000 DKK
HVLP pistols	10000 DKK
Pistol washer	15000 DKK
Computer controlled weight	30000 DKK
Education	24000 DKK
Lost working hours	8000 DKK
Total investment	247000 DKK

The increased drying time from the introduction of water-based paints can be reduced by infrared dryers. The High Volume Low Pressure (HVLP) spraying system reduces the amount of paint needed.

After the changes are implemented both personal cars and trucks are painted in the new way with lower NMVOC emissions.

3.3.1.2 Financial analysis

If it is assumed that the water based paint option is implemented in all 500 workshops (Plum, 2001) in Denmark the results would be a total investment of 123.5 MDKK. A 20-year operating period is as-

[7] These investment costs reflect the incremental costs, i.e. saved expenses from not having to invest in conventional equipment have been subtracted.

sumed for those additional investments. Assuming a 6% financial interest rate would result in annual investment costs of 10.8 MDKK per year.

The cost for water-based paints is higher per unit than the type of paint used in the basis scenario. However, with the additional investments in extra equipment described above, less paint is needed and therefore no extra material costs are assumed. The manpower part of the annual Operation & Maintenance (O&M) cost, however, increases since the time it takes to paint a car is increased by about 10 minutes, because it takes longer time to dry. With a total of 715000 cars (680000+35000) treated annually and a workshop price of 360 DKK/hour this amounts to 42.9 MDKK for the personal cars. In order to include the trucks this amount is scaled up with the factor 100/60. The total annual extra O&M cost is therefore 71.5 MDKK.

The only other part of the O&M cost which changes is the cost of getting rid of the waste. By changing to water-based paints it is estimated that this cost is reduced by 50%. On average the annual cost is about 15000 DKK per workshop (Plum, 2001) or 7.5 MDKK for the 500 workshops. A 50% reduction therefore means an annual saving of 3.75 MDKK.

After implementation of the emission reduction option the emissions are reduced to 5.5 kg NMVOC per whole car painted. With the 125000 cars and the 100/60 up scaling factor (to include the trucks) the annual emission is then 1125 tonnes NMVOC.

As described above, the introduction of water-based paint saves about 750 tonnes of NMVOC emissions per year. The total net costs is 78.5 MDKK which is the sum of the annual investment costs of 10.8 MDKK and the increased annual labour cost of 71.5 MDKK subtracting the savings of 3.75 MDKK. The financial reduction cost is therefore 105000 DKK/tonne NMVOC as seen in Table 3.3.1.

After some time the emitted NMVOCs are converted to CO_2 in the atmosphere. Assuming that 1 kg NMVOC produces 3.1 kg CO_2 means that the emission reduction of 1875-1125=750 tonnes NMVOC reduces the CO_2 emission by 2300 tonnes CO_2.

It should be remarked that all investment costs, cost of increased time consumption and reduced waste expenses are related to the industrial sector (the car painting workshops).

3.3.1.3 Welfare economic analysis

Table 3.3.1 lists the different consequences in terms of investments and increased time consumption for switching to a water-based paint in all 500 workshops in Denmark. The investment amounts listed in column 2 of Table 3.3.1 are thus the total investments for all 500 workshops, based on the investment costs per workshop described previously. In order to obtain yearly investment amounts total investments are multiplied by a capital recovery factor using a social time preference rate of 3% and assuming an operating period of 20 years. The resulting annual investment amounts are then increased by a return on investment factor of 1.4463 in order to take into account the investment opportunities forgone. This return on investment factor was calculated using a social time preference rate of 3%, an economic investment rate of 6% and an operating period of 20 years.

Table 3.3.1. NMVOC reduction from car painting workshops.

Consequences	Real consequences		Financial calculations		Welfare economic price		
	unit	amounts	Price per unit	MDKK/year	NTF	Price per unit*	MDKK/year
Investment							
Infrared dryers	MDKK	75.0	(0.0872)	6.5	1.25	(0.1215)	9.1
New ventilation system	MDKK	5.0	(0.0872)	0.4	1.25	(0.1215)	0.6
HVLP pistols	MDKK	5.0	(0.0872)	0.4	1.25	(0.1215)	0.6
Pistol washer	MDKK	7.5	(0.0872)	0.7	1.25	(0.1215)	0.9
Computer controlled weight	MDKK	15.0	(0.0872)	1.3	1.25	(0.1215)	1.8
Education	MDKK	12.0	(0.0872)	1.0	1.17	(0.1137)	1.4
Lost working hours	MDKK	4.0	(0,0872)	0.3	1.17	(0.1137)	0.5
Total investment costs	MDKK	123.5		10.8			14.9
Increased time consumption	hours	198611	360	71.5	1.17	421.2	83.7
Total costs per year	MDKK			82.3			98.6
Reduced waste expenses	MDKK	-3.8		-3.8	1.17		-4.4
Net costs per year				78.5			94.1
Emissions saved							
NMVOC	tonne	750					
CO_2	tonne	2300					
Net costs per tonne NMVOC				0.105			0.126
Factors used in the calculations:							
Capital recovery factor (6%, 20 years):			0.0872				
Capital recovery factor (3%, 20 years):			0.0672				
Return on Investment Factor:			1.4463				

* The “price per unit” for investment items has been calculated as the product of capital recovery factor, return on investment factor and respective net-tax factor.

As discussed in Chapter 3.2, in order to correctly determine the opportunity costs of investments in a welfare economic analysis it is essential to know if these consist of nationally or internationally traded goods or services. In the case of equipment for water-based paint, dryers, ventilation system, pistols, washer and weight can be considered tradables. The annual investment amounts for these tradable items are therefore increased by the net-tax factor for internationally traded goods of 1.25. Expenses on education and working hours lost while attending those classes are non-tradables and their annual investment amounts are therefore increased by a net-tax factor of 1.17. The “price per unit” listed in the second last column for these items have been calculated as the product of capital recovery factor (0.0672), return on investment factor (1.4463) and respective net-tax factor.

A total of 119167 hours of extra drying time is required for the painting of personal cars (equal to 715000 cars x 10 extra minutes per car). In order to take into account the additional time required for drying the paint of trucks, total amount of hours are scaled up with the factor 100/60 (reflecting the fact that 40% of the paint sold is used for trucks). This results in a total of 198611 hours extra required. The opportunity costs of increased time consumption per year are calculated by increasing the financial hourly workshop price of 360 DKK/hour with the net-tax factor for nationally traded goods of 1.17 and then multiplying the resulting welfare economic wage per hour of 421.2 DKK by the total amount of 198611 hours per year. Adding those annual operating costs of approximately 84 MDKK to the total annual investment costs of 14.9 MDKK results in total annual costs of about 98 MDKK.

The application of water-based paint reduces waste expenses. Handling waste and disposing is considered a non-tradable service. The saved waste expenses are therefore increased by the net-tax factor of 1.17 and subtracted from the total costs calculated previously. Switching to water-based paint on a country-wide basis thus causes extra net costs of 94.1 MDKK per year or about 188000 DKK for each workshop on average, calculated using welfare economic prices.

As described in the financial analysis, introducing water-based paint saves about 750 tonnes of NMVOC emissions per year. With this measure thus NMVOC emission reductions require expenses of about 125500 DKK per tonne NMVOC in welfare economic prices. In addition to NMVOC emissions, replacing solvent-based paint with a water-based alternative results in annual emission savings of 2300 CO_2. The effect of placing a monetary value on emissions saved on total costs is described in Chapter 3.8.

3.4 Emission reduction measures in the energy sector

3.4.1 Large offshore wind turbine farms

3.4.1.1 Description of proposed measure and consequences

In 1997 The Danish Energy Agency published a report showing the five best areas for large offshore wind turbine farms. In February 1998 the Danish Energy Agency imposed the obligation on the Danish Utilities to build five 150 MW wind turbine farms before 2008 (three parks in East Denmark and 2 parks in West Denmark) as shown in Table 3.4.1.

Table 3.4.1. Planned offshore wind tubine farms.

Horns Rev	2002	160	MW
Rødsand	2003	150	MW
Læsø	2003	150	MW
Omø Stålgrund	2005	150	MW
Gedser Rev	2008	150	MW
Total until 2008		760	MW

According to the latest Danish energy plan Energy 21 the total size of offshore wind turbine farms should be 4000 MW in 2030. This means an additional offshore wind turbine farm of 150 MW should be build each year in the period 2008-2030. This development is the baseline used for calculating the emissions of SO_2, NO_x, and NMVOC.

The option introduced here to reduce the SO_2, NO_x, and NMVOC emissions below the baseline level in 2010 is the construction of an additional off shore wind turbine farm of 150 MW before 2010. This extra wind turbine farm is assumed to consist of 2 MW wind turbines as planned for the first two wind turbine farms in Table 3.4.1.

The wind resources have been measured by Risø at the sites in Table 3.4.1 and the equivalent full load hours was in the interval 3400-4000 hours. In the calculations here we assume 3500 full load hours, e.g. the production from the 150 MW wind tubine farms: 150*3500 MWh = 525 GWh.

3.4.1.2 Financial analysis

In order to estimate the costs of an extra 150 MW offshore wind turbine park the cost information from the latest offshore wind turbine farm in Denmark has been used. The total investment in this park at "Middelgrunden" outside the Copenhagen harbour of 20 MW wind turbines was about 340 million DKK. The % share for the different components in this investment are shown in Table 3.4.2 (see www.middelgrunden.dk/oekonomi/budget.htm). The best available estimate for the cost of the 150 MW parks in Table 3.4.1 is the information from the offshore wind turbine farm at Rødsand (see www.seas.dk). The total cost of this park is estimated here to be 1600 million DKK. This value is used in Table 3.4.2, and the disaggregation of the total cost into the components is done using the % shares from Middelgrunden in Table 3.4.2. The resulting cost of 938 MDKK for the turbines fits reasonably well with the current prices. The Bonus wind turbines erected at Rødsand will in size be of 2.1 MW and with the current price of such a turbine of 12.2 MDKK the price for 150 MW is around 900 MDKK. (Energi- og Miljødata, Vindmølleoversigten, November 2001).

The 5.9% for Consultants & planning in Table 3.4.2 include the costs for establishing the Wind Turbine Cooperative, which owns a share of the park. The "Unforeseen expenses" in Table 3.4.2 includes expenses for extra environmental measures, extra investments, service boats, and signposting e.t.c.

Table 3.4.2. The costs of an extra 150 MW park.

	Mio. DKK	% share
Turbines	938	58.7%
Foundations	347	21.7%
Gridconnection, manpower	76	4.8%
Gridconnection, cables	69	4.3%
Gridconnection, electronics	19	1.2%
Consultants & planning	94	5.9%
Unforeseen expenses	56	3.5%
Total	1600	100.0%

According to the latest energy projection from the Danish Energy Agency the 525 GWh electricity from the extra offshore wind turbine farm is assumed to replace some of the coal used to produce the 4770 GWh electricity in 2010 at block 5 at the Asnæs power plant. As a sensitivity analysis, the electricity from the wind turbine farm is assumed to replace natural gas on e.g. the Avedøre 2 power plant. It is assumed that the average fuel price in the period will be 14.4 DKK/GJ for coal and 25.4 DKK/GJ for natural gas (see the Danish report: Rapport fra arbejdsgruppen om kraftvarme og VE-elektricitet, Oktober 2001). The electric efficiency is 41.3 % for the coal power plant and 48% for the natural gas power plant. There are no taxes or subsidies on these fuels, when they are used to produce electricity.

The block 5 at the Asnæs power plant already has a desulphurisation unit installed and it is assumed that the planned Selective Catalytic Reduction (SCR) deNO_x unit is installed in 2007 before the wind turbine park is built. The natural gas power plant has also installed a (SCR) deNO_x unit.

The assumptions used are shown below. For the wind turbine farm it is assumed that the annual expenses for Operation & Maintenance is 2.4 % of the investment costs at year 1.

Reduction option: Wind Turbines		
O&M	2.4	% of investment
Activity	150000	kW
Investment in wind turbines	10667	DKK/kW
Annual capacity factor (h)	3500	hours
Annual production	525000	MWh

Reference option: Coal fired power		
Variable O&M	30	DKK/MWh
Fixed O&M	0	DKK/kW
Invest. in reference power plant	0	DKK/kW
Capacity credit	0	%
Annual production	525000	MWh
Annual coal saved	4576271	GJ
Coal price	14.4	DKK/GJ
Life time of power plant	20	years
Coal to elec. efficiency	41.3	%
NO_x emission factor	0.050	kg NO_x/GJ
NMVOC emission factor	0.0015	kg NMVOC/GJ
SO_2 emission factor	0.111	kg SO_2/GJ

Reference option: Natural gas fired		
Variable O&M	9	DKK/MWh
Fixed	0	DKK/kW
Invest. in reference power	0	DKK/kW
Capacity	0	%
Annual	525000	MWh
Annual coal	3937500	GJ
Natural gas price	25.4	DKK/GJ
Life time of power	20	years
Coal to elec.	48.0	%
NO_x emission	0.060	kg NO_x/G
NMVOC emission	0.0025	kg NMVOC/G
Sulphur emission	0.000	kg SO_2/GJ

The net annual financial costs in Table 3.4.3 are 96 MDKK. This is the sum of the 6 % annuity of total investment cost of 1600 MDKK in Table 3.4.2, the O&M costs of 38.4 MDKK subtracting the 66 MDKK fuel saved and 16 MDKK O&M saved at the power plant. Dividing the net annual costs by the amount of emission saved results in costs of 0.19

MDKK per tonne SO_2, 0.42 MDKK per tonne NO_x, and 13.7 MDKK per tonne NMVOC saved.

The calculations show that the 150 MW wind turbine farm reduces the emission from the coal fired (natural gas) power plant of SO_2 by 508 (0) tonnes, NO_x by 229 (236) tonnes, NMVOCs by 7 (10) tonnes and CO_2 by 439.8 (377.8) thousand tonnes in 2010.

3.4.1.3 Welfare economic analysis

Table 3.4.3 summarises the welfare economic analysis of establishing an offshore wind turbine farm, which partly replaces energy produced by a coal-fired power plant. Calculations regarding the replacement of a natural gas fired power plant by a wind turbine farm are described as part of the sensitivity analysis. It is assumed here that the electricity from one wind turbine farm is not enough to replace an entire power plant, therefore only saved costs from fuel, operation and maintenance are included in the analysis. Given the short-time horizon of this analysis, in which the focus is on possible emission reductions in the year 2010, excluding saved capital expenses from conventional electricity generation is an acceptable option. This approach, however, favours the conventional production over renewable energy technologies as for example offshore wind turbine farms, since no true choice between different technologies will be explored. In the long run, therefore, capital expenses should be included in the determination of saved expenses from conventional energy production.[8]

As described in Chapter 3.2 total investment costs as listed in the second column in Table 3.4.3 need to be increased by the respective net-tax factor for either internationally or nationally traded goods and services. Turbines, cables and electronics for grid connection and the unforeseen expenses for extra environmental measures, service boats etc. are internationally traded items. The use of these resources in establishing an offshore wind turbine farm therefore decreases the amount of foreign exchange available to other projects and their opportunity costs are therefore calculated by multiplying financial investment amounts by the net-tax factor of 1.25.

The wind turbine farm's foundation and any manpower applied in its construction including consultant and planners' time are nationally traded items or services and their financial investment amounts are therefore increased by the net-tax factor of 1.17 in order to reflect the foregone consumption possibilities to consumers if these resources would have been applied as input in other projects.

All investment expenses occurring in year one are annualised using a capital recovery factor calculated with a social time preference rate of 3% and the assumed operating period for the wind turbine farm of 20 years. The opportunity costs from foregone investments are included by multiplying annual welfare economic investment amounts by a

[8] Given the existence of a common energy market, a third option arises, where energy production is priced using world market prices for electricity. This approach, however, renders some problems with regard to the calculation of emission savings (what energy mix should be assumed) and the location of those emission savings (which does not necessarily have to be Denmark).

return on investment factor which is calculated using the economic investment rate of 6 %, social time preference rate of 3 % and the respective operating period of 20 years. “Price per unit” for investments in the welfare economic analysis thus is calculated as the product of net-tax factor (NTF), capital recovery factor and return of investment factor.

Operating and maintenance (O&M) costs, calculated as 2.4 % of total investment expenses in year one, are increased by the net-tax factor of 1.17. Total welfare economic costs per year are therefore equal to approximately 235 MDKK.

Electricity production by a coal-fired power plant is the assumed alternative to producing electricity by an offshore wind turbine farm. Thus the short-term savings or benefits for society from producing electricity by a wind turbine farm are equal to the saved expenses for fuel for the coal-fired power plant and part of the plant’s operating and maintenance costs. The financial fuel price of 14.4 DKK/GJ for coal is thus increased by the net-tax factor for internationally traded goods, resulting in a welfare economic coal price of 18 DKK/GJ. Saved O&M costs are set to 16 MDKK/year and multiplied by the net-tax factor for non-tradables of 1.17. Subtracting saved fuel and O&M costs from total costs per year results in net annual costs for establishing an offshore wind turbine farm of about 134 MDKK as shown in Table 3.4.3. Dividing welfare economic net costs by the amount of emissions saved results in costs of 0.26 MDKK per tonne SO_2, 0.59 MDKK per tonne NO_x and 19.16 MDKK per tonne NMVOC saved. By reducing electricity production at a conventional coal-fired power plant, the building of an offshore wind turbine farm also results in annual savings of 439146 tonnes CO_2. The effect of including a monetary value for these emission reductions on total costs is analysed in Chapter 3.8.

Table 3.4.3. Offshore wind turbine farm (replacing electricity from coal fired power plant).

Consequences	Real consequences		Financial calculations		Welfare economic calculations		
	unit	amounts	Price per unit	MDKK/ year	NTF	Price per unit*	MDKK/ year
Investment							
Turbines	MDKK	938	(0.0872)	81.8	1.25	(0.1215)	114.0
Foundation	MDKK	347	(0.0872)	30.3	1.17	(0.1137)	39.5
Gridconnection, manpower	MDKK	76	(0.0872)	6.6	1.17	(0.1137)	8.6
Gridconnection, cables	MDKK	69	(0.0872)	6.0	1.25	(0.1215)	8.4
Gridconnection, electronics	MDKK	19	(0.0872)	1.7	1.25	(0.1215)	2.3
Consultants & planning	MDKK	94	(0.0872)	8.2	1.17	(0.1137)	10.7
Unforeseen expenses	MDKK	56	(0.0872)	4.9	1.25	(0.1215)	6.8
Total investment costs	MDKK	1599		139.4			190.3
O&M	MDKK/ year	38.4		38.4	1.17		44.9
Total costs per year	MDKK/ year			178			235.2
Fuel saved	GJ	4576271	-14.4	-66	1.25	-18	-82.4
O&M saved	MDKK/ year	-16		-16	1.17		-18.7
Net costs per year				96			134.1
Emissions saved							
SO_2	tonne	508					
NO_x	tonne	229					
NMVOC	tonne	7					
CO_2	tonne	439146					
Net costs per tonne				MDKK/tonne			MDKK/tonne
SO_2				0.19			0.26
NO_x				0.42			0.59
NMVOC				13.70			19.16
Factors used in the calculation							
Capital recovery factor (6%, 20 years):				0.087185			
Capital recovery factor (3%, 20 years):				0.067216			
Return on investment factor (6%, 3%, 20 years):				1.446324			

* The "price per unit" for investment items has been calculated as the product of capital recovery factor, return on investment factor and respective net-tax factor.

3.4.1.4 Sensitivity analysis

In the first scenario it was assumed that the offshore wind turbine farm replaces electricity produced at a coal fired power plant. Alternatively electricity produced at the wind turbine farm could replace capacity at a natural gas fired power plant (see Table 3.4.4 below). In the latter case cost savings in terms of saved fuel and operation & maintenance costs amount to approximately 170 MDKK per year (using welfare economic prices) and are thus about 70 % higher than costs savings from a coal-fired power plant. This would result in a lower net welfare economic cost per year, which now amounts to approximately 61 MDKK.

Table 3.4.4. Offshore wind turbine farm (replacing electricity from natural gas fired power plant).

Consequences	Real consequences		Financial calculations		Welfare economic price		
	unit	amounts	Price per unit	MDKK/year	NTF	Price per unit	MDKK/year
Investment							
Turbines	MDKK	938	(0.0872)	81.8	1.25	(0.1215)	114.0
Foundation	MDKK	347	(0.0872)	30.3	1.17	(0.1137)	39.5
Gridconnection, manpower	MDKK	76	(0.0872)	6.6	1.17	(0.1137)	8.6
Gridconnection, cables	MDKK	69	(0.0872)	6.0	1.25	(0.1215)	8.4
Gridconnection, electronics	MDKK	19	(0.0872)	1.7	1.25	(0.1215)	2.3
Consultants & planning	MDKK	94	(0.0872)	8.2	1.17	(0.1137)	10.7
Unforeseen expenses	MDKK	56	(0.0872)	4.9	1.25	(0.1215)	6.8
Total investment costs	MDKK	1599		139.4			190.3
O&M	MDKK/year	38.4		38.4	1.17		44.9
Total costs per year	MDKK/year			178			235.2
Fuel saved	GJ	3937500	-25.4	-100	1.25	-31.75	-125.0
O&M saved	MDKK/year	-42		-42	1.17		-49.1
Net costs per year				36			61.1
Emissions saved							
SO_2	tonne	0					
NO_x	tonne	236					
NMVOC	tonne	10					
CO_2	tonne	377848					
Net costs per tonne				MDKK/tonne			MDKK/tonne
NO_x				0.15			0.26
NMVOC				3.58			6.10
Factors used in the calculation							
Capital recovery factor (6%, 20 years):				0.087185			
Capital recovery factor (3%, 20 years):				0.067216			
Return on investment factor (6%, 3%, 20 years):				1.446324			

Replacing electricity in this scenario with wind energy, however only leads to reductions in NO_x and NMVOC emissions. With about 236 tonnes NO_x and 10 tonnes NMVOC those emission reductions are not much different from those in the first scenario. As total net costs are lower in the natural gas scenario, cost-effectiveness measures per emission reduced are consequently lower, resulting in 0.26 MDKK per tonne NO_x (compared to 0.59) and 6.1 MDKK per tonne NMVOC (compared to 19.16). CO_2 emission savings are with 377848 tonnes per year somewhat lower than in the base case. Table 3.4.5 below summarises emission reductions and cost-effectiveness measures for the two alternatives, using welfare economic prices.

Table3.4.5. Sensitivity analysis (MDKK per tonne) using welfare economic prices.

Off-shore wind turbine farm replacing energy from …	SO_2		NO_x		NMVOC	
	Tonnes reduced in 2010	MDKK/ tonne	Tonnes reduced in 2010	MDKK/ tonne	Tonnes reduced in 2010	MDKK/ tonne
Coal-fired power plant	508	0.26	229	0.59	7	19.16
Natural gas fired power plant	NA	NA	236	0.26	10	6.10

3.4.2 Reduction of NO_x emissions from large power plants (>25MW)

3.4.2.1 Description of proposed measure and consequences

According to the Danish Energy Agency (Sigurd L. Pedersen, Danish Energy Agency, Personal Communication, November 2001) and the Danish Utilities (Eltra/Elkraft, 2001) it is expected that before 2010 nine power plants in Denmark larger than 25 MW will have installed a SCR unit, which will reduce the NO_x emissions considerably.

Several technologies exist to remove the NO_x from the flue gas, but only very few have been used on a commercial scale. Mainly two technologies are used: The primary method is called low NO_x combustion (the Danish abbreviation is LNF). In this method a strict control of the combustion processes reduces the NO_x produced to a minimum. This technology is now installed on 13 of the large power plants that are expected to be producing electricity in 2010.

In the secondary method the produced NO_x is removed from the flue gas. The secondary methods either reduce the NO_x to atmospheric nitrogen (N_2) or oxidise the NO_x to nitrate and remove it as nitric acid. The reduction of NO_x to free N_2 is performed by the use of reducing nitrogen compounds: The most popular process called Selective Catalytic Reduction (SCR) uses ammonia (NH_3). In 2010 it is expected that 9 large Danish power plants will have installed a SCR unit. In another process called Selective Non Catalytic Reduction (SCNR) the reduction is done by ammonia urea and other reducing nitrogen compounds. In Denmark only one such unit exists at the bio fuelled unit at Ensted.

When the demand for NO_x emission reduction is moderate the primary method LNF is used. When the NO_x reduction requirement is higher the secondary method SCR is used. In the SCR process the oxidised nitrogen in NO_x reacts with the reduced nitrogen in NH_3 producing free nitrogen and water. The active elements in the catalysts used are Vanadium (V), Molybdenum (Mo) and Wolfram (W). In order to get the NH_3 and the NO_x in contact with the catalysts the SCR unit is build like a honeycomb or with cassettes in relative open structures.

An old-fashioned coal fired power plant without LNF or SCR units was emitting about 400 gNO_x/GJ. A LNF unit can reduce the emission to about 250 gNO_x/GJ and a SCR unit can reduce the emission to about 70 gNO_x/GJ. The latest SCR unit was installed in Denmark in 1996 on the 630 MW power plant at Ensted. In the financial analysis below information from this unit is used in order to calculate the costs associated with the hypothetical installation of $deNO_x$ units at the two 350 MW units (block 3 and 4) at the Studstrup power plant at Århus.

3.4.2.2 Financial analysis

According to information from ELSAM (ELSAM homepage, 2002) the total cost for a SCR $DeNO_x$ unit for a 350 MW power plant is 175 MDKK.

In the baseline used by the Danish Energy Agency and the Danish utilities most of the large coal fired units have installed a SCR unit. We are here assuming that deNO_x units also are installed at the two 350 MW units (block 3 and 4) at the Studstrup power plant in Århus. We assume that the investment costs scale with the size in MW. The total investment for the 700 MW at Studstrup will therefore be 350 MDKK.

The Operation & Maintenance costs (O&M) cover the cost of ammonia (NH_3), electricity, other material and manpower. No detailed information on the O&M cost is available since this data is only for internal use in the companies. The information obtained from ELSAM shows that the total cost for NO_x reduction is 9.82 DKK/kgNO_x (ELSAM homepage, 2002). This figure includes the investments levelized over 10 years with a 6.5 % discount rate and the O&M cost. We subtracted the investment part from this figure and found an O&M cost of 2.33 DKK/kgNO_x. The 350 MW unit will presumably operate 6000 hours per year and reduce the NO_x emission by 80 %, this would amount to a reduction of 3230 tonnes NO_x per year. Assuming that the two 350 MW units at Studstrup will reduce the emission by the double amount the emission reduction will be 6460 tonnes NO_x per year. The total O&M cost will therefore be 15.1 MDKK per year.

With a capital recovery factor (calculated with 6 %) the annual investment costs are 47.6 MDKK, and adding the O&M costs of 15.1 MDKK gives a total annual financial cost of 62.7 MDKK. Dividing this cost with the 6460 tonnes NO_x annual reduction results in reduction costs of 9700 DKK per tonne NO_x.

3.4.2.3 Welfare economic analysis

Table 3.4.6 includes the welfare economic calculations of installing a SCR unit at the Studstrup power plant. Total financial investment costs of 350 MDKK (see previous financial analysis) are increased by the net-tax factor for internationally traded goods of 1.25, while the annual operation and maintenance costs of 15.1 MDKK are increased by the NTF for nationally traded items of 1.17. Total investment costs in welfare economic prices are also multiplied by a return on investment factor in order to take into account the opportunity costs from foregone investments and then annualised over the assumed operating period of 10 years by applying a capital recovery factor calculated based on a social time preference rate of 3%. Annual investment costs are thus equal to 64.4 MDKK.

Table 3.4.6. Reduction of NO_x emissions from large power plants.

Consequences	Real consequences		Financial calculations		Welfare economic calculations		
	unit	amounts	Price per unit	MDKK/ year	NTF	Price per unit*	MDKK/ year
Investment							
Total investment costs	MDKK	350	(0.1359)	47.6	1.25	(0.1840)	64.4
O&M	MDKK/year			15.1	1.17		17.7
Total costs per year				62.7			82.1
Emissions saved							
NO_x	tonne	6460					
Costs per tonne NO_x				0.0097			0.0127
Factors used in the calculations:							
Capital recovery factor (6%, 10 years):		0.1359					
Capital recovery factor (3%, 10 years):		0.1172					
Return on Investment Factor:		1.2559					

* The “price per unit” for investments have been calculated as the product of capital recovery factor, return on investment factor and respective net-tax factor.

Adding annual welfare economic O&M costs of 17.7 MDKK to annual investment costs and dividing the total annual costs of 82.1 MDKK by the annual amounts of 6460 tonnes of NO_x emissions saved, results in reduction costs of about 12700 DKK per tonne NO_x in the welfare economic analysis.

3.4.3 Reduction of SO_2 emissions from large power plants (>25MW)

According to the Danish Energy Agency (Sigurd L. Pedersen, Danish Energy Agency, Personal Communication, November 2001) and the Danish Utilities (Eltra/Elkraft, 2001) 14 Danish power plants larger than 25 MW producing electricity in 2010 will have installed a desulphurisation unit, which reduces the SO_2 emissions considerably. No additional desulphurisation units are expected to be installed before 2010 in the baseline scenario from these two institutions.

3.4.3.1 Description of proposed measure and consequences

Not all sulphur in the fuels is converted to SO_2. Natural gas contains no sulphur. For liquid fuels all the sulphur in the fuel is converted to SO_2 in the flue gas. In regard to coal Eltra/Elkraft assumes that 5%/2% of the sulphur remains in the ash.

Since the middle of the 1970s, when the sulphur problematic was realised, many different desulphurisation technologies have been worked out. However, only a few of these technologies have been established as commercially. In Denmark three different desulphurisation technologies have been used. A sulphuric acid-producing unit (SNOX unit) was installed on block 3 at Vestkraft. However, this plant is not expected to be operational in 2010 and the technology is not expected to be used in the future.

In the two other technologies the flue gas containing the SO_2 passes through a mixture of limestone ($CaCO_3$), oxygen and water in the absorber (SO_2 scrubber). In this process the SO_2 is turned into gypsum ($CaSO_4 \cdot 2H_2O$). In the chemical process a molecule of CO_2 is produced each time a molecule of SO_2 is absorbed:

$$CaCO_3 + SO_2 + ½O_2 + 2H_2O \rightarrow CO_2 + CaSO_4 \cdot 2H_2O \qquad (3.4.1)$$

In the second technology $CaSO_3$ is produced – in Danish called TASP (Tør AfSvovlings Product). This technology was installed at four plants in Jutland in about 1990. In the TASP process the ash is removed from the flue gas after the SO_2 scrubber.

The third technology, in which the flue ash is removed before the SO_2 scrubber, has been most successful – it produces clean gypsum, which can be sold on the market. It is installed on 10 large Danish power plants. This is the technology expected to be used in the future and is therefore used in our calculation. When the deNO$_x$ unit, mentioned in the deNO$_x$ option, was installed in 1996 on the 630 MW power plant at Ensted, a desulphurisation unit with this technology was also installed. In the financial analysis below information from this unit is used.

The desulphurisation technology reduces the SO_2 emissions considerably. In the reporting from the Danish utilities on SO_2 and NO_x emissions for the year 2000 (Sigurd L. Pedersen, Danish Energy Agency, Personal Communication, November 2001) 95-98 % of the SO_2 in the flue gas is removed by the desulphurisation plants.

3.4.3.2 Financial analysis

According to information from ELSAM (ELSAM homepage, 2002) the total cost for a gypsum producing desulphurisation unit for a 350 MW power plant is 555 MDKK. This cost also includes all the investment costs needed to build the storages for limestone, gypsum and sewage water.

The Operation & Maintenance costs (O&M) cover the cost of limestone, water, electricity, other materials and manpower. No detailed information on the O&M cost is available since this data is only for internal use in the companies. The information obtained from ELSAM was that the total cost for SO_2 reduction is 4.08 DKK/kgSO_2 (ELSAM homepage, 2002). This figure includes the investments levelized over 10 years with a 6.5 % discount rate and the O&M cost. We subtracted the investment part from this figure and found an O&M cost of 0.42 DKK/kgSO_2.

The 350 MW unit is assumed to operate 6000 hours per year and to reduce the SO_2 emission by 95 %, this amounts to a reduction of 21111 tonne SO_2 per year.

In the baseline used by the Danish Energy Agency and the Danish Utilities all the large coal fired units producing electricity in 2010, except block 6 at Østkraft in Rønne, have installed a desulphurisation unit. We therefore assume here that a desulphurisation unit is installed in Rønne. We assume that the investment costs scale with the size in MW. The investment for the 38 MW unit in Rønne would therefore be 60 MDKK and the O&M cost 0.96 MDKK.

The life span of a desulphurisation unit is expected to be 10 years (ELSAM homepage, 2002). In the financial calculation shown in Table 3.4.7 we use a discount rate of 6% meaning that the total costs per kg SO_2 will be lower than the figure obtained from ELSAM, in which a discount rate of 6.5 % was used. The annual investment cost is thus 8.19 MDKK and adding the O&M cost (including the income from sale of gypsum) of 0.96 MDKK gives a total annual cost of 9.15 MDKK. Dividing this by the 2292 tonnes of SO_2 saved results in a financial cost of 4000 DKK per tonne SO_2 reduced.

3.4.3.3 Welfare economic analysis

Table 3.4.7 presents the welfare economic cost calculations. The welfare economic analysis follows the same procedure as outlined in the SCR (deNO_x) analysis. Investment costs are increased by the net-tax factor for internationally traded goods of 1.25, while operation and maintenance costs are multiplied by the net-tax factor for nationally traded goods and services of 1.17. Total investment costs are also increased by the return on investment factor in order to include opportunity costs from foregone alternative investments in the analysis and multiplied by a capital recovery factor in order to obtain annual investment amounts. The operating period is assumed to be 10 years.

Total welfare economic costs for the installation of a gypsum producing desulphurisation unit amount to 12.2 MDKK. Dividing annual costs by the amount of SO_2 emissions saved per year results in costs of 5300 DKK per tonne SO_2 reduced.

Table 3.4.7. Reduction of SO_2 emissions from large power plants.

Consequences	Real consequences		Financial calculations		Welfare economic calculations		
	unit	amounts	Price per unit	MDKK/ year	NTF	Price per unit*	MDKK/ year
Investment							
Total investment costs	MDKK	60	(0.1359)	8.19	1.25	(0.1840)	11.09
O&M	MDKK			0.96	1.17		1.13
Costs per year				9.15			12.22
Emissions saved							
SO_2	tonne/year	2292					
Costs per tonne SO_2				0.0040			0.0053
Factors used in the calculations							
Capital recovery factor (6%, 10 years):			0.1359				
Capital recovery factor (3%, 10 years):			0.1172				
Return on Investment Factor:			1.2559				

* The "price per unit" for investments have been calculated as the product of capital recovery factor, return on investment factor and respective net-tax factor.

3.5 Emission reduction measures in the transport sector

3.5.1 Emission reductions from the introduction of electrical vehicles

An introduction of electrical vehicles replacing gasoline driven vehicles will reduce the emissions of NO_x, SO_2 and NMVOCs due to the higher energy efficiency in these vehicles.

3.5.1.1 Description of proposed measure and consequences

It is assumed that the electrical vehicle technology will not be ready to penetrate into the marked until 2004. In this option a part of the smaller gasoline fuelled average sized cars, assumed here to be private cars<1.4 litre, are replaced with electrical vehicles. In the period 2004-2010 a total of 285282 new cars will be added to this group of cars (Eltra/Elkraft, 2001). In alternative I we replace 70000 of these new cars with electrical vehicles corresponding to an annual sale of 10000 small electrical vehicles every year in the period 2004 until 2010. In alternative II all the 285282 new cars in this group will be replaced, e.g. 215282 more cars than in alternative I. To reach this goal a sale of about 40000 small electrical vehicles is needed every year in the period from 2004 until 2010.

It is assumed that the vendors of the cars have a profit of 10 %, because according to the law the profit must be more than 9 % and because for new cars the profit is seldom much above this value (Sigurd L. Pedersen, Danish Energy Agency, Personal Communication, November 2001). The registration tax is calculated as 105 % of 55300 DKK plus 180 % of the part of the price, which is above 55300 DKK.

The annual mileage for a car was calculated to be 25660 km (Eltra/Elkraft, 2001).

3.5.1.2 Financial analysis

This section starts with a description of the economic assumptions concerning the reference option, gasoline fuelled cars, and continues with the reduction for the emission reduction option – the electrical cars. For both gasoline cars and electric cars the annual green owner tax was not included, because it is small.

Reference option:

The reference is a small average gasoline driven car like Polo. In the calculation we make the following assumptions (ELSAM homepage, 2002):

Importprice:	49000	DKK
Profit:	5000	DKK
Registration tax:	58000	DKK
Value added tax:	28000	DKK
Sales price:	140000	DKK
Lifetime:	16	years
Gasoline consumption:	15	km/l

The sales price for unleaded gasoline is assumed to be 8.50 DKK/l in the entire period until 2010. This price consists of the following elements:

Gasoline price:	3.69	DKK/l
Energy tax:	3.11	DKK/l
(according to the Energy Agency=	102.18	DKK/GJ)
Value added tax:	1.70	DKK/l
Sales price:	8.50	DKK/l

In the calculations we use emission factors listed below for 2010 (Eltra/Elkraft, 2001). These emission factors are the same in the two alternatives since the annual replacement of cars for each year in the period 2004-2010 is proportional:

0.057	kg NO_x/GJ gasoline
0.005	kg SO_2/GJ gasoline
0.053	kg NMVOC/GJ gasoline

Reduction option:

All the small electrical cars are assumed to be like the Citroen Saxo. In the calculation we make the following assumptions (ELSAM homepage, 2002):

Import price:	129000	DKK
Profit:	13000	DKK
Registration tax:	0	DKK
Value added tax:	35000	DKK
Sales price:	177000	DKK

We assume that electrical cars will continue to be without registration tax.

A battery change is assumed every 10th year for 40000 DKK (ELSAM homepage, 2002). In the economic calculation we therefore add 22300 DKK to the investment in year 1 – this is equal to 40000 DKK discounted back in 10 years with a discount rate of 6 %. It is assumed that it is a Nickel metal hydride battery, which will last for 150 km between recharges. It is further assumed that this battery will cost the same as the present Nickel Cadmium battery, which only lasts for 75 km between recharges.

Life span:	16	years
Electricity consumption:	0.15	kWh/km

It is assumed that the electricity is produced on a natural gas fuelled power plant with an electrical efficiency of 45 %. The losses in the electrical grid are assumed to be 7 %, and it is assumed that the electricity price will remain at about 1.50 DKK/kWh, a bit above the current average in Denmark.

For the natural gas fuelled power plant the following emission factors are used for NMVOC (Hakon Christensen, Personal Communication, January 2002). The emission factor for NO_x is the highest emission factor for the power plants with SCR $DeNO_x$ units in 2010:

0.075	kg NO_x / GJ
0.004	kg NMVOC / GJ natural gas

The electricity price consists of the following elements:

Productions price:	0.549	DKK / kWh
CO_2 tax:	0.100	DKK / kWh
Electricity tax:	0.551	DKK / kWh
Value added tax:	0.300	DKK / kWh
Sales price:	1.500	DKK / kWh

Emission reductions in the two alternatives:

The emission reduction in this alternative in 2010 will be:

SO_2:	0.020	kt (0.080 kt)
NMVOC:	0.199	kt (0.812 kt)
NO_x:	0.051	kt (0.209 kt)
CO_2:	0.136	Mt (0.553 Mt)

These emission results are for alternative I (70000 electrical cars in 2010). The values in the brackets are for alternative II (in which the stock of electrical cars is increased by an extra 215000). Please remark that the NO_x emissions reduction is rather small due to the very low NO_x emissions after the introduction of the EURO III and IV norms.

The financial analysis presented in Table 3.5.1 is similar to the welfare economic analysis of the differences in annual costs for the private consumer presented in Table 3.5.3. However, for the financial calculations a 6 % discount factor is used as can be seen in Table 3.5.1. The incremental cost of 37000 DKK for buying an electric car is multiplied by 10000 for each year in the period 2004-2010. The net present value in 2004 is then calculated with the 6 % discount rate and annualises over the 16-year lifetime with the annuity factor shown. The result is that the total extra annual investment cost for the 70000 electric vehicles is 216.6 MDKK. Using the same procedure for the 40000 DKK for the change of battery every 10th year results in an annual cost of 130.8 MDKK. Including the cost for the electricity used and the gasoline saved results in a negative net annual cost of 266.3 MDKK for all 70000 electric cars. The net cost per tonne of emission reduced can also be seen in Table 3.5.1.

Table 3.5.1. Replacing gasoline driven vehicles with electrical vehicles (Financial analysis).

70000 electrical vehicles	**Real consequences**		**Financial costs**	
Investment	unit	amounts	Price per unit (DKK)	MDKK/year
Marketsprice (difference, PV 6%)		2189.4	0.0990	216.6
Battery replacement		1321.7	0.0990	130.8
Total investment costs		3511.1		347.4
Electricity used	1000 kWh	269430.0	1500	404.1
total costs per year				751.6
Gasoline saved	1000 liter	119746.7	8500	1017.8
Net costs per year				-266.3
Emissions saved				
SO_2	tonne	20		
NO_x	tonne	51		
NMVOC	tonne	199		
CO_2	tonne	136000		
Net costs per tonne				
SO_2				-13.3
NO_x				-5.2
NMVOC				-1.3

3.5.1.3 Welfare economic analysis

The calculations below are based on the first scenario, an assumed annual replacement of 10000 conventional small cars with electrical cars in the period 2004 until 2010. Incremental costs to society are calculated based on the difference between import prices for conventional and electrical cars, which is equal to 80000 DKK per car. A positive difference between import prices leads to higher import costs and thus decreases the amount of foreign exchange available for use in other projects. Assuming a replacement of 10000 cars per year, annual incremental costs amount to 800 MDKK per year in the period 2004 until 2010. Total present value costs are thus equal to 5133.8 DKK using a 3 % discount rate. Battery replacement costs per car (before VAT) are equal to 32000 DKK. However, since these costs occur only after 10 years of driving, present value replacement costs per car are equal to 23800 DKK (using a discount rate of 3 %). Present value costs for all 70000 cars in scenario I are thus equal to 1528 MDKK.

In order to calculate welfare economic costs for this measure, incremental costs for buying electrical cars and battery replacement costs are increased by the net-tax factor for internationally traded goods. Opportunity costs for foregone investment alternatives are taken into consideration by multiplying total welfare economic costs by a return on investment factor (calculated based on a financial interest rate of 6%, a social time preference rate of 3 % and an assumed life span per vehicle of 16 years).[9] A capital recovery factor (based on 3 % and 16 years) is applied in order to obtain annual investment costs. As can be seen in Table 3.5.2 total annual welfare economic costs amount to nearly 913 MDKK.

Assuming an annual mileage per car of 25660 km and an electricity consumption of 0.15 kWh/km results in an annual electricity consumption of 3849 kWh per car. In the welfare economic analysis these

[9] One could also assume that money alternatively would have been consumed instead of invested, which would indicate zero opportunity costs.

kilowatt-hours are priced according to the welfare economic costs of producing them. As in the offshore wind turbine farm analysis it is assumed that this only affects the variable costs of producing electricity, i.e. fuel and operation and maintenance costs, i.e. that there exists enough unused capacity at power plants in Denmark to extend production in order to meet the additional demand. In the offshore wind turbine farm scenario welfare economic costs of producing 525000 MWh of electricity using a conventional coal-fired power plant are equal to 101.1 MDKK or approximately 0.19 DKK/kWh.

As mentioned in the previous chapter losses in the electrical grid are assumed to amount to 7 %. These losses need to be included in the production costs and are therefore added to the total electricity consumption of electrical cars. As shown in Table 3.5.2 electricity consumption for all 70000 electrical vehicles in 2010 amounts to about 288 million kWh per year, which - assuming a welfare economic price of 0.19 DKK/kWh – adds about 55.5 MDKK to the annual investment costs. Saved gasoline consumption (here assumed to be nearly 120 million litre annually for all 70000 cars), on the other hand reduces annual costs by about 552 MDKK per year[10], resulting in net operating "benefits" of 496.5 MDKK for all 70000 electrical cars. These benefits in terms of reduced operating expenses, however, are not enough to outweigh the higher annual investment costs of 913 MDKK calculated previously.

In addition it must be assumed that the replacement of gasoline driven vehicles by electrical vehicles results in a utility loss to the consumer in terms of a reduced driving range of electrical vehicles. Since no monetary measure for this utility loss exists, these costs are approximated by calculating the difference in annual costs (investment and operating expenses) for the private consumer from switching from conventional to electrical cars. The argumentation is that consumers would be willing-to-pay more on an annual basis for driving a conventional car, if these extra expenses were equal to the utility gain from an unrestricted driving range (and other advantages connected to driving a conventional car).

Table 3.5.3 below describes the calculation of differences in private costs, using a social time preference rate of 3%, based on sales prices for the different cars, electricity and gasoline. The consumer faces higher investment costs in terms of a higher sales price for electrical vehicles (after taxes) and a required battery replacement after 10 years. On the other hand, the consumer faces a reduction in annual operating costs, as total expenses for electricity are less than alternative expenses for gasoline. Incremental costs for buying an electrical car instead of a conventional car are equal to 37000 DKK per car. Present value costs of replacing the battery after ten years are equal to 29800 DKK per car, using a discount rate of 3 %.

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[10] Saved gasoline costs are calculated assuming an annual mileage of 25660 km per car and a gasoline consumption of 15 km/liter.

Table 3.5.2. Replacing gasoline driven vehicles with electrical vehicle (welfare economic costs).

70000 electrical vehicles	**Real consequences**			**Welfare economic calculations**		
Investment	unit	amounts	Price per unit (DKK)	NAF	Price per unit* (DKK)	MDKK/year
Import price difference (PV 3%)		5133.8		1.25	(0.1370)	703.4
Battery replacement		1528.0		1.25	(0.1370)	209.4
Total investment costs		6661.8				912.8
Electricity used	1000 kWh	288290.1			192.57	55.5
Gasoline saved	1000 liter	119746.7	3690.00	1.25	-4612.5	-552.3
Consumers utility loss						272.6
Total costs per year						688.6
Emissions saved						
SO_2	tonne	20				
NO_x	tonne	51				
NMVOC	tonne	199				
CO_2	tonne	136000				
Net costs per tonne						
SO_2						34.4
NO_x						13.5
NMVOC						3.5

Factors used in the calculations		
Capital recovery factor (3%, 16 years):	0,0796	
Return on investment factor:	1.3768	

*"Price per unit" in the second last column is calculated as the product of capital recovery factor, return on investment factor and net-tax factor.

The investment amounts listed in column 3 are the total costs for all 70000 cars (difference in sales price and battery replacements), discounted back to the year 2004 using a 3 % discount rate. Total present value costs are then annualised over the assumed life span of an electrical vehicle of 16 years, which results in annual costs in terms of higher sales prices of 189 MDKK and about 152 MDKK for battery replacements, as shown in Table 3.5.3.

As shown in Table 3.5.3 electricity consumption for all 70000 electrical vehicles in 2010 amounts to about 269 million kWh per year, which - assuming a sales price of 1.5 DKK per kWh – adds about 404 MDKK to the annual investment costs.[11] Saved gasoline consumption, on the other hand, calculated using the Danish sales price of 8.5 DKK/litre, reduces annual costs by about 1017 MDKK per year, resulting in negative net costs (i.e. actual benefits in terms of saved expenses) per year of 272 MDKK for all 70000 electrical cars. Based alone on annual expenses, consumers thus should prefer to buy electrical vehicles instead of conventional cars. Should they instead choose to purchase gasoline driven cars, it can be assumed that the additional expenses reflect their willingness-to-pay for an increased driving range, higher speed and other advantages connected with conventional vehicles.

[11] Here the loss of 7% in the electrical grid does not need to be included, as the producer costs connected with it are already included in the sales price for electricity.

Table 3.5.3. Replacing gasoline driven vehicles with electrical vehicles: Differences in annual expenses.

70000 electrical vehicles	**Real consequences**		**Welfare economic analysis**		
Investment	unit	amounts	NTF	Price per unit*	MDKK/ year
Sales price (difference, PV 3%)	MDKK	2374.4	-	(0.0796)	189.0
Battery replacement	MDKK	1910.0	-	(0.0796)	152.1
Total investment costs	MDKK	4284.4			341.1
Electricity used	1000 kWh	269430.0		1500	404.1
Total costs per year					745.2
Gasoline saved	1000 liter	119746.7		-8500	-1017.8
Net costs per year					-272.6
Factors used in the calculations					
Capital recovery factor (3%, 16 years):		0.0796			

*"Price per unit" for investment items is here equal to the capital recovery factor.

Net costs per tonne based on welfare economic prices are thus equal to 34.4 MDKK per tonne SO_2, 13.5 MDKK per tonne NO_x and 3.5 MDKK per tonne NMVOC. Welfare economic costs per tonne to society are thus substantially different from the financial costs calculated before.

Increasing the total amount of electrical cars to about 285000 as suggested in alternative II, implying about 40000 sales per year, leads – as expected - to four times as much emissions savings as in the first alternative. However, as costs are also increased about fourfold, emission reduction costs, in terms of DKK per tonne, stay about the same.

3.5.2 Exhaust Gas Recirculation (EGR) for heavy duty vehicles

3.5.2.1 Introduction

For most emission components the future total emissions gradually decrease due to the step-wise implementation of stricter emission legislation levels. However, in some situations the emissions from road traffic can be reduced even further by making options in which emission reduction technologies already developed are introduced prior to the expected year they will be ready for market. The Exhaust Gas Recirculation (EGR) technology is a realistic emission reducing technology used by engine producers to comply with the EURO IV emission legislation standard for heavy-duty vehicles which will be implemented in 2007. Tests have recently been made on urban buses in Denmark (Færdselsstyrelsen, 2001). Although only a limited number of tests have been conducted the results of the measurement programme shows the potential of using EGR on a more wide spread scale. However, the question concerning how many older vehicles can actually use the EGR technology still remains open. The manufacturers of the EGR technology are very optimistic about its potential in terms of units installed, while some engine producers and people employed with the field tests have more moderate expectations.

In this scenario the emission impact and the economic costs of using EGR on heavy-duty vehicles are assessed. Three different options are investigated in terms of emission reductions achieved and their related economical costs:

- EGR retrofitting on vehicles no more than 10 years old and line installation on new vehicles.
- EGR retrofitting on vehicles no more than 5 years old and line installation on new vehicles.
- EGR line installation on new vehicles.

In the first two cases results are obtained from making retrofit installations of the EGR technology on older vehicles and obligatory installations on new vehicles before they enter traffic. Retrofitting is made for vehicles no more than 5 and 10 years old, respectively in the first year of the scenario period. For new vehicles in the scenario period, line installation of EGR can be made, at a lower economic cost. In the third situation only results for a line-installation of the EGR technology on new vehicles are examined. In all three cases the actual installation programme begins in 2002 and will proceed until 2007, when the EURO IV emission legislation comes into force.

3.5.2.2 EGR technology description

In the low pressure EGR system the exhaust gas passes through the turbo and a catalytic particulate filter (CRT filter). CO and VOC emissions are reduced in the catalytic converter, while the particulate filter brings down the total mass of particulate matter. A venturi picks up some of the cleaned exhaust gas. This gas streams further through the exhaust gas cooler, continues to the mixing valve, passes through the turbocharger and the inter cooler, and is finally let into the engine cylinder. The increased CO_2 concentration reduces the content of oxygen in the intake air. This as an end result brings down the combustion temperature and thus the final emissions of NO_x.

The EGR technology is assumed to last for the entire life span of the vehicle. On average the CRT filter must be replaced by a new one for every 400000 km driven, while packings (and clips) must be replaced more often, typically for a total mileage increase of around 100000 km (Jensen, 2001). It is assumed to be 25 % more expensive to make a retrofit installation compared with the line-installation prices.

Using the EGR technology brings down the emissions substantially. In this way an emission reduction of 75 %, 90 % and 95 % has been used for NMVOC, CO and particulate matter, respectively (Bak, 2002). The reductions mentioned are irrespective of the engine Euro emission standard in question. For NO_x the emission reduction is in the order of 50% irrespective of the Euro emission standard. This is equal to the lowering of NO_x emissions, which can be obtained by changing from a conventional engine to EURO II, EURO I to EURO III and EURO III to EURO IV. In the latter situation emissions can only be reduced to a level comparable with the emissions from an EURO IV engine. The reason is that EGR is one of the realistic emission reducing technologies used by engine producers in the future to comply with this legislation level.

Table 3.5.4. Fleet development for vehicles equipped with EGR.

Veh. Age	Category	2002	2003	2004	2005	2006	2007	2008	2009	2010
1-10	7.5-16 t.	6606	6295	5979	5658	5333	5003	4669	4329	3985
	16-32 t.	11328	10687	10037	9378	8710	8032	7345	6648	5942
	>32 t.	10510	9916	9313	8701	8081	7452	6815	6168	5513
	Urban bus	2801	2651	2500	2349	2197	2045	1892	1740	1586
	Coach	3304	3133	2961	2788	2613	2437	2260	2082	1903
1-10 Total		34550	32683	30791	28874	26934	24969	22981	20967	18930
1-5	7.5-16 t.	3744	3591	3436	3279	3119	2957	2792	2626	2457
	16-32 t.	6552	6237	5918	5595	5266	4933	4595	4253	3906
	>32 t.	6079	5787	5491	5191	4886	4577	4264	3946	3624
	Urban bus	1593	1518	1443	1367	1291	1216	1140	1064	987
	Coach	1879	1794	1709	1623	1536	1449	1361	1273	1184
1-5 Total		19846	18928	17997	17054	16099	15132	14152	13161	12157
New	7.5-16 t.	855	1685	2490	3270	4023	3867	3708	3548	3384
	16-32 t.	1523	2995	4415	5780	7089	6767	6441	6111	5775
	>32 t.	1414	2779	4096	5362	6577	6279	5976	5670	5358
	Urban bus	365	715	1050	1371	1678	1602	1527	1451	1375
	Coach	430	845	1244	1628	1996	1910	1824	1737	1649
New Total		4586	9019	13296	17411	21362	20426	19477	18515	17542

Table 3.5.5. Number of EGR installations per year for new vehicles.

Veh. Age	Category	2002	2003	2004	2005	2006	2007	2008	2009	2010
New	7.5-16 t.	855	860	866	871	877				
	16-32 t.	1523	1533	1544	1554	1564				
	>32 t.	1414	1423	1432	1441	1451				
	Urban bus	365	365	366	366	366				
	Coach	430	432	433	434	436				
New Total		4586	4613	4640	4667	4694				

3.5.2.3 Scenario calculations

As mentioned previously the analysis comprises three different scenarios: Two of the scenarios include the retrofitting of EGR on all vehicles no more than 10 years and 5 years old, respectively, starting in 2002. Both scenarios include a line-installation of EGR on all new vehicles entering the market in the period 2002 – 2006. The third scenario only includes the line installation of EGR on new vehicles.

In the first two scenarios the development in the number of heavy duty vehicles equipped with EGR is found as the sum of new vehicles, and 1-10 and 1-5 year old vehicles, respectively from Table 3.5.4. A certain number of vehicles are being scrapped each year in the scenario period, as can be seen from the reduction in total numbers in the case of 1-10 and 1-5 year old vehicles. The fleet development for new vehicles shown in Table 3.5.4 includes thus a reduction in total vehicle numbers because of scrapping and the effect of new vehicle sales. Total numbers *per year* of EGR installations for new vehicles are shown in Table 3.5.5.

The total mileage driven determines the number of filters and packings replaced for each vehicle and the related economic costs. Since a considerable part of the total driving actually takes place outside Denmark it can be discussed if the expenses for operation and maintenance should be fully accounted for or not. On the one hand only the costs related to the Danish mileage should be accounted for as they are set in relation to only emission savings within the national boarders. Emission savings outside Denmark are not accounted for in

Table 3.5.6. Number of packings and filter replaced in the scenario period (based on total mileage).

Scenario	No.	2002	2003	2004	2005	2006	2007	2008	2009	2010
1: 1-10 and new	Packings	0	14273	27122	17448	34718	20945	23167	23220	24928
	Filters	0	0	0	0	9261	1188	3362	1478	10127
2: 1-5 and new	Packings	0	9011	17928	12956	24788	17241	18965	18602	20191
	Filters	0	0	0	0	6066	1188	2609	1478	7519
3: New	Packings	0	1706	4810	6398	9981	11448	12200	10404	11940
	Filters	0	0	0	0	1180	1188	1470	1478	2711

the calculations below. On the other hand a strong argument also exists to include the costs related to the mileage driven abroad, since – in the absence of international partners - all costs have to be met by national counterparts in order to achieve the environmental benefits in Denmark. The following calculations therefore also include the O&M costs related to mileage driven abroad. The annual mileage driven for each vehicle category is described in Appendix 3.1. The extra information on the international mileage is provided by Ekman (2002). No data was available to distinguish between domestic and international mileage for tourist buses.

Based on the sum of domestic and international mileage the numbers of filters and packings replaced can be calculated. They are presented in Table 3.5.6 as totals for each of the three scenarios since the financial prices for materials and manpower per replacement is the same for all vehicle categories.

3.5.2.4 Emissions calculations

Emissions are calculated using the emission forecasting model developed in the present project. The baseline calculation procedure is to combine emission factors for each forecast year with the number of vehicles and their annual mileage driven on different road types. For each forecast year the vehicle stock is grouped in number of vehicles according to the present emission legislation levels and correspondent emission factors. In the scenario calculations the baseline emission factors for conventional and EURO I-III engines are replaced by emission factors reduced as described previously (see also Table 3.5.9). The corresponding vehicle numbers are shown in Appendix 3.2. The difference between the latter figures and the ones given in Table 3.5.4 lies on the different groupings; the total numbers are the same.

Table 3.5.7. Emission factors for NO_x and NMVOC used in the scenario calculations.

Category	Basis EU Legislation level	Reg. Year	Veh. Age	Basis NO_x	Basis NMVOC	EGR NO_x	EGR NMVOC
7.5-16 t.	Conv.	<1994	10-9	5.02	1.22	2.74	0.31
	EURO I	1994-1996	8-6	3.68	0.92	1.92	0.23
	EURO II	1997-2001	5-1	2.74	0.86	1.34	0.21
	EURO III	2002-2006	New	1.92	0.60	1.34	0.15
16-32 t.	Conv.	<1994	10-9	9.20	1.05	4.02	0.26
	EURO I	1994-1996	8-6	5.27	0.66	2.82	0.17
	EURO II	1997-2001	5-1	4.02	0.60	1.97	0.15
	EURO III	2002-2006	New	2.82	0.42	1.97	0.10
>32 t.	Conv.	<1994	10-9	13.70	1.05	5.99	0.26
	EURO I	1994-1996	8-6	7.84	0.66	4.19	0.17
	EURO II	1997-2001	5-1	5.99	0.60	2.93	0.15
	EURO III	2002-2006	New	4.19	0.42	2.93	0.10
Urban bus	Conv.	<1994	10-9	13.39	0.90	7.06	0.23
	EURO I	1994-1996	8-6	9.53	0.68	4.94	0.17
	EURO II	1997-2001	5-1	7.06	0.63	3.45	0.16
	EURO III	2002-2006	New	4.94	0.44	3.45	0.11
Coach	Conv.	<1994	10-9	9.44	1.24	4.05	0.31
	EURO I	1994-1996	8-6	5.38	0.74	2.84	0.18
	EURO II	1997-2001	5-1	4.05	0.67	1.98	0.17
	EURO III	2002-2006	New	2.84	0.47	1.98	0.12

Table 3.5.8. Total NO_x and NMVOC emissions and reductions (based on Danish mileage).

Scenario	Emissions	Unit	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
Basis	NO_x Total	Tonnes	8631	8759	8862	8938	8987	8392	7787	7171	6544	74072
1: 1-10 and new	NO_x Total	Tonnes	4371	4554	4720	4870	5002	4687	4366	4039	3706	40313
2: 1-5 and new	NO_x Total	Tonnes	2195	2517	2825	3119	3398	3232	3063	2891	2716	25956
3: New	NO_x Total	Tonnes	412	813	1201	1577	1939	1858	1776	1692	1606	12875
1: 1-10 and new	NO_x Reduction	Tonnes	4260	4206	4142	4068	3985	3706	3422	3132	2838	33759
2: 1-5 and new	NO_x Reduction	Tonnes	2039	2129	2213	2289	2358	2234	2109	1981	1850	19201
3: New	NO_x Reduction	Tonnes	178	350	517	679	835	800	765	729	692	5545
Basis	NMVOC Total	Tonnes	1020	1045	1067	1086	1101	1032	962	890	817	9019
1: 1-10 and new	NMVOC Total	Tonnes	255	261	267	271	275	258	240	223	204	2255
2: 1-5 and new	NMVOC Total	Tonnes	139	153	166	178	189	180	171	161	151	1487
3: New	NMVOC Total	Tonnes	19	38	56	74	91	87	84	80	76	606
1: 1-10 and new	NMVOC Reduction	Tonnes	765	784	800	814	826	774	721	668	613	6765
2: 1-5 and new	NMVOC Reduction	Tonnes	417	458	497	534	568	540	512	483	453	4462
3: New	NMVOC Reduction	Tonnes	58	115	169	222	274	262	251	239	227	1818

Table 3.5.8 provides an overview of expected emission reductions in the year 2010 and a summary of total emission reductions in the whole period 2002 until 2010.

3.5.2.5 Financial and welfare economic calculations

The EGR installation costs consists of the following components:

- retrofit installation costs (investment costs) in terms of material and manpower for vehicles no more than 10 or 5 years old occurring in the year 2002;
- line-installation costs (investment costs) for new vehicles entering the vehicle stock in the years 2002-2006; and
- Operation and Maintenance (O&M) costs for filter and packings replacements and manpower over the years 2002 to 2010 for retrofitted and new vehicles.

Table 3.5.9. Financial prices for retrofit and line installation of the EGR technology.

		Coach/tourist bus	Trucks		
Gross veh. Weight (Power)	Unit	240 hk	7,5-16 tonnes (180 hk)	16-32 tonnes (325 hk)	> 32 tonnes (515 hk)
Retrofit installation	DKK	155000	158000	161000	185000
- materials	DKK	139000	142000	143000	164000
- manpower	DKK	16000	16000	18000	21000
Line-installation	DKK	116300	118500	120800	138800
- materials	DKK	104300	106500	107300	123000
- manpower	DKK	12000	12000	13500	15800
O&M costs for EGR					
- Filter (400000 km)	DKK	14000	14000	14000	14000
- Packings (100000 km)	DKK	1000	1000	1000	1000
- Manpower (100000 km)	DKK	650	650	650	650
NO_x-reduction		Two Euro levels*	Two Euro levels*	Two Euro levels*	Two Euro levels*
CO-reduction	%	90	90	90	90
HC-reduction	%	75	75	75	75
Particulate-reduction	%	95	95	95	95

*) Conv. to EURO II, EURO I to EURO III and EURO III to EURO IV.

Thus each year's costs related to the EGR installations are estimated using information about:

- the number of vehicles equipped with EGR (Table 3.5.4 and Table 3.5.5);
- the number of filters and packings replaced (Table 3.5.6); and
- the financial prices given in Table 3.5.9 (retrofit and line installations, respectively).

The EGR installation costs for all three scenarios based on total mileage (i.e. Danish plus international) are shown in Table 3.5.10. The O&M cost estimates allocated to the Danish mileage only are found for each vehicle category and each year as the O&M costs for all mileage driven multiplied by the ratio between Danish and total mileage. O&M costs only related to the Danish mileage are shown in Table 3.5.11.

Table 3.5.10. EGR installation costs for the three scenarios (based on total mileage).

Scenario	Costs	2002	2003	2004	2005	2006	2007	2008	2009	2010
1: 1-10 and new	Investment	6332	577	581	584	587	0	0	0	0
	O & M	0	24	45	29	187	51	85	59	183
2: 1-5 and new	Investment	3883	577	581	584	587	0	0	0	0
	O & M	0	15	30	21	126	45	68	51	139
3: New	Investment	574	577	581	584	587	0	0	0	0
	O & M	0	3	8	11	33	36	41	38	58

Table 3.5.11. EGR installation costs for the three scenarios (based on Danish mileage).

Scenario	Costs	2002	2003	2004	2005	2006	2007	2008	2009	2010
1: 1-10 and new	Investment	6332	577	581	584	587	0	0	0	0
	O & M	0	11	27	10	80	9	38	14	75
2: 1-5 and new	Investment	3883	577	581	584	587	0	0	0	0
	O & M	0	7	16	6	48	5	23	9	48
3: New	Investment	574	577	581	584	587	0	0	0	0
	O & M	0	2	5	7	18	20	25	22	35

The detailed cost calculations for each scheme and the different scenarios are presented in Appendix 3.3. It was decided to base cost calculations entirely on the annual costs presented in Table 3.5.10 i.e. they include O&M costs based on total mileage (Danish and international). It was considered essential that the measures included in the cost-effectiveness calculations in this report should reflect true costs to companies, consumers and society, which logically would include all O&M costs as no other part outside the Danish boarders is likely to contribute their share of O&M costs. In addition, O&M costs make up only between 7.2 % and 4.8 % of total costs, when based on total mileage. These percentages are reduced to 4.5 % and 3.4 % respectively O&M costs based solely on Danish mileage. A comparison of calculations with O&M costs based only on Danish mileage with those using total mileage shows only minor differences in total costs of 2.8 % to 1.3 %, depending on the scheme chosen.[12]

In order to subsequently make the financial and welfare economic analysis all costs have been discounted back to 2002, using a discount rate of 6 % for the financial analysis and 3 % for the welfare economic analysis. Three different cost calculation schemes are used in order to assess the economical impact of introducing EGR prior to EU implementation dates: (I) annual costs for all remaining vehicles in 2010, (II) annual costs for remaining and scrapped vehicles and (III) total costs for all vehicles with EGR installation. A summary of cost estimates and emission reductions is presented for each scheme in the different sections below.

In general the calculation of welfare economic prices is based on the financial prices for filter installation, filter and packings replacements and manpower employed in the installation and O&M processes in the period 2002 until 2010. As can be seen in Appendix 3.3 total present value investment costs and present value costs for packings and filter replacements are increased by the net-tax factor for internationally traded goods and services of 1.25, while costs for manpower employed are increased by the national net-tax factor of 1.17. Besides applying the net-tax factors for installation and O&M expenses, total welfare economic costs for those items are increased by a return on investment factor in order take into account the opportunity costs from foregone investments.

1) Remaining vehicles with EGR in 2010

As a starting point the annual costs (installation costs plus O&M) are estimated for all remaining vehicles with EGR in 2010. In the end situation, only these vehicles bring down the 2010 scenario emissions total. In order to achieve these emission reductions in 2010 it is, however, necessary to also invest in the installation of EGR in vehicles that will be scrapped before the year 2010. The reason being that it is impossible to determine beforehand which vehicles will survive until 2010. The calculated annual costs for vehicles still in use in 2010 can therefore be considered a minimum estimate for annual emission reduction costs.

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[12] Example calculations with O&M costs based on Danish mileage are not presented in this report, but can be obtained from the authors upon request.

It has not been possible to obtain accurate information regarding the scrapping of heavy-duty vehicles. Instead life span approximations have been made using the background traffic data from the emission forecasting model (see Table 3.5.12). In the model all forecast years use the same vehicle age distribution. This distribution is given as figures per vehicle age in percentages of the total fleet. The inaccuracy of using the latter distribution is that it reflects both the scrapping of vehicles and yearly variations in new sales in the years prior to the analysis of the fleet distribution.

Table 3.5.12. Remaining lifetimes for heavy-duty vehicles in 2010.

Age in 2010	Age in 2002	Remaining lifetime in 2010	Scenario period	Costs annualised No of years
8	0	4.88	8	13
9	1	4.56	8	13
10	2	4.25	8	12
11	3	3.94	8	12
12	4	3.64	8	12
13	5	3.36	8	11
14	6	3.08	8	11
15	7	2.83	8	11
16	8	2.60	8	11
17	9	2.41	8	10
18	10	2.27	8	10

In order to calculate the annual financial and welfare economic costs for each scenario total costs are annualised over the respective estimated life span of the different vehicles, where life span vary depending on the age of the vehicles at the point of EGR installation as shown in Table 3.5.12. Annual investment and O&M costs for the different scenarios, using financial and welfare economic prices are summarised in Table 3.5.13 (costs per tonne emission reduced). Total annual costs are then compared to the respective emission savings in terms of NO_x and NMVOC emissions to derive costs per tonne emission reduced.

Table 3.5.13. Financial and welfare economic analysis: Remaining vehicles with EGR in 2010.

	<=10		<=5		New	
MDKK	Financial	Welfare-econ.	Financial	Welfare-econ.	Financial	Welfare-econ.
Annual investment costs						
EGR installations	540.15	754.68	410.42	578.37	195.76	284.85
Manpower	66.02	86.34	50.23	66.25	23.99	32.67
Total (annual) investment costs	606.17	841.02	460.65	644.62	219.75	317.53
Annual O&M costs						
Filter replacements	25.40	41.50	18.95	31.05	7.98	13.18
Packings replacements	13.02	20.43	10.02	15.80	4.95	7.94
Manpower	8.46	12.43	6.51	9.61	3.22	4.83
Total (annual) O&M costs	46.87	74.36	35.48	56.46	16.16	25.95
Total (annual) costs in 2010	653.04	915.38	496.13	701.08	235.91	343.48
Emissions saved	tonnes		tonnes		tonnes	
NO_x	2838		1850		692	
NMVOC	613		453		227	
Costs per tonne	MDKK/tonne		MDKK/tonne		MDKK/tonne	
NO_x	0.23	0.32	0.27	0.38	0.34	0.50
NMVOC	1.07	1.49	1.10	1.55	1.04	1.51

2) Including annual costs for vehicles with EGR scrapped in the scenario period

Although EGR installations on those vehicles being scrapped before 2010 do not have an impact on emission reductions in the reference year, their installation costs are – as previously mentioned - a necessary investment for achieving the desired emission reduction. Therefore these extra costs should be included as part of the total costs for achieving the reduction. EGR installations on vehicles being scrapped before 2010 do however, contribute to emission reductions during their operation period. Installation costs for these vehicles are therefore annualised over their average years of operation, which is assumed to be 4 years. Those annual costs are then added to the annual costs for still existing vehicles with EGR installations in the year 2010.

Again, as in scheme 1, welfare economic calculations of annual costs for scrapped vehicles are based on the present value financial costs (discounted with 3 %), which are increased by the respective net-tax factor and return on investment factor as presented in Appendix 3.3. The financial and welfare economic analysis of cost calculation scheme 2 is presented in Table 3.5.14.

Table 3.5.14. Financial and welfare economic analysis: Including annual costs for vehicles with EGR scrapped in the scenario period.

	<=10		<=5		New	
MDKK	Financial	Welfare-econ.	Financial	Welfare-econ.	Financial	Welfare-econ.
Annual investment costs						
EGR installations	1377.24	1848.88	906.70	1231.15	361.72	509.81
Manpower	168.86	212.17	111.20	141.33	44.39	58.56
Total (annual) investment costs	1546.10	2061.05	1017.90	1372.48	406.11	568.37
Annual O&M costs						
Filter replacements	36.48	57.77	25.42	40.58	9.98	16.17
Packings replacements	22.61	33.87	15.75	23.78	6.94	10.63
Manpower	14.70	20.72	10.24	14.58	4.51	6.58
Total (annual) O&M costs	73.80	112.35	51.41	78.93	21.43	33.38
Total (annual) costs in 2010	1619.89	2173.40	1069.31	1451.41	427.54	601.74
Emissions saved	tonnes		tonnes		tonnes	
NO_x	2838		1850		692	
NMVOC	613		453		227	
Costs per tonne	MDKK/tonne		MDKK/tonne		MDKK/tonne	
NO_x	0.57	0.77	0.58	0.78	0.62	0.87
NMVOC	2.64	3.55	2.36	3.20	1.88	2.65

3) Total costs for all vehicles with EGR in the scenario period

As mentioned before an extra price must be paid for the EGR installation and O&M costs for the vehicles being scrapped before the end of the scenario period, in order to ensure a certain "survival" rate for vehicles in 2010. Another way of calculating costs, in this case the maximum amount of costs, is therefore to calculate total present value costs for all vehicles, remaining and scrapped, including O&M costs for the period 2002-2010.

In order to arrive at welfare economic costs, present value costs (discounted using a 3 % interest rate) are increased by the respective net-tax factor and a return on investment factor as can be seen in Appendix 3.3. A summary of the financial and welfare economic analysis for all vehicles with EGR installations is presented in Table 3.5.15.

Table 3.5.15. Financial and welfare economic analysis: All vehicles with EGR in the scenario period.

	<=10		<=5		New	
MDKK	Financial	Welfare-econ.	Financial	Welfare-econ.	Financial	Welfare-econ.
Investment costs						
EGR installations	7438	11618	5256	8386	2308	3866
Manpower	911	1332	644	962	283	444
Total investment costs	8350	12950	5900	9348	2591	4309
O&M costs						
Filter replacements	251	473	185	354	78	151
Packings replacements	143	255	106	193	51	95
Manpower	93	155	69	118	33	58
Total O&M costs	487	884	361	665	161	304
Total costs in 2010	8836	13834	6261	10013	2752	4614
Emissions saved	tonnes		tonnes		tonnes	
NO_x	2838		1850		692	
NMVOC	613		453		227	
Costs per tonne	MDKK/tonne		MDKK/tonne		MDKK/tonne	
NO_x	3.11	4.87	3.38	5.41	3.98	6.67
NMVOC	14.42	22.57	13.82	22.11	12.10	20.28

Table 3.5.16. Financial and welfare economic analysis: Average costs for the whole period.

	<=10		<=5		New	
MDKK	Financial	Welfare-econ.	Financial	Welfare-econ.	Financial	Welfare-econ.
Total costs in 2010	8836	13834	6261	10013	2752	4614
Emissions saved	tonnes		tonnes		tonnes	
NO_x	33759		19201		5545	
NMVOC	6765		4462		1818	
Costs per tonne	MDKK/tonne		MDKK/tonne		MDKK/tonne	
NO_x	0.26	0.41	0.33	0.52	0.50	0.83
NMVOC	1.31	2.05	1.40	2.24	1.51	2.54

As can be expected, dividing the present value of all installation costs merely by the emission reduction in 2010 substantially increases the costs per tonne of emission reduced. In order to compare these costs with average reduction costs, Table 3.5.16 summarises a cost-effectiveness analysis where total costs (for all vehicles with EGR) are set in relation to total emission reductions in the whole period 2002-2010. Thus these calculations show average emission reduction costs for the whole scenario period. In this situation reduction costs per tonne NO_x and NMVOC are much closer to the reduction costs calculated for the first scheme.

3.5.2.6 Summary

Table 3.5.17 summarises the results from the different analysis presented above in terms of cost-effectiveness measures (MDKK / tonne). Annual emission reduction costs, calculated for all remaining vehicles in the first cost calculation scheme, represent the lower end of cles in the first cost calculation scheme, represent the lower end of costs while present value costs for all vehicles with EGR installations divided only by the emission reductions achieved in the year 2010 are more than ten times higher per tonne emission reduced.

Comparing the different EGR installation scenarios within cost calculation schemes, however, presents a more varied picture of cost-effectiveness measures. In all cases, NO_x reduction costs per tonne increases from a scenario where EGR filters are installed on all vehicles not more than 10 years old in 2002 to a scenario, where EGR filters are only installed on new vehicles. The reason for this is that the total amount of NO_x emissions saved in each scenario decreases (in percent) more than costs from one scenario to another. For NMVOC emissions this is only true for the first cost calculation scheme, in which costs per tonne NMVOC increase slightly, when retrofitting is restricted to vehicles up to 5 years old. However, costs per tonne also decrease here, when EGR filters are only installed on new vehicles. For all other cost calculation schemes, NMVOC emission reduction costs decrease from the first to the third EGR installation scenario, indicating that here, emission savings decrease by a lower rate than total costs for installation. EGR filter installation also results in savings of CO and particle emissions. The effect of a monetary valuation of the potential benefits from foregone damages from these emission reductions is analysed in Chapter 3.8.

The financial effects of installing EGR filter technology for the owners of heavy-duty vehicles are only analysed here on an aggregate level. On a national level, requirements for EGR filter installations prior to the introduction of EURO IV emission legislation standards result in total present value costs as presented in Table 3.5.15 or annual costs as shown in Table 3.5.14. As can be expected, costs are lowest if EGR filters are only installed in new vehicles and highest if installation is required for all vehicles up to 10 years old. No further analysis has been undertaken regarding the effects these additional costs might have on the competitiveness of single companies operating in the Danish and international market or the size of potential compensation payments to these companies by the Danish government.

Table 3.5.17. Comparison of all three schemes plus average costs for the whole period.

NO_x reduction (MDKK/tonne)						
	<=10		<=5		New	
MDKK	Financial	Welfare-econ.	Financial	Welfare-econ.	Financial	Welfare-econ.
Remaining vehicles, annualised	0.23	0.32	0.27	0.38	0.34	0.50
All vehicles, annualised	0.57	0.77	0.58	0.78	0.62	0.87
All vehicles, total costs	3.11	4.87	3.38	5.41	3.98	6.67
All vehicles, average	0.26	0.41	0.33	0.52	0.50	0.83
NMVOC reduction (MDKK/tonne)						
	<=10		<=5		New	
MDKK	Financial	Welfare-econ.	Financial	Welfare-econ.	Financial	Welfare-econ.
Remaining vehicles, annualised	1.07	1.49	1.10	1.55	1.04	1.51
All vehicles, annualised	2.64	3.55	2.36	3.20	1.88	2.65
All vehicles, total costs	14.42	22.57	13.82	22.11	12.10	20.28
All vehicles, average	1.31	2.05	1.40	2.24	1.51	2.54

3.6 Emission reduction measures in the agricultural sector

3.6.1 Increased grazing of dairy cows during the summer months

3.6.1.1 Description of basis/business as usual scenario

Ammonia emissions from agriculture amount to approximately 98 % of all ammonia emissions in Denmark. As part of special environmental action plans such as the Danish Action Plan on the Aquatic Environment I and II, these emissions have already undergone substantial reductions in recent years. However, most of the measures implemented or suggested for the future have focused on the handling of manure and its application on the fields. No demands have been made regarding the keeping of animals, especially dairy cows, despite the fact that different stable systems, including grazing outside, lead to substantial differences in ammonia production.

In 1999/2000 milk production in Denmark was based on a total of 630951 dairy cows distributed over 10047 holdings with an average of 62.8 cows per year per holding. Yearly milk production amounted to 7312 kg milk[13] on average per cow (SJFI, 2001b). According to statistics published by the Danish Agricultural Advisory Center (Trinderup et al., 2001) approximately 83 percent of all cows are allowed to graze outside during the summer months. This number, however, does not clearly distinguish between different types of grazing and the length of the grazing period and can therefore be considered to be a substantial overestimate. In other stock-taking assessments of ammonia emissions from agriculture an average of 55 grazing days per dairy cow was assumed (Andersen et al., 2001).

Dairy cows are kept in different stable types, with approximately half kept in stanchion barns/tie-up cowsheds and the other half in loose housing systems. In the loose housing system approximately 77 % of the dairy cows are kept in bed booths, the rest are placed on deep litter.

Current ammonia emissions resulting from dairy cows based on the above described distribution between different stable systems and outside grazing amount to 15575 tonnes NH_3-N per year, assuming that cows are kept 100 % inside. Assuming an average of 55 grazing days per cow, total NH_3-N emissions are reduced to 14015 tonnes per year. Recent years have shown a general tendency toward more dairy cows being kept in loose housing systems. Loose housing systems lead to higher ammonia emissions compared to stanchion barns or tie-up cowsheds.

3.6.1.2 Description of proposed measure and consequences

In the following analysis the incremental costs and benefits per cow grazing are compared to a baseline scenario in which dairy cows are kept inside all year round. The baseline situation, where cows on average have 55 grazing days per year, was, however, taken into consideration when calculating potential emission savings for all cows in

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[13] Kg milk is calculated as "energy corrected milk" in order to account for differences in fat and protein content.

the year 2010. While this chapter contains a description of the proposed measure and the resulting consequences in physical units, the following chapter describes the financial and welfare economic calculations of the costs and benefits associated with the measure. All three types of analyses are combined in Table 3.6.4 below. This table also lists the direct environmental consequences in form of reduced ammonia emissions.

Financial and welfare economic costs of the proposed measure are calculated as the additional costs (or benefits, in the case where costs are reduced or saved completely) compared to the baseline scenario. Given the current development in stable systems, loose housing systems are assumed to be the most representative stable system and are therefore used as the baseline.

The maximum of grazing days per cow is set to 150 per year (from mid May to mid October). Allowing dairy cows to graze outside for this time period reduces ammonia emissions by 7.65 kg NH_3-N (or 9.29 kg NH_3[14]) per cow per year, compared to a dairy cow being kept inside all year round. Calculations of the incremental costs per cow provide a cost-effectiveness measure of DKK per kg ammonia reduced.

Milk production

According to Trinderup et al. (2001) keeping cows in loose housing systems with grazing during the summer months reduces milk production by approximately 2.2 percent per cow compared to milk production from a cow kept inside all days. Based on the average milk production of 7312 kg milk in 1999/2000 described in SJFI (2001b) a 2.2 % loss thus results in approximately 161 kg of milk produced less per cow per year.

Changes in land use

Home grown roughage requirements for one dairy cow are assumed to be 3185 feed units per year, consisting primarily of home grown grass and home grown silage maize/cereals with a minor part of feed units consisting of home grown beets incl. top (SJFI, 2001b). It is assumed that this is the representative fodder mix for a cow kept inside all year round. In Table 3.6.1 the amount of ha necessary to produce each type and amount of homegrown fodder for an average cow are calculated.

[14] Most emission calculations use NH_3-N as unit measure, while reporting to the UNECE convention is based on NH_3 units. In the following calculations therefore, both unit measures are calculated. The conversion factor from NH_3-N to NH_3 is 17/14.

Table 3.6.1. Number of ha required per cow for roughage production in the baseline.

Type of roughage	Crop yield per ha	Feed units required	Number of ha required
Beets incl. top	13333	316	0.024
Grass	6837	1602	0.234
Silage maize	8962	317*	0.035
Silage cereals	5560	950*	0.171
SUM		3185	0.464

* SJFI (2001b) lists a total number of 1267 feed units of silage maize and cereals combined, without detailed information about the feed units for each type of roughage. Numbers here are calculated assuming a split up between maize and cereals of 25% and 75% respectively, which follows the land use distribution described in SJFI (2001b) Source: SJFI (2001b) and own calculations.

It is assumed that during the 150 days of grazing outside, roughage requirements are entirely met through grass.[15] This requires the establishment of additional ha of grass in rotation. Crop yields in terms of feed units per ha are lower per ha grass in rotation compared to yields per ha from fodder beets and silage maize, while being somewhat higher compared to silage cereals. Assuming that the fodder mix between beets, grass, maize and cereals should remain the same during the part of the year, when cows are kept inside, 41 % of the ha (=150/365) available now to produce these roughage types can be dedicated to grass in rotation during summer months. The calculations are shown in Table 3.6.2 below. 41% of ha available for home grown fodder production in the baseline scenario are equal to 0.191 ha.

Farming statistics and other publications available in Denmark differ with regard to total number of feed units obtained from either mowing or pasturing on grass in rotation. While for example LR (2001) shows a higher yield of kg N harvested per ha grazing area compared to mowed acreage, LR (2000b) assumes a 7.06 % reduction in yield for grazing areas. Total yield in terms of feed units is also dependent on the type of pasture chosen. Strip grazing, where the grazing area is subdivided into different strips and grazing alternates between strips, results in higher yields, however, this grazing type also requires extra investments in either fencing material or labour to move fences during rotations. In the following analysis unchanged yields are assumed as the starting point. However, a sensitivity analysis is undertaken in which yields from grazing are reduced by 7 %.

Fodder requirements for 150 days of grazing are equal to 1309 (= 3185*150/365) feed units of grass per cow. If it is assumed that one ha of grass in rotation has an average crop yield of 6837 and this average yield is the same in the case of grazing as in the case of harvesting, 0.191 ha allow the production of 1305 FE. Thus, only 4 additional feed units need to be produced or 0.00062 ha need to be converted from for example former cash crop production to grass in rotation.

[15] In order to simplify calculations, all other (purchased) fodder consumption, e.g. concentrates, molasses etc., is assumed to be independent of the number of grazing days. In reality farmers are likely to differ with regard to their individual fodder plans, which in turn might effect total milk production.

Table 3.6.2. Ha of grass available for grazing and resulting feed units.

Type of roughage	Total number of ha available	Ha available for grazing	Resulting feed units grass
Beets incl. top	0.024	0.010	67
Grass	0.234	0.096	658
Silage maize	0.035	0.015	99
Silage cereals	0.171	0.070	480
SUM	0.464	0.191	1305

This result, however, is dependent on the assumed ratio between maize and cereals of 25 % and 75 % respectively. Area with silage maize has increased in the last years and this trend can be assumed to continue if future increases in average temperature provide more favourable terms for maize production. Therefore a sensitivity analysis is conducted in which the proportion between silage maize and cereals is changed to 50 % each. The calculation of opportunity costs associated with using these ha for grazing instead of their next best alternative use (assumed here to be cereal production) is described in the next chapter.

Labour input

According to LR (2000a) labour input for dairy cows grazing outside is between 3.5 % and 5 % lower than for cows kept inside, depending on the type of milking and feeding technology employed. This is primarily due to the reduced time required for feeding in the grazing period. Taking the more labour efficient technology as the starting point, an outside grazing dairy cow requires 3.51 minutes of daily attention, while for dairy cows kept inside daily labour requirements for milking and feeding are 3.63 minutes. Multiplying the resulting difference of 0.12 minutes saved per cow per day by the total period of 150 outside grazing days, results in 18 minutes (or 0.3 hours) saved per cow per year. Assuming a herd size of 100 dairy cows this corresponds to about 30 hours saved per year.

The above mentioned timesavings do not include working time saved due to the reduced demand for harvesting and transporting roughage to the stables. According to LR (2000a) total working hours required for ensiling grass (from swathing over gathering to final storage) is 5.45 hours per ha per year on average.[16] Thus for the total amount of 0.191 ha dedicated to grazing per cow 1.04 working hours can be saved because ensiling is no longer required.

Fencing requirements

Grazing of dairy cows during summer months requires additional investments for fencing of grazing areas. Meters of fence required per cow will depend on assumptions about herd size. Assuming an average herd size of 80 cows would result in 31.6 m fence per cow[17]. Since cows in the baseline situation are already assumed to have on average 55 grazing days per year, extra fencing costs for some herds might be closer to zero, as fences already exist in the baseline situation. It is assumed that fences will need to be renewed completely

[16] LR (2000a), p. 88, time required for four times mowing and ensiling per year, assuming average type of equipment.

[17] Calculated as total length of fencing area = $(10000m^2*40)^{1/2}*4$ (assuming two dairy cows per ha), divided by total number of cows (=80).

every 10 years and a sensitivity analysis is conducted assuming a life span of 5 years for fencing material.

3.6.1.3 Financial and welfare economic analysis

Fencing investments

Investment costs for fencing amount to 10 DKK/m (material and setting-up) or a total of 316 DKK per dairy cow, based on the calculated 31.6 m per cow required, with an assumed flock size of 80 cows. Annual investment amounts are then equal to 42.9 DKK based on an assumed life span of 10 year and a financial/economic discount rate of 6 percent.

In order to obtain annual investments in welfare economic prices, the financial investment amount of 316 DKK per cow is multiplied by the net-tax factor for tradables as it is assumed that material costs make up most of total investments. Total investment is then annualised using a capital recovery factor calculated with a social time preference rate of 3 % and a life span of 10 years. The opportunity costs in terms of foregone alternative investment returns are then included by multiplying the annual investment amount by the return on capital factor calculated using the social time preference rate of 3 %, the economic investment rate of 6% and a life span of 10 years. As shown in Table 3.6.4 this results in an annual welfare economic investment cost of 58.2 DKK per cow for fencing of grazing areas.

Milk production lost

According to SJFI (2001b) milk price per kg in 1999 was equal to 2.31 DKK. Given an annual loss in milk production of 161 kg, 150 days of outside grazing result in financial costs of 371.9 DKK per cow, which is by far the biggest portion of total costs as can be seen in Table 3.6.4.

Milk is an internationally traded item, thus the producer price of 2.31 DKK is increased by a net-tax factor of 1.25, resulting in a welfare economic price per kg milk of 2.89 DKK. The total welfare economic loss from reduced milk production is equal to 464.9 DKK per year and dairy cow.

Lost income from cash-crop production

Extending the available grazing area as calculated in the previous chapter will only have a minor impact on land use for cereal production. Assuming a ratio of ¼ maize and ¾ silage cereals for the production of roughage, nearly all of the required extra ha of grazing area can be converted from roughage production. The ridiculously small amount of 0.00062 ha is, however, included in the financial and welfare economic analysis to allow for sensitivity analysis later on.

Cereal production accounts for approximately 77 % of all cash crop production in Denmark and this cash crop type has therefore been chosen as the reference situation. That is, lost income from cereal production is included as the opportunity costs associated with any land use change that happens in addition to those changes possible on area used for roughage production in the basis scenario.

Table 3.6.3. Financial and welfare economic cost-benefit analysis for cereal production.

DKK/ha	Financial calculations	Welfare economic calculations	
1999 prices	DKK	NTF	DKK
Enterprise output			
Grain	5092	1.25	6365
Straw	512	1.17	599
Compensation payments	2245	1.25	2806
Total	7849		9770
Costs			
Seeds for sowing	400	1.17	468
Fertilizers	477	1.25	596
Manure	412	1.25	515
Chemicals	507	1.25	634
Energy	193	1.25	241
Contract operations	476	1.17	557
Other costs	136	1.17	159
Calculated interest, stocks	123*	1.17	72
Costs I	2683		3242
Gross margin I	5166		6528

*In SJFI (2001a) interest on stocks in calculated using a financial interest rate of 4 %, resulting in 82 DKK/year/ha. For the analysis here, the financial interest on stocks has been calculated using an economic investment rate of 6 %.
Source: SJFI (2001a), numbers for 1999 and own calculations.

Table 3.6.3 shows the gross margin calculation both in financial and economic prices for cereal production based on information on costs and income taken from SJFI (2001a). Gross margin I (i.e. enterprise output minus variable costs) is chosen here as the lost income, because – given the marginal changes in land use required – no changes in investments can be expected in the short-run. Basically all financial prices are either increased by the net-tax factor for internationally or nationally traded goods and services. Only interest on stocks is recalculated using a social time preference rate of 3 %.

The gross margin amounts of DKK 5166 and DKK 6528 are then entered in Table 3.6.4 as the opportunity costs per ha of lost income from cash crop production for the financial and welfare economic analysis respectively. This results in the minor costs of DKK 3.20 (financial) and DKK 4 (welfare economic) assuming the conversion of 0.00062 ha per cow.

Working hours saved

Hourly wages of DKK 181 per hour are taken from LR (2000a) for machine station rates for one extra worker. Multiplying the hourly rate by the 0.3 hours saved from feeding grazing dairy cows results in DKK 54.3 saved in the financial analysis. In order to obtain the welfare economic wage rate, the financial wage rate is increased by the NTF of 1.17, which raises the hourly wage to DKK 212. Welfare economic savings are thus equal to 63.5 DKK per dairy cow.

Table 3.6.4. Increased grazing days for dairy cows: Financial and welfare economic analysis (per cow).

Consequences	Real consequences		Financial calculations		Welfare economic price		
	unit	amounts	Price per unit	DKK/year	NTF	Price per unit*	DKK/year
Investments							
Fence	m	31.6					
	DKK/m	10					
	DKK	316	(0.1359)	42.9	1.25	(0.1840)	58.2
Other costs							
Milk production lost	kg	161	2.31	371.9	1.25	2.89	464.9
Lost income cash crop	ha	0.00062	5166	3.2		6528	4.0
Total costs per year				418.0			527.1
Working hours saved							
milking & feeding	hours	0.3	181	-54.3	1.17	212	-63.5
ensiling of grass	hours	1.04	181	-188.2	1.17	212	-220.2
Net costs per year				175.5			243.3
Emissions saved							
NH_3-N	kg	7.65					
(or NH_3)	kg	9.29		DKK/kg			DKK/kg
Net costs per kg NH_3-N				22.94			31.81
(Net costs per kg NH_3)				18.89			26.19
Factors used in the calculations:							
Capital recovery factor (6%):		0,135868					
Capital recovery factor (3%):		0,117231					
Return on Investment Factor:		1,255906					

*"Price per unit" for fencing investments is calculated as the product of capital recovery factor, return on investment factor and net-tax factor.

Multiplying the 1.04 hours saved for ensiling by the hourly wage rates results in DKK 188 and DKK 220 saved using financial and welfare economic prices respectively. These cost savings must be considered a conservative estimate, as they do not include possible cut backs in investments in machines employed in the ensiling process. Most farmers are likely to hire machine pools for this kind of job and their hourly rates will lay considerably above the rate of DKK 181 used in the analysis.

Saved emissions

Total NH_3-N emissions saved per dairy cow amount to 7.65 kg/cow with 150 grazing days per year (or 9.29 kg NH_3). Using the financial and welfare economic net costs per cow of DKK 175.5 and DKK 243.3 and dividing them by the kg of emissions saved results in costs of approximately 23 DKK/kg NH_3-N in financial prices (18.89 DKK/kg NH_3) and 32 DKK/kg NH_3-N (26.19 DKK/kg NH_3) using welfare economic prices. Assuming a total number of dairy cows of 559073 in 2010, maximum NH_3-N savings possible amount to 4277 tonnes NH_3-N (or 5193 tonnes NH_3) per year, with 150 days of grazing per cow. In the baseline scenario, however, an average grazing period of 55 days per dairy cow (equal to NH_3-N savings of 2.79 kg per cow) has already been included in emission calculations. The maximum of incremental NH_3-N savings possible for Denmark with this measure is therefore equal to only 2717 tonnes per year (or 3299 tonnes of NH_3).

3.6.1.4 Sensitivity analysis

Loss in milk production

Costs incurred due to a calculated 2.2 % reduction in milk production per cow make up most of the opportunity costs from increased grazing. Therefore varying the percentage shows, not surprisingly, a substantial sensitivity of the overall result to changes in milk yield per cow. If losses for example are reduced to only 1 %, costs per kg ammonia reduced become negative, indicating that increasing grazing days of dairy cows could be a self-paying measure, even without taking increased animal welfare into consideration.

Changes in land use

If the proportion between silage maize and silage cereals is changed to 50 % each, total amount of ha required for production of roughage in the baseline scenario is reduced from 0.464 (see Table 3.6.1) to 0.443. This also reduces the amount of ha available for conversion to grass in rotation from 0.191 to 0.182, resulting in only 1244 feed units produced on existing ha of roughage production. Thus, although parts of the fodder beets and silage maize/cereal areas used to produce extra roughage in the baseline scenario can be turned into grazing areas, additional ha of grazing area need to be established on former cash crop areas. The difference of 65 feeding units requires an additional ha of 0.01 cash crop production converted to grass in rotation per cow. This results in cost increases of DKK 51 and DKK 65 using financial and welfare economic opportunity costs respectively for a calculated conversion of 0.01 ha of cereal production.

Assuming a reduction in feed unit yields from pasturing of 7 % reduces the amount of feed units that can be obtained from already existing roughage areas. This implies likewise that additional ha of former cash crop production need to be converted to pasture areas. As can be seen in Table 3.6.5 the negative effect on costs per kg ammonia from yield reduction is somewhat larger than that from changes in maize and cereal distribution.

Fencing requirements

Although fencing investment is the next biggest expense after loss in milk production, it makes up only 10 percent of total costs. Reducing the assumed life span for fencing material from 10 to 5 years therefore only has a marginal impact on the final results as demonstrated in Table 3.6.5.

Table 3.6.5. Sensitivity analysis (DKK per kg NH_3-N).

(DKK/kgNH_3-N)	**Financial calculations**	**Welfare economic calculations**
Basic assumptions	22.94	31.81
Only 1% loss in milk production	-3.63	-1.41
Ratio between maize and cereal changed to 50/50	28.95	39.39
Yields from grazing are reduced w/7%	32.67	44.10
Fencing material: lifetime 5 years	27.14	37.03

Summary

As can be seen from Table 3.6.5 assumptions regarding the loss in milk production have the strongest effect on total costs for both, the farmer and society as a whole, followed by a reduction in yields from grazing. If no losses in milk production are assumed, increasing the grazing days for dairy cows could actually lead to financial savings for the individual farmer. The analysis above, however, is based on the situation of an average farmer in Denmark. Costs for individual farmers are likely to vary substantially across country and region, depending on soil quality, land ownership and other specific conditions for milk production.

3.6.2 Application of slurry and manure within one hour after spreading on the field

3.6.2.1 Description of basis/business as usual scenario

Slurry and manure spread on the fields as fertiliser results in ammonia emissions to the air. The total amount of emissions depends on the time-span in which the natural fertiliser is allowed to remain on the bare soil. The current rules governing the application of slurry and manure on bare ground require an application no later than 12 hours after spreading on the field.[18] Starting August 1, 2002, however, it is expected that the Danish Ammonia Plan of Action will reduce the time-span to a maximum of six hours after spreading. The additional costs incurred by the farmer and society and the environmental benefits in terms of reduced emissions obtained through this reduction in maximum time allowed have been calculated as part of the Danish “Climate 2012” project (Olesen et al., 2001).

Total amounts of domestic animal manure affected by these rules are estimated to be about 7 million tonnes in the year 2010. Assuming a distribution of the total amount between 25 % slurry and 75 % manure respectively results in approx. 1.5 million tonnes of slurry and 5.4 million tonnes of manure that are applied per year on bare ground in 2010. Total amounts and their distribution between slurry and manure are listed in Table 3.6.6 and Table 3.6.7.

3.6.2.2 Description of proposed measure and consequences

In the following analysis it is assumed that the maximum time span of 6 hours from the spreading to the application of manure, prescribed in the Ammonia Plan of Action, is further reduced to one hour. Relevant for the calculations in this report are only the incremental consequences and costs resulting from the reduction from six to one hour and not the total reduction from 12 to one hour.

There are basically two options to increase the application speed and thereby reduce the time span between spreading and application:

1) Decreasing the speed of spreading the manure on the fields in order to allow ploughing to take place immediately afterwards. Ploughing generally requires more time than spreading, thus a reduction in spreading speed implies that for example only one slurry tanker is used for transporting slurry to the fields (instead

[18] Husdyrbekendtgørelse, BEK nr. 877 af 10/12/1998.

of two) and that manure needs to be transported in several rounds. These activities involve opportunity costs in terms of increased transport costs and additional work hours.

2) Increased ploughing capacity through either hiring of additional manpower from a tractor station or closer co-operation with neighbouring farms. This second option is closely related to the first since decreasing spreading speed also allows for better utilisation of existing ploughing capacity.

Reducing the maximum time span from 12 to 6 hours
The first option represents the cheapest way of reducing the time span between spreading and application and has been applied in Olesen et al. (2001) for the calculation of the costs involved in reducing the time span from a maximum of 12 to a maximum of 6 hours, as prescribed in the Ammonia Plan of Action. Reducing ammonia emissions after spreading of manure increases the N-content accessible to the plants, thus reducing the extra amount of fertiliser needed for supporting plant growth in the baseline scenario. For the year 2010 (see Table 3.6.6) this results in fertiliser savings of 877 tonnes per year.

The spreading and application of fertiliser also results in ammonia emissions to the air, thus fertiliser savings imply additional savings in ammonia emissions, which are equal to 19 tonnes. Total emission reductions per year, being equal to the sum of emission reduction from animal manure (858 tonnes) and emission reductions from saved fertiliser application (19 tonnes) are equal to 877 tonnes as listed in Table 3.6.6 below.

Reducing the maximum time span from 6 hours to 1 hour
An additional reduction in the maximum time span will most likely require substantial increases in ploughing capacity with accompanying opportunity costs as described above. Thus the incremental costs per tonne animal manure for the extra reduction of 5 hours will be higher than in the first reduction scenario. Total extra savings in terms of saved fertiliser application and total extra reductions in ammonia emissions are listed in Table 3.6.7 below. The table illustrates that total costs per tonne for a total of 5-hour reduction are higher than in the first reduction scenario. However, total savings in fertiliser and total reductions in ammonia emissions are also higher than in the first reduction scenario.

3.6.2.3 Financial and welfare economic analysis

The following chapter includes a description of the financial and welfare economic analysis of two emission reduction measures, the reduction of the maximum time span from 12 to 6 hours and the additional reduction from 6 hours to a maximum of one hour. The first scenario represents an already adopted measure, which is close to its implementation. Ammonia emission reductions from this measure are included in the baseline projections described in the first part of the report. The second measure is the one suggested here to contribute to an additional reduction in ammonia emissions. Only the second measure is included in the comparison of cost-effectiveness between measures.

Reducing the maximum time span from 12 to 6 hours

Additional costs resulting from a reduction of spreading speed in the first scenario are assumed to be 2 DKK per tonne slurry and 4 DKK per tonne manure, according to Olesen et al. (2001). As mentioned previously these costs are based on the assumption that the farmer incurs extra costs from transporting manure and slurry in several rounds to the field in order to decrease the speed of spreading. This estimation is connected with some uncertainty, as the farmer's individual situation with regard to the utilisation of existing equipment will vary to a great extent. Costs per tonne slurry or manure are thus average costs for the total reduction of 6 hours. Assuming a linear cost curve for the first 6 hours implies thus that each of the first six hours costs about 0.33 DKK/hour/tonne slurry and 0.66 DKK/hour/tonne manure. The price for saved fertiliser is set to 3.5 DKK per kg N and is the same in both scenarios. Physical consequences, prices and final calculations are described in Table 3.6.6.

Opportunity costs in welfare economic prices are obtained by multiplying financial prices by the net-tax factor of 1.17 as it is assumed that the biggest part of extra costs are additional manpower hours for transporting and spreading manure, which is a nationally traded service. As shown in Table 3.6.6, welfare economic prices are thus 2.34 DKK per tonne slurry and 4,68 DKK per tonne manure. Multiplying the respective financial and welfare economic prices by the amounts of slurry and manure results in total annual costs in 2010 of 28 MDKK as listed in Table 3.6.6.

However, the measure also entails savings in the form of less fertiliser needed. Fertiliser is an internationally traded good and thus the financial price of 3.5 DKK per kg N (3500 DKK per tonne) is increased by the net-tax factor of 1.25 in order to obtain the welfare economic price per kg N. Multiplying again financial and welfare economic prices with the respective amounts of saved fertiliser per year results in cost savings of 3 million and 3.8 million DKK per year in 2010 in financial and welfare economic prices respectively.

Dividing net costs by the total amount of ammonia emissions saved results in cost-effectiveness measures of 24.50 DKK per kg NH_3-N in 2010 in the financial analysis, while the welfare economic "price" per kg NH_3-N is 28.38 DKK in 2010.

Table 3.6.6. Reduction of maximum time span from 12 hours to 6 hours.

	Real consequences (2010)		Financial Calculations		Welfare economic calculations		
	Unit	Amounts	Price per unit (DKK)	MDKK/ year	NTF	Price per unit (DKK)	MDKK/ year
Costs							
Animal manure							
Slurry	Tonne	1537793	2	3.076	1.17	2.34	3.598
Manure	Tonne	5369834	4	21.479	1.17	4.68	25.131
Total costs		6907627		24.555			28.729
Benefits							
Reductions in fertiliser application	Tonne	877	-3500	-3.070	1.25	-4.37	-3.837
Net costs per year				21.485			24.892
Emissions saved							
NH_3-N	Tonne	877					
(or NH_3)	Tonne	1065					
Annual net costs per kg NH_3-N (DKK per kg)				24.50			28.38
Annual net costs per kg NH_3 (DKK per kg)				20.18			23.37

Reducing the maximum time span from 6 hours to 1 hour

Since a natural limit to further decreases in the speed of manure spreading can be assumed, an additional reduction in maximum time span will eventually require the use of extra ploughing capacity. Jacobsen (1999) estimates the additional costs for a doubling of ploughing capacity to be in the order of 500 – 600 DKK per ha.[19] Assuming that on average 25 tonnes of slurry are spread per ha, he calculates average costs of 20 DKK per tonne slurry for a reduction in time span from 12 hours to one hour. By taking into consideration that the additional costs can be considerably reduced when the spreading speed is reduced parallel as described in option one, Jacobsen (1999) uses maximum costs of 20 DKK per tonne manure and 10 DKK per tonne slurry for his calculations. By arguing that the extra ploughing in a number of cases can be carried out using existing (formerly unemployed) equipment, the author argues for a further halving of costs per tonne. In the following analysis thus, costs of DKK 10 per tonne manure and DKK 5 per tonne slurry are applied for a measure that reduces maximum time span from 12 hours to one hour. The higher costs of DKK 20 and 10, however, are used in the sensitivity analysis. Again the costs of DKK 10 (20) and DKK 5 (10) are total costs per tonne manure or slurry for a total reduction of 11 hours. Average costs per hour are thus equal to about 0.91DKK / tonne manure / hour and 0.45 DKK / tonne slurry / hour.

As mentioned before, part of this reduction in maximum time span will already be implemented in the year 2010 and thus the following analysis focuses on the incremental costs connected with a further reduction from 6 hours to one hour, which are equal to 3 DKK per tonne slurry and 6 DKK per tonne manure as listed in Table 3.6.7

[19] Jacobsen (1999), p.38.

(and 8 and 16 DKK per tonne in the sensitivity analysis) and shown in Figure 3.6.1.[20] Table 3.6.7 thus shows calculations based on the *additional* costs incurred and the *additional* benefits obtained (in terms of emissions reduced) from hiring extra ploughing capacity to further increase application speed from 6 hours to one hour. Costs per hour for each of the last 5 hours of extra reduction are thus equal to DKK 0.60/tonne slurry/hour and DKK 1.20/tonne manure/hour. Marginal costs per hour for the last 5 hours of reduction are thus higher than marginal reduction costs per hour for the first 6 hours, as could be expected, assuming that the cheapest reduction methods are implemented first.

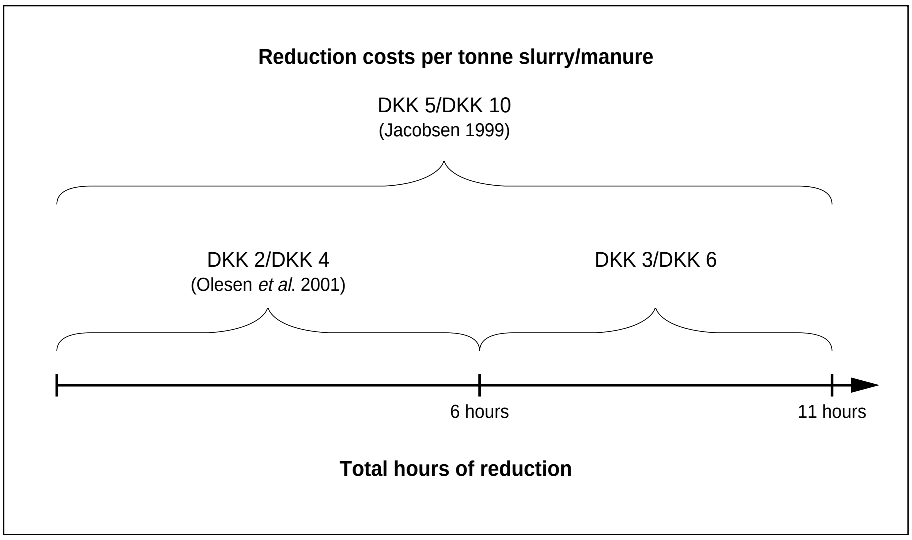

Figure 3.6.1. Reduction costs for slurry and manure application (per tonne slurry or manure).

The calculation of the welfare economic costs and benefits follows the procedure outlined before, e.g. additional costs for manure handling are increased by the net-tax factor for nationally traded services, while the saved expenses for fertilisers are increased by the net-tax factor for internationally traded goods. Dividing net costs by the total amount of emissions saved results in substantial increases in the reduction costs per kg N as shown in Table 3.6.7. Additional ammonia emissions reductions achieved by reducing the maximum time span between spreading and application of manure from six hours to one hour causes costs of DKK 30.67 per kg NH_3-N in financial prices and DKK 35.60 per kg NH_3-N in welfare economic prices.

[20] Incremental costs per tonneare calculated as the difference between average reduction costs from 12 hours to one hour and average reduction costs from 12 hours to 6 hours.

Table 3.6.7. Reduction of maximum time span from 6 hours to 1 hour.

	Real consequences (2010)		Financial calculations		Welfare economic calculations		
	Unit	Amounts	Price per unit (DKK)	MDKK/ year	NTF	Price per unit (DKK)	MDKK/ year
Costs							
Animal manure							
Slurry	Tonne	1537793	3	4.613	1.17	3.51	5.398
Manure	Tonne	5369834	6	32.219	1.17	7.02	37.696
Total costs		6907627		36.832			43.094
Benefits							
Reductions in fertiliser application	Tonne	1078	-3500	-3.773	1.25	-4.375	-4.716
Net costs per year				33.059			38.378
Emissions saved							
NH_3-N	Tonne	1078					
(or NH_3)	Tonne	1309					
Annual net costs per kg NH_3-N (DKK per kg)				30.67			35.60
Annual net costs per kg NH_3 (DKK per kg)				25.26			29.32

3.6.2.4 Sensitivity analysis

If it is assumed that no existing ploughing capacity can be used for further reducing the maximum time span from 6 hours to one hour, the costs per tonne animal manure increase to 10 DKK per tonne slurry and 20 DKK per tonne manure. This leads to incremental costs for reducing the time span from 6 hours to 1 hour of 8 DKK/tonne slurry and 16 DKK/tonne manure. The doubling of costs per tonne results in a substantial increase in reduction costs per kg NH_3-N as shown in Table 3.6.8.

3.6.2.5 Summary

As can be seen in Table 3.6.7 and Table 3.6.8, a further reduction of the maximum time span from 6 hours (as required under the Danish Ammonia Plan of Action) to only 1 hour leads to substantial increases in costs to the farmer and society. Total costs, however, are likely to vary according to the specific farming situation, existing technology and equipment and can increase substantially if total additional ploughing capacity need to be bought externally (e.g. by hiring a machine station).

Table 3.6.8. Summary of emission reduction costs per kg NH_3-N from different scenarios.

Summary of results (DKK per tonne NH_3-N)	Financial results	Welfare economic results
Reduction from 12 to 6	24.50	28.38
Reduction from 6 to 1 (3 and 6 DKK per tonne)	30.67	35.60
Reduction from 6 to 1 (8 and 16 DKK per tonne)	87.61	102.23

3.7 Comparison of results across sectors

3.7.1 Cost conclusions (financial analysis)

In Chapters 3.3 – 3.6 a number of options to reduce the SO_2, NO_x, NMVOC and NH_3 emissions were investigated. Table 3.7.1 summarizes the results for the financial cost calculations.

The table first shows the total extra investments needed in order to implement the reduction measure. Next it shows the total annual cost for each measure. This includes the levelized investment with a 6% discount rate, the annual maintenance costs and the fuel costs. Finally the annual extra costs were divided by the annual emission reductions for each of the pollutants in order to give a feeling for the relative difference between the costs of the measures.

For SO_2 the desulphurisation measure is clearly the most cost effective (the electric car option is cheaper but the reduction from this measure is only 0.02 kt SO_2). For NO_x the deNO$_x$ measure is the cheapest (again with electric cars being cheaper but only a small reduction of 0.05 kt NO_x). For NMVOC the electric car measure is again the cheapest, but in this case with 0.2 kt NMVOC followed by the car painting workshop measure (the reduction from the wind turbine farm is only 0.01 kt NMVOC). For NH_3 the cheapest measure is the increased grazing of dairy cows, which also gives the largest NH_3 reduction.

3.7.2 Results of welfare economic calculations

The UNECE Convention on Long-Range Transboundary Air Pollution requires the reduction of SO_2, NO_x, NMVOC and NH_3 emissions up to certain maximum limits (emission ceilings) in the year 2010. Welfare economic reduction costs per tonne of these various emissions have been calculated in the previous chapters based on different measures suggested for the industry, energy, transport and agricultural sector. This chapter presents a summary of the welfare economic results and suggested ranking of initiatives based on their cost-effectiveness, i.e. costs per tonne of emission reduced, to meet the UNECE emission ceilings in the year 2010. The calculation of costs for EGR-filter installation has been based on the second cost calculation scheme, which also includes annualised costs for those vehicles that are taken out of operation before the year 2010 (see Chapter 3.5.2.5).

Table 3.7.1. The financial cost for the investigated reduction measures.

Reduction options not included in the reference scenario	Extra Investment in MDKK	Annual extra cost in MDKK	MDKK/ tonne SO_2	MDKK/ tonne NO_x	MDKK/ tonne NMVOC	DKK/ kg NH_3-N*
NMVOCs from car painting workshops	123.5	78.5			0.105	
150 MW offshore wind turbine farm	1599.0	96.0	0.19	0.42	13.7	
Two 350MW plants with deNO$_x$	350.0	62.7		0.0097		
The last 38 MW with desulphurisation	60.0	9.2	0.004			
70000 electric cars in 2010	3511.1	-266.3	-13.3	-5.2	-1.3	
EGR on heavy duty vehicles (<10 yr.)	8350.0	1619.9		0.57	2.64	
Increased grazing of dairy cows	176.7	98.1				22.9
Fast application of manure	0.0	3.8				30.7

* Ammonia emissions are reported as NH_3 units in the summary and conclusions chapters, while for emission calculations from agriculture and in the cost-effectiveness calculations NH_3-N is used as the unit measure (conversion factor from NH_3-N to NH_3 is 17/14).

Desulpurisation and de-NO_x-unit installations at large power plants are the most favourable options for reducing SO_2 and NO_x emissions respectively followed by the building of offshore wind turbine farms. For SO_2 and NO_x emissions, replacing conventional cars with electrical ones represents the most expensive option, primarily because of the relatively low total emissions reductions that can be achieved with this measure.

For NMVOC emissions the introduction of water-based paint in car-painting workshops represents the cheapest option, followed by the installation of EGR-filters on heavy-duty vehicles. Building an additional offshore wind turbine farm results in only minor NMVOC savings with corresponding high-costs per tonne NMVOC reduced.

The two offshore wind turbine farm scenarios and the three different scenarios calculated for EGR-filter installations are mutually exclusive (i.e. only one can be implemented at a time). As can be seen in Table 3.7.2 the different scenarios do not have an effect on the total ranking of measures in the case of NO_x emission reductions, e.g. the building of offshore wind turbine farms to reduce NO_x emissions is always more cost-effective than installing EGR filters. However, in the case of NMVOC emissions the introduction of electrical vehicles is more cost-effective than installing EGR filters on all heavy-duty vehicles no more than 10 years old. However, cost-effectiveness is only one criterion on which choices for emission reduction measures should be based. Total emission reduction potential, other side effects (positive and negative) and the total costs of the measure should also be considered in the decision making process. In addition, measures are likely to vary according to their distributional consequences as shown in the financial analyses.

Table 3.7.2. Contribution of the different measures to emission reductions in 2010, ranking based on costs per tonne emission reduced (welfare economic costs).

	SO_2-emissions		
		MDKK/tonne	Amount 2010 (tonnes)
1.	Desulphurisation unit at large power plant	0.005	2292
2.	Offshore wind turbine farm (replaces coal-fired power plant)	0.264	508
3.	Electrical vehicles (70.000 in 2010)	34.428	20
	NO_x-emisions		
		MDKK/tonne	Amount 2010 (tonnes)
1.	SCR (de-NO_x) unit installation at large power plant	0.013	6460
2.a	Offshore wind turbine farm (replaces natural gas-fired power plant)	0.259	236
2.b	Offshorewind turbine farm (replaces coal-fired power plant)	0.586	229
3.a	EGR-filter installation (all vehicles not more than 10 years old)	0.766	2838
3.b	EGR-filter installation (all vehicles not more than 5 years old)	0.785	1850
3.c	EGR-filter installation (only new vehicles)	0.870	692
4.	Electrical vehicles (70.000 in 2010)	13.501	51
	NMVOC emissions		
		MDKK/tonne	Amount 2010 (tonnes)
1.	Car-painting workshops: water-based paint	0.126	750
2.a	EGR-filter installation (only new vehicles)	2.646	227
2.b	EGR-filter installation (all vehicles not more than 5 years old)	3.205	453
3.	Electrical vehicles (70.000 in 2010)	3.460	199
	EGR-filter installation (all vehicles not more than 10 years old)	3.546	613
4.a	Offshore wind turbine farm (replaces natural gas-fired power plant)	6.103	10
4.b	Offshore wind turbine farm (replaces coal-fired power plant)	19.157	7
	NH_3-emissions		
		MDKK/tonne	Amount 2010 (tonnes)
1.	Increased grazing of dairy cows	0.026	3299
2.	Manure application within one hour after spreading	0.029	1309

However, if costs calculations for EGR installations are based on total present value costs for all vehicles (i.e. including costs for all vehicles being scrapped before 2010) EGR filter installation in all three scenarios becomes the most expensive option (20 – 22.5 MDKK/tonne) for NMVOC reduction, as can be seen from a comparison with Table 3.5.17. In the case of NO_x emission reductions, however, cost calculations based on total present value costs do not change the ranking of initiatives, as costs per tonne with 4.8 – 6.6 MDKK/tonne are still lower than the 13 MDKK/tonne calculated for the introduction of electrical vehicles.

Almost all atmospheric emissions of NH_3 stem from agricultural activities. Therefore, the only two potential reduction measures considered in this report are placed in the agricultural sector. The emission reduction potential for the “increased grazing” scenario is based on the assumption that all dairy cows in 2010 will have on average 150 grazing days (compared to approximately 55 grazing days in the baseline scenario). As this might cause a range of practical problems for some farms in Denmark, total emission reductions of 3299 tonnes per year should be regarded a maximum estimate.

Increasing the amount of grazing days per dairy cow features as the most cost-effective alternative. However, the differences in reduction costs are not substantial. The results of the sensitivity analyses in Chapter 3.6 (Table 3.6.5) suggests that the "grazing scenario" becomes more expensive than changes in manure application, only if yields from grazing are reduced by at least 7 % (instead of remaining constant).

The total emission reduction potential of these two measures is thus equal to 4608 tonnes NH_3 per year. Projections of NH_3 emissions for Denmark show, however, that the national emission ceiling of 69000 tonnes is exceeded with more than 14000 tonnes in the year 2010.

Applying a social time preference rate of 6 % in the welfare economic calculations

The welfare economic calculations in the previous chapters have been based on a social time preference rate of 3 %. This time preference rate has been applied in the calculations of present value costs, capital recovery factors and return on investment factors. Using instead a social time preference rate of 6 % in all calculations (i.e. including the calculation of capital recovery factor and return on investment factors) reduces annual costs for the different measures, as can be seen in Table 3.7.3. Cost reductions range from 1.9 % to 32 % and are highest for those measures that require extremely high up-front investments (i.e. building an offshore wind turbine farm) or investments over a longer period of time, e.g. the replacement of conventional vehicles with electrical ones in the time period 2004 – 2010. Cost savings are only modest for those measures that require relatively small investments (e.g. fencing equipment for increased grazing) or in cases of modest investment expenses resulting in high emission savings, e.g. the installation of De-NO_x and desulphurisation units at large power plants. However, applying a social time preference rate of 6 % instead of 3 % does not change the ranking of initiatives based on their cost-effectiveness measures.

Table 3.7.3. Cost reductions from applying a social time preference rate of 6 % in welfare economic calculations (compared to baseline calculations with 3%).

SO_2-emissions	Costs /tonne calculated w/ 6%	Cost reductions/tonne compared to calculation w/3%	
	MDKK/tonne	MDKK/tonne	%
Desulphurisation unit at large power plant	0.005	0.0004	7.01%
Offshore-wind farm (replaces coal-fired power plant)	0.225	0.0387	14.64%
Electrical vehicles (70.000 in 2010)	24.289	10.1392	29.45%
NO_x-emisions	Costs /tonne calculated w/ 6%	Cost reductions/tonne compared to calculation w/3%	
	MDKK/tonne	MDKK/tonne	%
SCR (de-NO_x) unit installation at large power plant	0.012	0.0008	6.05%
Offshore wind turbine farm (replaces natural gas-fired power plant)	0.175	0.0832	32.17%
Offshore wind turbine farm (replaces coal-fired power plant)	0.500	0.0857	14.64%
EGR-filter installation (all vehicles not more than 10 years old)	0.708	0.0575	7.51%
EGR-filter installation (all vehicles not more than 5 years old)	0.717	0.0673	8.58%
EGR-filter installation (only new vehicles)	0.767	0.1029	11.83%
Electrical vehicles (70.000 in 2010)	9.525	3.9762	29.45%
NMVOC emissions	Costs /tonne calculated w/ 6%	Cost reductions/tonne compared to calculation w/3%	
	MDKK/tonne	MDKK/tonne	%
Car-painting workshops: water-based paint	0.123	0.0025	1.99%
EGR-filter installation (only new vehicles)	2.333	0.3131	11.83%
EGR-filter installation (all vehicles not more than 5 years old)	2.930	0.2748	8.58%
Electrical vehicles (70.000 in 2010)	2.441	1.0190	29.45%
EGR-filter installation (all vehicles not more than 10 years old)	3.280	0.2663	7.51%
Offshore wind turbine farm (replaces natural gas-fired power plant)	4.140	1.9635	32.17%
Offshore wind turbine farm (replaces coal-fired power plant)	16.352	2.8050	14.64%
NH_3-emissions	Costs /tonne calculated w/ 6%	Cost reductions/tonne compared to calculation w/3%	
	MDKK/tonne	MDKK/tonne	%
Increased grazing of dairy cows	0.026	0.0005	1.86%
Manure application within one hour after spreading	0.029	0.0000	0.00%

Marginal cost curves

As an example, Figure 3.7.1 presents the marginal cost function for reducing NO_x emissions based on the different measures selected before and their respective costs-per-tonne NO_x. Total costs from implementing these options can be calculated as the area under the marginal cost function. According to the projected emissions Denmark needs to reduce its baseline NO_x emissions in 2010 with an additional 19000 tonnes per year in order to comply with UNECE emission ceilings. The marginal cost function could serve as an inspiration to achieving those ceilings in the most cost-effective way.

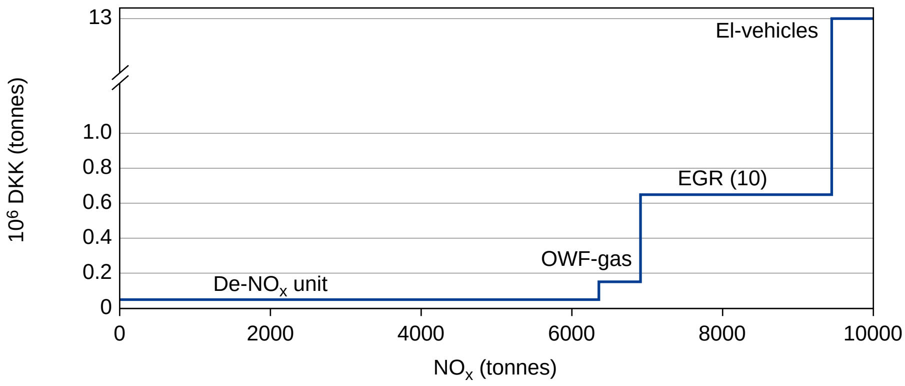

Figure 3.7.1. Marginal cost function for future reductions of NO_x emissions.

The cost-effectiveness measures in the previous chapters have been calculated without explicit incorporation of other side effects in terms of other emissions reduced than the particular one in focus. However, adhering to the emission ceilings prescribed in the UNECE Convention, implies the simultaneous reduction of different types of emission. In addition, Denmark has committed itself to reducing its CO_2 emissions under the Kyoto Protocol. One possible solution to taking these other side effects into account in the calculation of costs-per-tonne measures consists of the monetary valuation of those effects, i.e. the foregone environmental and health damages by reducing other emissions. Different methods for monetary valuation of non-market resources and services have been developed in the last decade, however, their methodology still incorporates substantial uncertainties and results should therefore be applied with considerable caution and only for illustrative purposes in economic analyses of emission reduction measures. The following chapter contains such an example of illustrating the potential effects of including monetary values for emissions reduced on the final results of the analyses presented in this chapter.

3.8 Monetary valuation of environmental benefits from emission reduction initiatives

3.8.1 Introduction

Many emission reduction measures reduce more than one type of emission covered under the UNECE Convention on Long-Range Transboundary Air Pollution. In addition, the measures suggested in this report also contribute to the reduction of non-UNECE emission, i.e. particulates, CO and CO_2. For a consistent comparison of the cost-effectiveness of the different types of emission reduction initiatives it would therefore be useful to include monetary values for these environmental benefits.

The UNECE itself has initiated research on the costs and benefits of air pollution reductions. Preliminary findings and observations were presented at an international workshop in February 2001. These findings indicate that a better linkage between epidemiology and economics, and improved description of the linkages between ecosystems and economics, are required in order to reach reliable estimates for the benefits of air pollution control. Due to the ongoing UNECE work on cost-benefit analysis, the recent cost-benefit assessment of the EU's sixth environmental action programme did not include estimates for the benefits of reducing air pollution.

The issue of valuation estimates for the benefits of reducing greenhouse gas emissions is not covered by the UNECE. Different estimates are available in the international literature, but due to the complex relationships inherent in the climate change issue, and due to the inter-generational dimension of the problem itself, it is increasingly recognised that the benefits are very difficult to monetize. The IPCC's socio-economic panel in its third assessment report neither recommends the use of benefit estimates for reduced greenhouse gases in cost-benefit analysis, nor proposes any specific figures. The various benefit estimates that are proposed in the international literature are dated, and refer to the second or even the first assessment report of the IPCC. They do not reflect the present state of knowledge on the climate issue, as expressed in the third assessment report.

However, the Danish ministries have in a recent report proposed benefit estimates for various air pollutants, including greenhouse gas emissions (Ministerierne, 2001). These benefit estimates are derived from various sources in the international literature. They include a range of monetary values for damages associated with SO_2, NO_x, particulates (PM_{10}), VOC, CO, HC and CO_2 emissions. According to the sources stated in the publication, those estimates are primarily based on the latest results of the European ExternE project (Schleisner and Nielsen, 1997), specific calculations of the damages from transport emission for Denmark (COWI, 1999), an ExternE summary report for externalities from transport and some not further specified sources within the Danish Ministry for the Environment and Energy (now Ministry for the Environment).

The benefit estimates are provided as average pro rata estimates, and do not reflect marginal benefit curves. No analysis of the actual damages and the benefits of rectifying these is included in the report of the Ministries. For comparison, the US EPA has undertaken a detailed analysis of the actual damages associated with air pollution in its 1999 cost-benefit analysis of the Clean Air Act Amendments of 1990, but reflecting North American circumstances.

Given the limited resources available for the cost-effectiveness analyses in this report, NERI has neither had the opportunity to review the literature on benefit valuation of air pollution, nor to produce an update of the physical damage estimates in Denmark. By request of the Danish EPA (Miljøstyrelsen) NERI has based the monetary benefit valuations on the range of monetary estimates applied in the previously mentioned publication from the Danish Ministries. The following calculations should therefore solely be seen as an illustrative attempt to assess the potential influence of incorporating monetary estimates for environmental benefits in a cost-effectiveness analysis. Given the high uncertainty associated with determining the damages from emissions and the valuation of these damages, neither the different prices chosen for emissions avoided nor the results of the following analyses should be interpreted as the correct estimate of foregone damages from emission reductions in Denmark. As mentioned before, the monetary estimates are in most cases transferred from studies abroad, but no correction regarding purchasing power parities or domestic preferences for environmental protection has been applied. The authors of this report do not recommend an application of the benefit estimations in this chapter in policy decisions without detailed analysis of the primary sources for the valuation estimates applied and a more proper method of benefit transfer.

Range of monetary values applied in the analyses
As explained previously the monetary values applied in Ministerierne (2001) are primarily based on the results of the European *ExternE National Implementation project*. The ExternE project aims to provide a comprehensive and comparable data set on externalities from power generation in all EU member states plus Norway. A common ExternE methodology was applied to the most important fuel cycles for each country in order to derive country specific values for damages from different pollutants. Impacts included are mainly health effects resulting from different emissions, i.e. acute effects on mortality (mostly cardio-respiratory causes), hospital admissions, restricted activities days (e.g. because of asthma attack), chronic mortality and morbidity (e.g. chronic bronchitis and asthma). Other effects included are impacts on terrestrial ecosystem (forest and agricultural damages) and the impact of air pollution on building materials.

The main part of the Extern E methodology consists of a so-called EcoSense model. This model includes a database on technology, receptors, meteorology and emissions, exposure-response functions and monetary values for different impact categories. In addition EcoSense consists of an impact assessment module that calculates physical impacts and resulting damage costs by using the information from the database for each country and air transport models for describing emissions transport on a local and European wide scale. Monetary values used in the calculation of damages are based on either willingness-to-pay estimates for health effects (mortality and morbidity) or repair and maintenance costs in the case of material damages (e.g. acidification). The ranges of monetary values reported in Ministerierne (2001) for the different types of emissions are listed in Table 3.8.1. Single values reported for e.g. NMVOC and CO emissions are only best guesses with a considerable amount of uncertainty attached to them and should not be interpreted as more reliable estimates for the respective damages associated.

Table 3.8.1. Range of monetary values reported in Ministerierne (2001).

Damage estimates	Electricity /Distance Heating Production	Individual Heating	Transport
(DKK/kg, 2000 prices)			
SO_2	34-35	34	44-77
NO_x	29-38	34	87-93
Particles (PM 10)	39-53	53	193-723
NMVOC	50	-	50
CO	0.01	0.01	0.01
PM	39-53	53	193-723

Source: Ministerierne (2001), p. 152, Table 9.3.

Using these values to represent the foregone damages from emissions in the welfare economic analyses in this report causes some theoretical problems. The welfare economic calculations in this report are based on the accounting price method, i.e. a method that uses consumers' willingness to pay for goods and services given existing taxes and subsidies in a market. As ExternE has been a European project, it must be suspected that many of the cost calculations and prices used in determining a monetary value for different damages from air pollution are based on factor-prices, i.e. prices in which taxes have been subtracted and any subsidies added. In addition, calculations might be based on discount rates that differ from the ones applied in the present report. This causes some inconsistencies in the cost calculations in the present analyses. Another critical point is that contingent valuation studies used to elicit willingness-to-pay estimates, e.g. to determine the value of a statistical life or the welfare loss associated with illnesses, are carried out as partial analyses (i.e. assuming all other prices remain unchanged). This implies in general, that it is not possible to simply add different prices for non-market goods and services, without ensuring first, that respondents have also taken all other price changes/extra expenses into account when stating their willingness-to-pay.

Table 3.8.2 summarises the different values used in the following calculations. MIN and MAX values refer to the estimates used in sensitivity analyses. For SO_2, NO_x, and particulates they represent the lower and upper ranges of estimates reported in Ministerierne (2001) as can be seen in Table 3.8.1. Basis values for damages are simply calculated as the average of lower and upper estimates reported.[21] Again it should be noted that the different values applied here should only be regarded as illustrative examples of possible monetary valuations of damages from the different types of emissions. They should in no case be regarded as representing the true costs (or benefits) associated with emissions (or emission reductions), nor does the range of values reported in Table 3.8.2 reflect the true uncertainty associated with the valuation of damages.

[21] Example calculations in Ministerierne (2001) are based on values per tonne emission that differ from the ones calculated as average figures (BASIS prices) in this report. Unfortunately the publication (Ministerierne (2001)) does not account for the reasons behind choosing those particular values, which sometimes are closer to the lower range of values reported in Table 3.8.1, sometimes even lie outside the range, as for example in the case of SO_2 emissions from energy production (see Ministerierne (2001), p. 157, table 9.6 for example calculations and values chosen).

Table 3.8.2. Monetary values used in the calculations in this report.

DKK/tonne	Industry/Energy Sector			Transport Sector		
	MIN	BASIS	MAX	MIN	BASIS	MAX
SO_2	34000	34500	35000	44000	60500	77000
NO_x	29000	33500	38000	87000	90000	93000
Particulates (PM_{10})	39000	46000	53000	193000	458000	723000
VOC	-	50000	-	-	50000	-
CO	-	10	-	-	10	-
CO_2	150	260	375	150	260	375

Source: Ministerierne (2001), p. 152, Table 9.3; Holland et al. (1999), p. 101ff and own calculations.

Ministerierne (2001) use in their calculations average damage costs per tonne CO_2 of DKK 45, reported in Fankhauser (1994), as the lower margin and as a higher margin the average value of DKK 260 per tonne reported in ExternE. However, Fankhauser's estimates from 1994 represents an unacceptably dated estimate of CO_2 damages, reflecting only the knowledge presented in the IPCC's first assessment report and, given the recent advances in our understanding of this particular issue, is not acceptable for illustrative purposes. Damage estimates for CO_2 emissions are based on the results of the "base case" calculations undertaken in ExternE (Holland et al., 1999), using two integrated assessment models (FUND and Open Framework) and different discount rates (1 % and 3 %).[22] Again MIN and MAX values represent the upper and lower range of estimates reported in ExternE, while the BASIS value is calculated as the average value. The ExternE results present a 'best guess estimate' for the benefits of greenhouse gas emission reductions, but the uncertainties are of course inherent.

The Danish Energy Agency (Energistyrelsen) has initiated work on the calculation of costs associated with reducing CO_2 emissions in different sectors, including the potential price of CO_2-quotas, if a trading system emerges as part of the flexible mechanism under the Kyoto Protocol (Energistyrelsen, 2001). Given the huge uncertainties associated with the calculation of potential damages from climate change, it might be more acceptable in the case of CO_2 emissions, to use the "shadow-price" per tonne CO_2 calculated in order to meet Denmark's international commitments under the Kyoto Protocol as an expression for the socio-economic benefits associated with reducing CO_2 emissions in other measures. According to the calculations in Energistyrelsen (2001), the marginal costs (i.e. the costs associated with the most expensive measure[23] necessary to fulfil the obligations) are equal to 243 DKK/tonne CO_2. However, the measures presented in that report have been rather arbitrarily selected and therefore do not necessarily reflect the full range of emission reduction opportunities in Denmark.

3.8.2 Including monetary values in the welfare economic analyses

The following sections show the results from including a monetary value for emission reductions in the welfare economic cost-effectiveness analyses of the different measures. Measures from the

[22] For a more detailed explanation see Holland et al. (1999), p. 101ff or Schleisner and Nielsen (1997).

[23] In this case the building of off-shore wind farms.

agricultural sector are not included here, as the above mentioned publication (Ministerierne, 2001) does not include damage values for ammonia emissions. Determining the damages from ammonia emissions is extremely difficult and given the limited resources available in the current project no original research has been initiated.

3.8.2.1 Reduction of NMVOCs from car painting workshops

As described in Chapter 3.3.1 changing from traditional car paint to water-based paint solutions in all Danish car-painting workshops has an emission savings potential of 750 tonnes NMVOC per year. After some time NMVOC emissions would have been converted to CO_2 in the atmosphere resulting in an additional 2300 tonnes of CO_2 emissions saved on a yearly basis. Applying the suggested value (see Table 3.8.2 above) of DKK 50000 per tonne[24] for reduced damages from NMVOC reduction, amounts to approximately 37.5 MDKK per year as can be seen in Table 3.8.3. Applying the basis value of 260 DKK per tonne CO_2 results in climate change damages saved of 0.6 MDKK. Total damages saved from reducing NMVOC and CO_2 emissions are thus equal to 38.1 MDKK, a sum that does not outweigh the total net costs of 94.2 MDKK.

Including the monetary benefits from CO_2 emission reductions in the calculations of costs per tonne NMVOC only has minor impacts. Annual net costs per tonne NMVOC are equal to 0.125 MDKK, i.e. only 1000 DKK less than those calculated previously.

Given the rather modest amount of CO_2 savings possible when implementing this measure, applying minimum and maximum estimates for CO_2 damages only changes annual net costs with +/-300000 DKK and therefore has no impact on the final costs per tonne NMVOC.

Table 3.8.3. NMVOC reduction from car painting workshops.

	Real consequences		Welfare economic calculations	
	unit	amounts	Price per unit	MDKK/year
Net costs per year				94.2
Emissions saved				
NMVOC	tonne	750		
CO_2	tonne	2300		
Net costs per tonne NMVOC	MDKK/tonne			0.126
Including environmental benefits (baseline)				
Emissions saved			DKK/tonne	MDKK/year
NMVOC	tonne	750	50000	37.5
CO_2	tonne	2300	260	0.6
SUM				38.1
Annual net costs				56.1
				MDKK/tonne
Annual net costs per tonne NMVOC reduced*				0.125

*Net costs per year minus benefits from CO_2 reduction, divided by tonnes of NMVOC reduction.

[24] It is here assumed that the price of 50000 DKK per tonne NMVOC only includes the damages related to NMVOC and not those related to CO_2 emissions.

3.8.2.2 Large offshore wind turbine farms

Replacing electricity produced at a coal-fired power plant in Denmark with electricity production at the large offshore wind turbine farm described in Chapter 3.4.1 results in yearly emission reductions of 508 tonnes SO_2, 229 tonnes NO_x and 7 tonnes NMVOC. In addition the measure also leads to savings of 439000 tonnes of CO_2 per year. Like in the former analysis of the reduction of NMVOCs from car painting a value of 50000 DKK per tonne NMVOC is used. Prices per tonne SO_2 and NO_x are 34500 DKK and 33500 DKK respectively. A basis value of DKK 260 per tonne CO_2 is applied for the monetary valuation of CO_2 emissions. The total value of damages saved is thus equal to approximately 140 MDKK per year as shown in Table 3.8.4. Subtracting the savings from total net costs per year results in negative costs or net benefits to society of about 5.6 million DKK per year in welfare economic prices.

If environmental benefits are included in the calculation of cost-effectiveness measures for the different emissions, net costs per tonne SO_2 reduced amount to 0.02 MDKK per tonne, while the reduction of one tonne NO_x costs 0.01 MDKK per tonne. Costs per tonne SO_2 and NO_x including a monetary value for the positive side-effects from reducing other than those emissions, are thus lower than the monetary value of the damages caused by emitting one tonne of these emissions to the atmosphere. Reducing NMVOC emissions and taking into consideration the benefits obtained from a reduction of SO_2, NO_x and CO_2 emission amounts to negative costs for society of – 0.75 MDKK per tonne NMVOC.[25]

[25] Net costs per type of emission are calculated by subtracting the monetary value of environmental benefits obtained through the reduction of the remaining emissions from the total net costs per year calculated before and than dividing the resulting amount by the number of respective tons reduced.

Table 3.8.4. Offshore wind turbine farm (replacing electricity from coal fired power plant).

Consequences	Real consequences		Welfare economic calculations	
	unit	amounts	Price per unit	MDKK/ year
Net costs per year				134.1
Emissions saved				
SO_2	tonne	508		
NO_x	tonne	229		
NMVOC	tonne	7		
Net costs per tonne				MDKK/tonne
SO_2				0.26
NO_x				0.59
NMVOC				19.16
Including environmental benefits (baseline)				
Emissions saved			DKK/tonne	MDKK/year
SO_2	tonne	508	34500	17.52
NO_x	tonne	229	33500	7.67
NMVOC	tonne	7	50.000	0.35
CO_2	tonne	439146	260	114.18
SUM				139.72
Annual net costs				-5.63
				MDKK/tonne
Net costs per tonne SO_2 reduced*				0.02
Net costs per tonne NO_x reduced**				0.01
Net costs per tonne NMVOC reduced***				-0.75

* Net costs per year minus benefits from NO_x, NMVOC and CO_2 reduction, divided by number of tonnes SO_2 reduced.
** Net costs per year minus benefits from SO_2, NMVOC and CO_2 reduction, divided by number of tonnes NO_x reduced.
*** Net costs per year minus benefits from SO_2, NO_x and CO_2 reduction, divided by number of tonnes NMVOC reduced.

If electricity produced at the offshore wind turbine farm replaces electricity from a natural gas fired power plant total emission savings change slightly as can be seen in Table 3.8.5. Using the same monetary values for NO_x, NMVOC and CO_2 emission as above results in total environmental benefits of 106.6 MDKK per year. Deducting these benefits from net costs calculated before results again in net negative costs (or net benefits) to society, which are equal to 45.6 MDKK per year. Including environmental benefits in the cost-per-tonne calculations results in negative costs of –0.16 MDKK/tonne NO_x and – 4.5 MDKK/tonne NMVOC.

Table 3.8.5. Offshore wind turbine farm (replacing electricity from natural gas fired power plant).

Consequences	Real consequences		Welfare economic calculations	
	unit	amounts	Price per unit	MDKK/year
Net costs per year				61.0
Emissions saved				MDKK/tonne
SO_2	tonne	0		
NO_x	tonne	236		0.26
NMVOC	tonne	10		6.10
CO_2	tonne	377848		
Including environmental benefits (baseline)				
Emissions saved			DKK/tonne	MDKK
SO_2	tonne	0	0	0.00
NO_x	tonne	236	33500	7.91
NMVOC	tonne	10	50.000	0.50
CO_2	tonne	377848	260	98.24
SUM				106.65
Annual net costs				-45.61
Net costs per tonne SO_2 reduced*				
Net costs per tonne NO_x reduced**				-0.16
Net costs per tonne NMVOC reduced***				-4.51

* Net costs per year minus benefits from NO_x, NMVOC and CO_2 reduction, divided by number of tonnes SO_2 reduced.
** Net costs per year minus benefits from SO_2, NMVOC and CO_2 reduction, divided by number of tonnes NO_x reduced.
*** Net costs per year minus benefits from SO_2, NO_x and CO_2 reduction, divided by number of tonnes NMVOC reduced.

An application of minimum and maximum values for the different types of emissions reduced by this initiative has a substantial impact on the final result. Here it is especially the value selected for CO_2 emissions that has the strongest impact. If a value of 150 DKK/tonne CO_2 is applied annual net costs (after incorporating environmental and health benefits) increase to approximately 43 MDKK per year for the first scenario in which wind electricity replaces coal produced electricity. If the conventional production is based on a natural gas fired power plant, annual net benefits are reduced to approximately 3 MDKK per year, when the lower value for CO_2 damages is applied. The “turning point”, when annual costs exceed annual benefits from emission reductions is already reached with a CO_2 price of 247 DKK/tonne in the first scenario, while in the second scenario using a price of 139 DKK/tonne leads to total net costs to society from constructing an offshore wind turbine farm. These calculations, however, do not include all positive and negative side effects from constructing an offshore wind turbine farm. Noise and amenity effects as well as possible negative effects on marine and on-shore biodiversity are not considered in the analysis.

3.8.2.3 Reduction of NO_x emissions from large power plants (>25MW)

Installing a SCR unit at the Studstrup power plant in Århus (as described in Chapter 3.4.2) results in annual emission savings of 6460 tonnes of NO_x. No other emissions are reduced by this technology. Using the basis value of 33500 DKK per tonne NO_x, as suggested in Table 3.8.2 results in a monetary value of 216.4 MDKK per year in terms of damages foregone. Subtracting the monetary benefits form the total costs per year of 82.1 MDKK calculated previously, results thus in net benefits to society of 134.3 MDKK per year (or 20800 DKK per tonne NO_x reduced) from installing the SCR unit.

Table 3.8.6. Reduction of NO_x emissions from large power plants.

Consequences	**Real consequences**		**Welfare economic calculations**	
	unit	amounts	Price per unit	MDKK/ year
Total costs per year				82.1
Emissions saved				
NO_x	tonne	6460		
Net costs per tonne NO_x				0.0127
Including environmental benefits (baseline)				
Emissions saved			DKK/tonne	
NO_x	tonne	6460	33500	216.41
Total annual net costs				-134.3

Applying the lower value for NO_x emissions (29000 DKK) and, alternatively the higher value (38000 DKK) reduces or increases net benefits by about 30 MDKK per year, but does not change the overall positive result for society.

3.8.2.4 Reduction of SO_2 emissions from large power plants

Installing a desulphurisation unit at the power plant in Rønne results in annual emission savings of 2292 tonnes of SO_2. The price per tonne SO_2 applied in the calculations shown in Table 3.8.7 is nearly 7 times larger than emissions reduction costs per tonne SO_2 calculated in Chapter 3.4.3. Again, seen from society's perspective, installing a desulphurisation unit in large power plants is a self-financing investment, when taking saved damages into consideration, resulting in net benefits of 66.86 MDKK per year (or 29000 DKK per tonne SO_2).

Given the rather limited range of values applied for SO_2 reductions, using minimum and maximum values in a sensitivity analysis only results in minor changes of +/- 1 MDKK in total net costs (or rather benefits) to society.

Table 3.8.7. Reduction of SO_2 emissions from large power plants.

Consequences	**Real consequences**		**Welfare economic calculations**	
	unit	amounts	Price per unit	MDKK/ year
Costs per year				12.22
Emissions saved				
SO_2	tonne/year	2292		
Costs per tonne SO_2				0.0053
Including environmental benefits				
Emissions saved			DKK/tonne	
SO_2	tonne/year	2292	34500	79.08
Total annual net costs				-66.86

3.8.2.5 Emission reductions from the introduction of electrical vehicles

The replacement of 70000 conventional cars with electrical vehicles results in annual emission savings of 20 tonnes SO_2, 51 tonnes NO_x, 199 NMVOC and 136000 tonnes CO_2. It is assumed that electrical vehicles will only replace gasoline driven cars. Therefore no particle emission reduction is included in the analysis below. Including monetary values for those emission reductions leads to health and environmental benefits of 51.1 MDKK per year, thus reducing total cost to approximately 637.4 MDKK per year. The inclusion of monetary values does not change costs per tonne emission reduced substantially as can be seen in Table 3.8.8. Net costs per tonne SO_2 and NO_x are still extremely high, with 31.93 MDKK/tonne SO_2 and 12.59 MDKK/tonne NO_x. Costs per tonne NMVOC are now equal to 3.25 MDKK/tonne. Given the rather limited emission savings possible with this measure, applying minimum and maximum values for emissions reduced only leads to minor changes in the total net costs of +/- 1 MDKK per year.

Not all positive side effects from the introduction of electrical cars have been included in the above analysis. In addition to rather moderate emission reductions electrical vehicles also lead to decreases in noise loads in inner cities and smell from exhaust gases.

Table 3.8.8. Replacing gasoline driven vehicles with electrical vehicles.

70,000 electrical vehicles	**Real consequences**		**Welfare economic analysis**	
	unit	amounts	Price per unit	MDKK/ year
Net costs per year				688.6
Emissions saved				
SO_2	tonne	20		
NO_x	tonne	51		
NMVOC	tonne	199		
CO_2	tonne	136000		
Net costs per tonne				
SO_2				34.4
NO_x				13.5
NMVOC				3.5
Including environmental benefits				
Emissions saved			DKK/tonne	
SO_2	tonne	20	60500	1.21
NO_x	tonne	51	90000	4.59
NMVOC	tonne	199	50000	9.95
CO_2	tonne	136000	260	35.36
Sum				51.1
Total annual net costs				637.4
Net costs per tonne SO_2 reduced*				31.93
Net costs per tonne NO_x reduced**				12.59
Net costs per tonne NMVOC reduced***				3.25

* Net costs per year minus benefits from NO_x, NMVOC and CO_2 reduction, divided by number of tonnes SO_2 reduced.

** Net costs per year minus benefits from SO_2, NMVOC and CO_2 reduction, divided by number of tonnes NO_x reduced.

*** Net costs per year minus benefits from SO_2, NO_x and CO_2 reduction, divided by number of tonnes NMVOC reduced.

3.8.2.6 Exhaust Gas Recirculation (EGR) for heavy duty vehicles

The installation of EGR filters in heavy duty-vehicles does not only contribute to NO_x and NMVOC emission savings but also to the reduction of CO and particulate emissions as shown in Table 3.8.9 below for the different scenarios.

Table 3.8.10 shows the calculation of (monetary) health and environmental benefits based on the annual emission reductions in 2010 and the average (baseline) prices per tonne emission presented in Table 3.8.2 for the three installation scenarios. Benefits are of course the same for all three cost calculation schemes, they only vary between installation scenarios (<=10, <=5 and only new vehicles). Annual benefits amount to approximately 405 MDKK per year in the first scenario (all vehicles not older than 10 years), 257 MDKK per year in the second scenario (all vehicles not older than 5 years) and approx. 108 MDKK in the third scenario (only new vehicles).

Table 3.8.9. Emission reductions for the different scenarios (2010 and 2002-2010).

Emissions	<=10	<=5	New
Emission reduction in 2010 (tonnes)			
NO_x	2838	1850	692
NMVOC	613	453	227
CO	1465	1054	529
PM	260	150	75
Total emissions reduction (2002-2010) (tonnes)			
NO_x	33759	19201	5545
NMVOC	6765	4462	1818
CO	16338	10404	4239
PM	3075	1479	603

Table 3.8.10. Calculating environmental benefits for the three EGR installation scenarios (average monetary values).

EGR scenario:	<=10		<=5		New	
Emissions saved	Tonnes	DKK/tonne	Tonnes	DKK/tonne	Tonnes	DKK/tonne
NO_x	2838	90000	1850	90000	692	90000
NMVOC	613	50000	453	50000	227	50000
CO	1465	10	1054	10	529	10
PM	260	458000	150	458000	75	458000
		MDKK/year		MDKK/year		MDKK/year
NO_x		255.40		166.50		62.27
NMVOC		30.65		22.65		11.37
CO		0.01		0.01		0.01
PM		119.01		68.72		34.52
Sum		405.08		257.88		108.16

The following tables describe the cost calculations per tonne emission reduced, when health and environmental benefits from emission reductions are included. Results show that environmental and health benefits cover less than half of total annual costs in the first cost calculation scheme, and less than one quart of total annual costs in the second scheme as can be seen in Table 3.8.11 and Table 3.8.12. The picture worsens substantially when cost calculations are based on total (present value) costs of installing EGR filters in the different scenarios (Table 3.8.13). Here environmental benefits contribute only with approximately 3% in total cost reductions. Table 3.8.14 shows average "cost-per-tonne" calculations, where total present value costs are set in relation to total emission reductions in the whole scenario period 2002-2010.

Table 3.8.11. Remaining vehicles with EGR in 2010 (welfare economic prices).

Scenario	<=10		<=5		New	
		MDKK/year		MDKK/year		MDKK/year
Total (annual) costs in 2010		915.38		701.08		343.48
Emissions saved	tonnes					
NO_x	2838		1850		692	
NMVOC	613		453		227	
Costs per tonne	MDKK/tonne					
NO_x		0.32		0.38		0.50
NMVOC		1.49		1.55		1.51
Total environmental benefits		405.08		257.88		108.16
Annual net costs		510.30		443.20		235.32
Net costs per tonne						
NO_x*		0.27		0.33		0.43
NMVOC**		0.88		1.03		1.08

* Net costs per year minus benefits from NMVOC, CO and PM reduction, divided by number of tonnes NO_x reduced.
** Net costs per year minus benefits from NO_x, CO and PM reduction, divided by number of tonnes NMVOC reduced.

Table 3.8.12. Including annual costs for vehicles with EGR scrapped in the scenario period (welfare economic prices).

Scenario	<=10		<=5		New	
		MDKK/year		MDKK/year		MDKK/year
Total (annual) costs in 2010		2173.40		1451.41		601.74
Emissions saved	tonnes					
NO_x	2838		1850		692	
NMVOC	613		453		227	
Costs per tonne	MDKK/tonne					
NO_x		0.77		0.78		0.87
NMVOC		3.55		3.20		2.65
Total environmental benefits		405.08		257.88		108.16
Annual net costs		1768.33		1193.53		493.58
Net costs per tonne						
NO_x*		0.71		0.74		0.80
NMVOC**		2.93		2.69		2.22

* Net costs per year minus benefits from NMVOC, CO and PM reduction, divided by number of tonnes NO_x reduced.
** Net costs per year minus benefits from NO_x, CO and PM reduction, divided by number of tonnes NMVOC reduced.

Table 3.8.13. All vehicles with EGR in the scenario period (welfare economic prices).

Scenario	<=10		<=5		New	
		MDKK/year		MDKK/year		MDKK/year
Total costs in 2010		13834		10013		4614
Emissions (annual) saved	tonnes					
NO_x	2838		1850		692	
NMVOC	613		453		227	
Costs per tonne	MDKK/tonne					
NO_x		4.87		5.41		6.67
NMVOC		22.57		22.11		20.28
Total environmental benefits		405.08		257.88		108.16
Total net costs		13428.96		9755.26		4505.39
Net costs per tonne						
NO_x*		4.82		5.36		6.60
NMVOC**		21.96		21.59		19.86

* Net costs per year minus benefits from NMVOC, CO and PM reduction, divided by number of tonnes NO_x reduced.

** Net costs per year minus benefits from NO_x, CO and PM reduction, divided by number of tonnes NMVOC reduced.

Table 3.8.14. Average costs for the whole period (welfare economic prices).

Scenario	<=10		<=5		New	
		MDKK/year		MDKK/year		MDKK/year
Total costs in 2010		13834		10013		4614
Emissions (total) saved	tonnes					
NO_x		33759		19201		5545
NMVOC		6765		4462		1818
Costs per tonne	MDKK/tonne					
NO_x		0.41		0.52		0.83
NMVOC		2.05		2.24		2.54
Including Environmental Benefits (Baseline)						
Emissions saved	Tonnes	DKK/tonne	Tonnes	DKK/tonne	Tonnes	DKK/tonne
NO_x	33759	90000	19201	90000	5545	90000
NMVOC	6765	50000	4462	50000	1818	50000
CO	16338	10	10404	10	4239	10
PM	3075	458000	1479	458000	603	458000
		MDKK/year		MDKK/year		MDKK/year
NO_x		3038.29		1728.09		499.09
NMVOC		338.23		223.09		90.90
CO		0.16		0.10		0.04
PM		1408.45		677.55		276.07
Sum		4785.13		2628.84		866.11
Total annual net costs		9048.90		7384.31		3747.44
Net costs per tonne						
NO_x*		0.36		0.47		0.77
NMVOC**		1.39		1.70		2.11

* Net costs per year minus benefits from NMVOC, CO and PM reduction, divided by number of tonnes NO_x reduced.

** Net costs per year minus benefits from NO_x, CO and PM reduction, divided by number of tonnes NMVOC reduced.

Changing the values for emissions reduced by this measure does not have substantial influence on the final results as can be seen in Table 3.8.15 below.

Table 3.8.15. Results from sensitivity analysis, all cost-calculation schemes.

NO_x reduction (MDKK/tonne)									
	<=10			<=5			New		
MDKK/tonne	MIN	BASIS	MAX	MIN	BASIS	MAX	MIN	BASIS	MAX
Remaining vehicles, annualised	0.29	0.27	0.25	0.35	0.33	0.31	0.46	0.43	0.40
All vehicles, annualised	0.74	0.71	0.69	0.76	0.74	0.71	0.83	0.80	0.77
All vehicles, total costs	4.85	4.82	4.80	5.38	5.36	5.34	6.63	6.60	6.57
All vehicles, average	0.38	0.36	0.33	0.49	0.47	0.45	0.79	0.77	0.74
NMVOC reduction (MDKK/tonne)									
	<=10			<=5			New		
MDKK/tonne	MIN	BASIS	MAX	MIN	BASIS	MAX	MIN	BASIS	MAX
Remaining vehicles, annualised	1.01	0.88	0.76	1.13	1.03	0.93	1.18	1.08	0.99
All vehicles, annualised	3.06	2.93	2.81	2.79	2.69	2.59	2.32	2.22	2.12
All vehicles, total costs	22.09	21.96	21.83	21.69	21.59	21.49	19.96	19.86	19.76
All vehicles, average	1.52	1.39	1.25	1.81	1.70	1.60	2.21	2.11	2.01

3.8.3 Summary of results

The valuation of environmental and health benefits from emission reductions has been based on a range of estimates taken from Ministerierne (2001). As discussed previously these estimates are extremely uncertain, especially regarding potential damage costs resulting from CO_2 emissions.

In order to determine the potential impact of monetary valuation of benefits on the ranking of measures according to their cost-effectiveness a sensitivity analysis has been conducted in which the different minimum and maximum estimates per tonne emission (as listed in Table 3.8.2) have been applied. The resulting rankings can be seen in Table 3.8.16. The size of the monetary value applied has the most drastic effect on the cost calculations for the offshore wind turbine farm. Here it is especially the value selected for CO_2 that determines total changes in the valuation of health and environmental benefits and thus resulting net costs per tonne emission reduced.

With respect to the ranking of measures based on their cost-effectiveness the inclusion of monetary values primarily effects the NO_x- and NMVOC reducing initiatives as can be seen in Table 3.8.16. Building an offshore wind turbine farm now replaces de-NO_x unit installations as the least expensive measure for reducing NO_x emissions in Denmark, when basis or maximum values for other side effects are applied. Also in the case of NMVOC reductions the offshore wind turbine farm initiative likewise becomes the most cost-effective measure, although the contribution of total emission reductions in this case is rather small, with 10 and 7 tonnes per year respectively.

Table 3.8.16. Ranking of measures based on costs per tonne emission reduced.

SO_2 emissions							
BASE		MIN		MAX		NO VALUATION	
Measure	MDKK/tonne	Measure	MDKK/tonne	Measure	MDKK/tonne	Measure	MDKK/tonne
De-Sox	0.005	De-Sox	0.005	OWF-coal	-0.078	De-Sox	0.005
OWF-coal	0.023	OWF-coal	0.121	De-Sox	0.004	OWF-coal	0.264
EV	31.933	EV	32.688	EV	31.143	EV	34.428
NO_x-emissions							
BASE		MIN		MAX		NO VALUATION	
Measure	MDKK/tonne	Measure	MDKK/tonne	Measure	MDKK/tonne	Measure	MDKK/tonne
OWF-gas	-0.160	De-NO_x	0.013	OWF-gas	-0.344	De-NO_x	0.013
OWF-coal	0.009	OWF-gas	0.016	OWF-coal	-0.213	OWF-gas	0.259
De-NO_x	0.013	OWF-coal	0.221	De-NO_x	0.013	OWF-coal	0.586
EGR (10)	0.713	EGR (10)	0.737	EGR (10)	0.689	EGR (10)	0.766
EGR (5)	0.735	EGR (5)	0.757	EGR (5)	0.714	EGR (5)	0.785
EGR (new)	0.803	EGR (new)	0.832	EGR (new)	0.775	EGR (new)	0.870
EV	12.589	EV	12.889	EV	12.276	EV	13.501
NMVOC emissions							
BASE		MIN		MAX		NO VALUATION	
Measure	MDKK/tonne	Measure	MDKK/tonne	Measure	MDKK/tonne	Measure	MDKK/tonne
OWF-gas	-4.511	OWF-gas	-0.249	OWF-gas	-8.963	Car-paint	0.126
OWF-coal	-0.754	Car-paint	0.125	OWF-coal	-8.152	EGR (new)	2.646
Car-paint	0.125	EGR (new)	2.317	Car-paint	0.124	EGR (5)	3.205
EGR (new)	2.220	EGR (5)	2.785	EGR (new)	2.123	EV	3.460
EGR (5)	2.685	EGR (10)	3.061	EGR (5)	2.585	EGR (10)	3.546
EGR (10)	2.935	EV	3.331	EGR (10)	2.809	OWF-gas	6.103
EV	3.253	OWF-coal	6.330	EV	3.172	OWF-coal	19.157

De-Sox (Desulphurisation unit at large power plant); OWF-coal (Offshore wind turbine farm, replaces coal-fired power plant); OWF-gas (Offshore wind turbine farm replaces natural gas fired power plant); EV (Electrical vehicles); De-NO_x (SCR unit installation at large power plant); EGR (10) (EGR filter installation, all vehicles not more than 10 years old); EGR (5) (EGR filter installations, all vehicles not more than 5 years old); EGR (new) (EGR filter installations, only new vehicles); Car-paint (Car-painting workshops: water based paint).

The ratio between potential benefits from emission reductions and total costs of implementing the different measures varies considerably between the analysed initiatives. Potential benefits in the case of substituting conventional vehicles with electrical cars, for example, make up only 2.3 % of total costs, if base values for reduced damages are applied, while benefits are higher than costs in the case of installing a SCR- or desulpurisation unit at large power plants and the building of an offshore wind turbine farm. Table 3.8.17 summarises the effect an application of different damage values has on total annual net costs for the different measures (negative costs here are thus indicating net benefits to society). For the offshore wind turbine farm measure the value for CO_2 damages selected has the strongest effect on the final cost result.

Table 3.8.17. Total annual net costs with different damage values (negative costs indicating net benefits).

Total net costs (MDKK per year)	NO VALUATION	BASE	MIN	MAX
Car-painting workshops: water based paint	94.2	56.1	56.3	55.8
Offshore wind turbine farm (replaces coal-fired power plant)	134.1	-5.6	44.0	-90.1
Offshore wind turbine farm (replaces gas-fired power plant)	61.0	-45.6	-3.0	-90.1
SCR (de-NO_x) unit installation	82.1	-134.3	-105.2	-163.3
Desulphurisation unit at large power plant	12.2	-66.9	-65.7	-68.0
Electrical vehicles	688.6	637.4	652.9	621.3
EGR-filter installation (< 10 years)	2173.4	1768.3	1845.7	1691.0
EGR-filter installation (< 5 years)	1451.4	1193.5	1238.8	1148.2
EGR-filter installation (only new vehicles)	601.7	493.6	515.6	471.5

Table 3.8.18. Ranking of measures according to their benefit-cost ratios.

	Costs	Benefits	Benefit/cost
	MDKK/year		ratio
Desulphurisation unit at large power plant	12.2	79.1	6.48
SCR (de-NO_x) unit installation	82.1	216.4	2.64
Offshore wind turbine farm (replaces natural gas-fired power plant)	61.0	106.6	1.75
Offshore wind turbine farm (replaces coal-fired power plant)	134.1	139.72	1.04
Car-painting workshops: water based paint	94.2	38.1	0.40
EGR-filter installation (< 10 years)	2173.4	405.1	0.19
EGR-filter installation (only new vehicles)	601.7	108.2	0.18
EGR-filter installation (< 5 years)	1451.4	257.9	0.18
Electrical vehicles	688.6	51.1	0.07

Table 3.8.18 shows a ranking of the different measures according to their benefit-cost ratios. As can be seen, installing desulphurisation unit at large power plants yields the highest benefits per DKK invested. For each DKK invested in the installation society gets about DKK 6.48 worth of benefits, in terms of the monetary value of emissions reduced by these measures. The replacement of conventional vehicles with electrical ones, on the other hand, produces only DKK 0.07 in benefits for each DKK invested.

As can be seen from Table 3.8.16 and Table 3.8.17 including monetary values for environmental and health effects can have an impact on the final result of the analysis and the ranking of different emission reduction measures. Valuation of non-market goods and services can thus serve as an indication of where other side effects should be taken into consideration, when making policy decision about implementing different measures. However, it is also essential to keep in mind that any valuation attempt due to its inherent uncertainty and lack of ability to cover all non-market effects only provides an incomplete picture of all positive and negative side effects associated with a particular measure.

4 Conclusions

4.1 Emissions

In Chapter 2.5 Pollutants summary the total emissions of SO_2, NO_x, NMVOC and NH_3 are shown for the baseline scenario. Table 4.1 summarizes the baseline emission values for 2010 along with the emission ceilings and the emission reductions achieved for each of the emission reduction options estimated in Chapter 3.

SO_2

The SO_2 emission ceiling for Denmark is 55 ktonnes in 2010. This is almost achieved in the baseline scenario in which the emission in 2010 is 56.1 ktonnes SO_2 or only 1.1 ktonnes above the target. However, the goal could be achieved if the desulphurisation option (reducing with 2.29 kt) was implemented. Use of fuels with lower content of sulphur than assumed in the baseline calculations will also reduce the emissions further.

NO_x

The projected NO_x emission in 2010 is somewhat higher than the emission ceiling. In the baseline calculations the emission is 146.4 ktonnes NO_x or 19.4 ktonnes above the target. The main reason is the large electricity export envisaged in the projection from the Danish Energy Agency. The large electricity export may also make it difficult to achieve the Danish CO_2 target under the Kyoto Protocol and some of the options considered for solving the problem may also reduce the NO_x emissions from the energy sector.

Table 4.1 shows that about half of the problem (9.6 ktonnes out of the 19.4 ktNO_x) could be solved by implementing the options in Table 4.1. The deNO_x unit (SCR) and Exhaust Gas Recirculation (EGR) on all trucks with an age less than 10 years would be especially effective in reducing the emission.

Table 4.1. Overview of total emission in 2010.

Reduction options not included in the reference scenario	**Option**	**Accum.**	**Option**	**Accum.**	**Option**	**Accum.**	**Option**	**Accum.**
	SO_2 kt/year		**NO_x kt/year**		**NMVOC kt/year**		**NH_3 kt/year**	
Car-painting workshops: water-based paint	0.00	0.00	0.00	0.00	0.75	0.75	0.00	0.00
Offshore wind turbine farm (replaces coal-fired power plant)	0.51	0.51	0.23	0.23	0.01	0.76	0.00	0.00
SCR (de-NO_x) unit installation at large power plant	0.00	0.51	6.46	6.69	0.00	0.76	0.00	0.00
Desulphurisation unit at large power plant	2.29	2.80	0.00	6.69	0.00	0.76	0.00	0.00
Electrical vehicles (70.000 in 2010)	0.02	2.82	0.05	6.74	0.20	0.96	0.00	0.00
EGR-filter installation (heavy duty vehicles < 10 yr.)	0.00	2.82	2.84	9.58	0.61	1.57	0.00	0.00
Increased grazing of dairy cows	0.00	2.82	0.00	9.58	0.00	1.57	3.30	3.30
Manure application within one hour after spreading	0.00	2.82	0.00	9.58	0.00	1.57	1.31	4.61
2010 emission:								
In the reference scenario		56.05		146.37		83.01		82.81
Extra reductions included		53.23		136.79		81.44		78.20
ECE goals		55.00		127.00		85.00		69.00

NMVOC

NMVOC is the only pollutant for which the emission ceiling will be achieved when the projected emissions are based on the baseline scenario. But the baseline projection is only about 2 ktonnes below the target of 85 ktonnes NMVOC. However, the projected emissions for NMVOC are very uncertain. Especially the emission estimates from use of solvents and offshore activities are attached with large uncertainties and it could well happen that the estimated emissions would change substantially should some research on this area be carried out. The only emission reduction option considered in the present project was the measure in car painting workshops. This measure could reduce the NMVOC emission by 0.75 ktonnes.

NH_3

The emission ceiling for NH_3 for Denmark in 2010 is 69 ktonnes NH_3 or 56.8 ktonnes NH_3-N. The projected emissions of NH_3 are about 14 ktonnes NH_3 above the goal. As mentioned in the agricultural sector, this obligation does not include the emission from crops and ammonia treated corn stalk for fodder. The projected NH_3 emissions are larger compared to earlier projections. The main reason being that estimates for the fraction of the manure distributed on crops in growth compared to manure distributed on fields without growth is larger than estimated in earlier projections. At present no statements exist on how the farmer is treating livestock manure in practice which makes the calculations uncertain. It is important to point out that no consideration has been given to technical measures in the baseline projection. Table 4.1 shows that implementation of the two extra measures could reduce the gap by about 4.6 ktonnes NH_3.

4.2 Financial and welfare economic analysis

In this report a total of eight potential future emission reduction initiatives have been analysed with regard to their financial and welfare economic costs and emission reducing capacity (Table 4.1).

The financial economic analysis shows that for SO_2 the desulphurisation measure is the most cost effective (the electric car option is cheaper but the reduction from this measure is only 0.02 kt SO_2). For NO_x the deNO_x measure is the cheapest (again with electric cars cheaper but only a small reduction of 0.05 kt NO_x). For NMVOC the electric car measure is again the cheapest, but here with 0.2 kt NMVOC followed by the car painting workshop measure (the reduction from the wind turbine farm is only 0.01 kt NMVOC). For NH_3 the cheapest measure is the increased grazing for dairy cows, which also results in the largest NH_3 reduction.

Using welfare economic prices desulpurisation and de-NO_x- unit installations at large power plants are the most favourable options for reducing SO_2 and NO_x emissions respectively, followed by the building of offshore wind turbine farms. For SO_2 and NO_x emissions, replacing conventional cars with electrical ones represents the most expensive option, primarily because of the relatively low total emission reductions that can be achieved with this measure. For NMVOC emissions the introduction of water-based paint in car-painting workshops represents the cheapest option, followed by the installation of EGR-filters on heavy-duty vehicles. Building an additional offshore wind turbine farm results in only minor NMVOC savings with corresponding high-costs per tonne NMVOC reduced. Increasing the amount of grazing days for dairy cows features as the most cost-effective alternative for reducing NH_3 emissions. Based on the cost-effectiveness measures calculated marginal cost curves for emission reductions of SO_2, NO_x, NMVOC and NH_3 can be constructed, showing the additional costs associated with reducing emissions with one extra tonne.

Many emission reduction measures reduce more than one type of emission covered under the UNECE Convention on Long-Range Transboundary Air Pollution. In addition, the measures suggested in this report also contribute to the reduction of non-UNECE emission, i.e. particulates, CO_2 and metan. In order to illustrate the effect the inclusion of these side-benefits can have on the final results of the analysis monetary estimates for the foregone damages associated with the different emissions have been included in a separate analysis. The benefit estimates applied in this analysis are based on a range of estimates taken from a report recently published by five different Danish ministries (Ministerierne, 2001). Those values, however, should still be regarded as extremely uncertain, especially regarding potential damage costs resulting from CO_2 emissions.

The ratio between potential benefits from emission reductions and total costs of implementing the different measures varies considerably between the analysed initiatives. Potential benefits in the case of substituting conventional vehicles with electrical cars, for example, make up only 7 % of total costs, if base values for reduced damages are applied, while benefits are higher than costs (thus resulting in net benefits to society) in the case of installing a SCR- or desulpurisation unit at large power plants and the building of an offshore wind turbine farm. In addition to applying base values a sensitivity analysis has been conducted in which different minimum and maximum estimates per tonne emission have been applied. The size of the monetary value applied has the most drastic effect on the cost calculations for the offshore wind turbine farm. Here it is especially the value selected for CO_2 that determines total changes in the valuation of health and environmental benefits and thus resulting net costs per tonne emission reduced.

The results of this analysis show, that including monetary values for environmental and health effects can have an impact on the final result of the analysis and the ranking of different emission reduction measures. Valuation of non-market goods and services can thus serve as an indication of where other side effects should be taken into consideration, when making policy decisions about implementing different measures. However, it is also essential to keep in mind that any valuation attempt due to its inherent uncertainty and lack of ability to cover all non-market effects only provides an incomplete picture of all positive and negative side effects associated with a particular measure.

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