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	55,000	127,000	85,000	69,000

* 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
	1,000 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 sulphur content in the fuel, sulphur retention in the ash and degree of

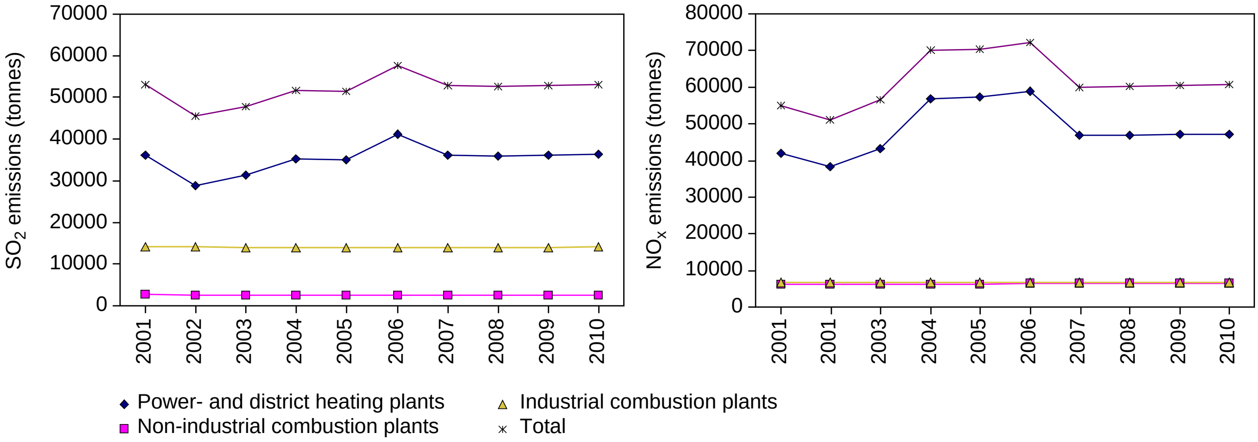

Figure 1. Projected SO_2 emissions from the energy sector.

Figure 2. Projected NO_x emissions from the energy sector.

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 from the Joint EMEP/EEA Atmospheric Emission Guidebook. Espe-

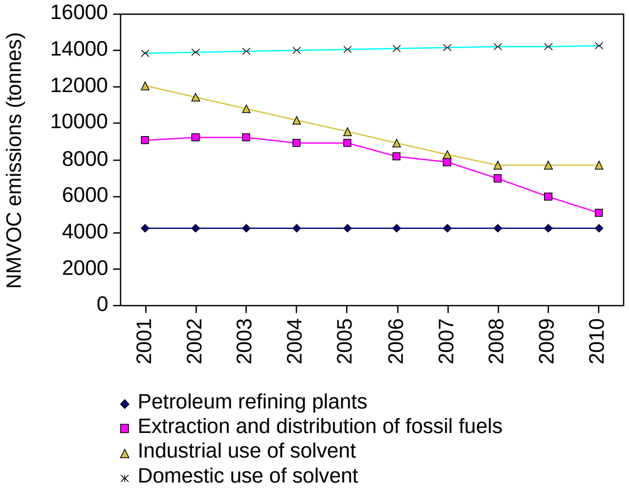

Figure 3. Projected NMVOC emissions from the main industrial sources.

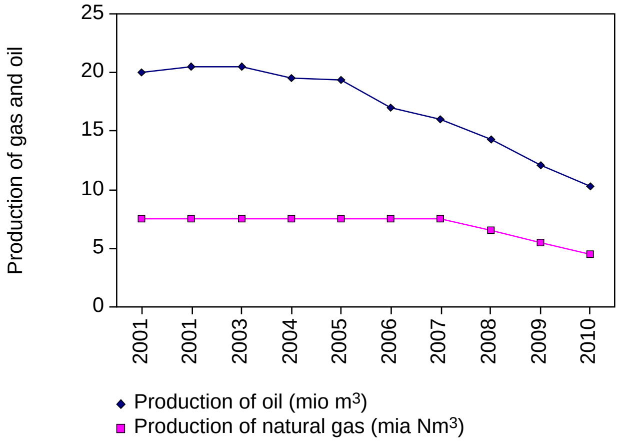

Figure 4. Projected production of oil and gas.

cially 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 have 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 emissions 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 evaporation factors. Consistency with historical emission figures is

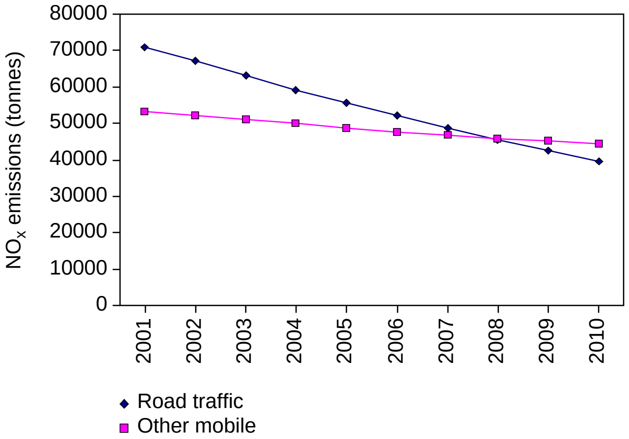

Figure 5. Projected NO_x emissions from road traffic and other mobile sources.

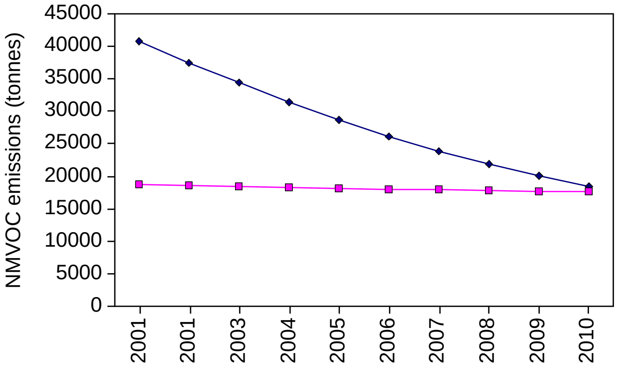

Figure 6. Projected NMVOC emissions from road traffic and other mobile sources.

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 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.

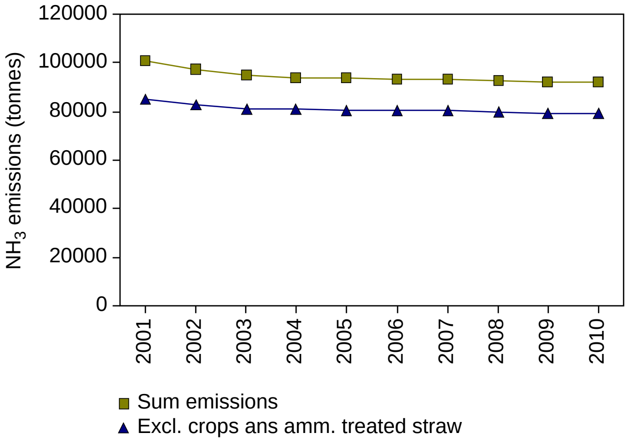

Figure 7. Projected NH_3 emissions from agricultural activities.

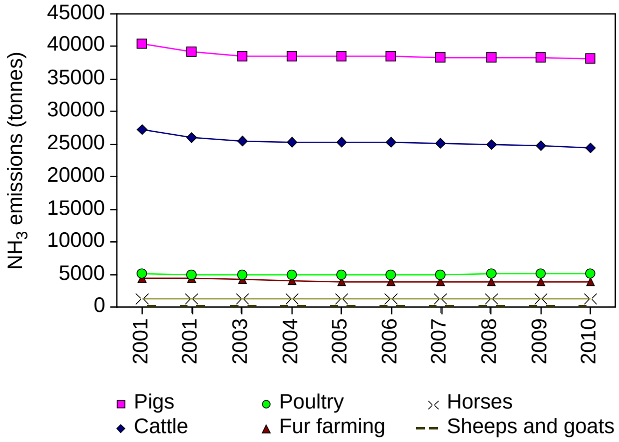

Figure 8. Projected NH_3 emissions from husbandry manure.

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

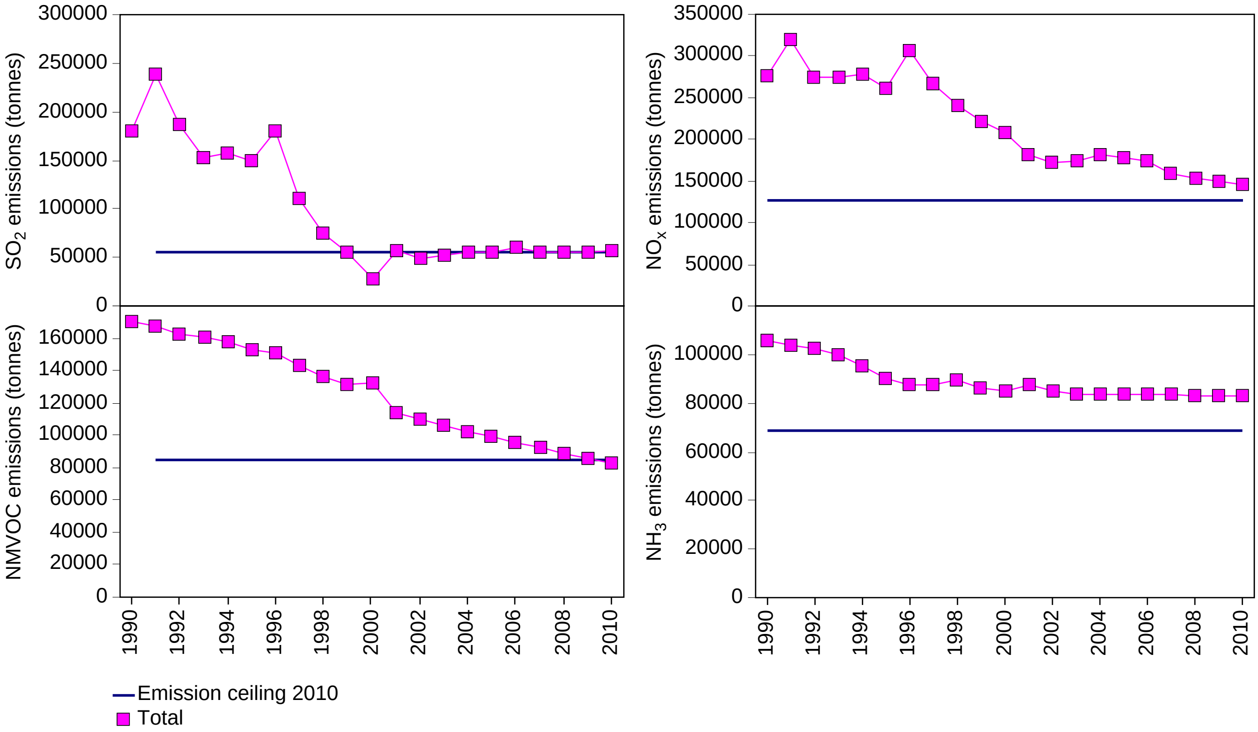

Figure 9. Historical and projected emissions together with the emission ceiling from 2010.

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 (re-places 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		3110.0	14420.0	
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. To install EGR on heavy duty vehicles will be very expensive according to the calculations. 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.

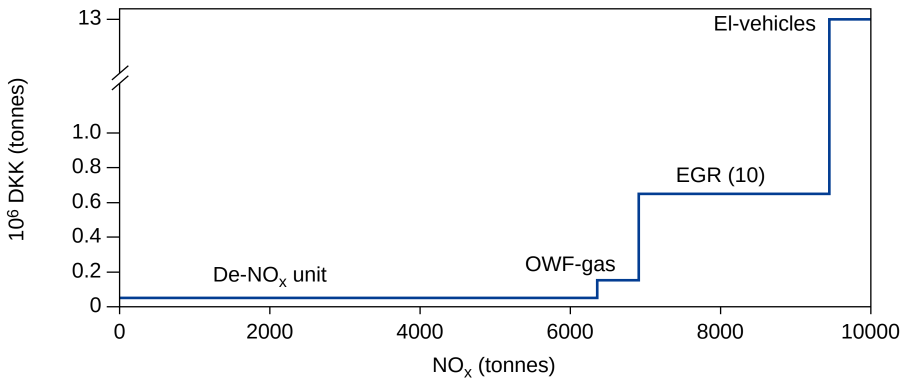

Figure 10. Marginal cost function for future reductions of NO_x emissions.

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 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.

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 3.12 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 0.16 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	38.1	3.12
SCR (de-NO_x) unit installation	82.1	139.7	1.70
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	15.8	0.01
EGR-filter installation (only new vehicles)	601.7	405.1	0.67
EGR-filter installation (< 5 years)	1451.4	257.9	0.18
Electrical vehicles	688.6	108.2	0.16