PBL Netherlands Environmental Assessment Agency

ASSESSMENT OF THE ENVIRONMENTAL IMPACTS AND HEALTH BENEFITS OF A NITROGEN EMISSION CONTROL AREA IN THE NORTH SEA

POLICY STUDIES

Assessment of the environmental impacts and health benefits of a nitrogen emission control area in the North Sea

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FINDINGS

Assessment of the environmental impacts and health benefits of a nitrogen emission control area in the North Sea

Summary

In the last five to ten years, concerns about the health and ecosystem effects of air polluting emissions from ships have grown in international policy debate regarding further air pollutant emissions control. As an outcome of the debate, the International Maritime Organisation adopted more stringent emission standards in 2008 to further control air pollution from sea shipping. For example, their most stringent nitrogen oxide emission standards are about 75 per cent lower than the standards for current ships. However, these most stringent standards are only mandatory in specific emission control areas designated by the IMO. Such specific areas aim to protect densely populated areas and sensitive ecosystems from air pollution from nearby international shipping. Prior to a possible application for designation of a nitrogen oxide emission control area, the eight North Sea countries commissioned an assessment of the environmental impacts and health benefits (this report) and the economic impacts and costs (Danish EPA, 2012). The main conclusions of this assessment are presented and concisely explained below. A detailed elaboration of the work carried out, the results and the uncertainties can be found in 'Full results'.

Cost-benefit analysis
- The introduction of a nitrogen emission control area in the North Sea from 2016 onwards would improve the air quality in the surrounding countries and would lead to net benefits in Europe. In 2030, the health benefits would exceed the costs to international shipping by a factor of two, according to the main estimates. The cost-benefit test is also passed in the least favourable situation, with a low value attributed to health impacts and a high cost estimate.

Comparing sea-based and land-based emission control measures
- The comparison of health benefits and costs between a nitrogen emission control area and additional land-based emission control measures indicates that there is still substantial potential for land-based emission control measures that yield higher health benefits on land at lower costs. In particular, such land-based emission control measures include ammonia measures in agriculture, a limited number of relatively cheap nitrogen oxide measures in industry and some particulate matter measures in industry and agriculture.
- Furthermore, the comparison indicates that, if air policy aims to simultaneously abate eutrophication, acidification, ozone and health impacts, nitrogen control at sea is about as cost-effective as nitrogen control in a medium air quality ambition for stationary land-based sources. This implies that a nitrogen emission control area fits a medium ambition for air quality improvement in Europe, or any higher ambition.
- Compared with land-based emission control measures in the North Sea coastal countries, a nitrogen emission control area in the North Sea provides a larger potential for relatively cheap nitrogen oxide reductions in the longer term (after 2030) if more and more old ships are gradually replaced by new ships with strict nitrogen control measures. The sooner a nitrogen emission control area is designated in the North Sea, the larger the reduction would be in subsequent years.

Health and ecosystem impacts
- A nitrogen emission control area would reduce the total years of life lost due to air pollution in the North Sea coastal countries by almost one per cent by 2030, and even further in subsequent years. For comparison, a low and medium ambition for land-based emission control

measures reduces the total years of life lost in the North Sea coastal countries by approximately 5 and 11 per cent respectively in the short term (2020).
- Impacts of eutrophication on the biodiversity of terrestrial ecosystems are still expected to occur on a wide geographical scale in Europe in 2030, by which time North Sea shipping will contribute nearly seven per cent of the excess nitrogen loads in the ecosystems of North Sea coastal countries. A nitrogen emission control area would reduce this contribution by about one third by 2030 (two percentage points) and even further in subsequent years.
- In contrast to eutrophication problems on land, it is not clear whether eutrophication in North Sea waters is still a problem in 2030. The North Sea countries currently aim to solve such problems before 2020. The contribution of a nitrogen emission control area to reducing atmospheric inputs is limited in the period up to 2020. This is explained by the slow replacement of ships with new and cleaner ships.

Contributions to air quality

- Nitrogen oxide emissions from North Sea shipping are responsible for 7–24 per cent of country-average nitrogen dioxide concentrations in North Sea coastal countries in 2030. Contributions to nitrogen deposition range from two to five per cent. Nitrogen oxide emissions from ships are also responsible for one to five per cent of the particulate matter concentrations ($PM_{2.5}$) in the North Sea countries. A nitrogen emission control area in the North Sea would reduce all these North Sea shipping contributions by about one third. Compared with the contribution made by North Sea shipping to nitrogen dioxide concentrations, the contribution to nitrogen deposition and particulate matter concentrations is relatively lower due the relatively higher contributions from various land-based sources.

Uncertainties

- The uncertainty analysis shows that the above cost-benefit analysis is rather robust against a number of potentially large uncertainties in the emission inventories, emission projections, emission scenarios and the applied air quality model resolution.
- New insights into the assumed harmfulness of specific particle species within particulate matter can change the conclusions reached as to whether a nitrogen emission control area would pass a cost-benefit analysis test. On the other hand, long-term exposure to low concentrations of ozone might prove to be more harmful to human health than currently assumed. The latter would give more emphasis to nitrogen oxide reductions as this pollutant is an ozone precursor, together with volatile organic compounds.
- The lack of a proper methodology to quantify the ecosystem benefits related to a nitrogen emission control area leads to a bias towards underestimation of the monetised benefits in this study.

Introduction

Policy context: emission and fuel standards for international shipping lag behind those of land-based sources

In the last five to ten years, concerns about the health and ecosystem effects of air polluting emissions from ships have grown in international policy debate regarding further air pollutant emissions control. The debate is taking place in a context in which emission and fuel standards for international shipping lag behind those of land-based sources. As an outcome of the debate, the International Maritime Organisation (IMO) adopted more stringent requirements in 2008 to further control air pollution from sea shipping (IMO, 2008). For example, their most stringent nitrogen oxide emission standards are about 75 per cent lower than the standards for current ships. However, these most stringent requirements for sulphur dioxide and nitrogen oxides are only mandatory in emission control areas (ECA).

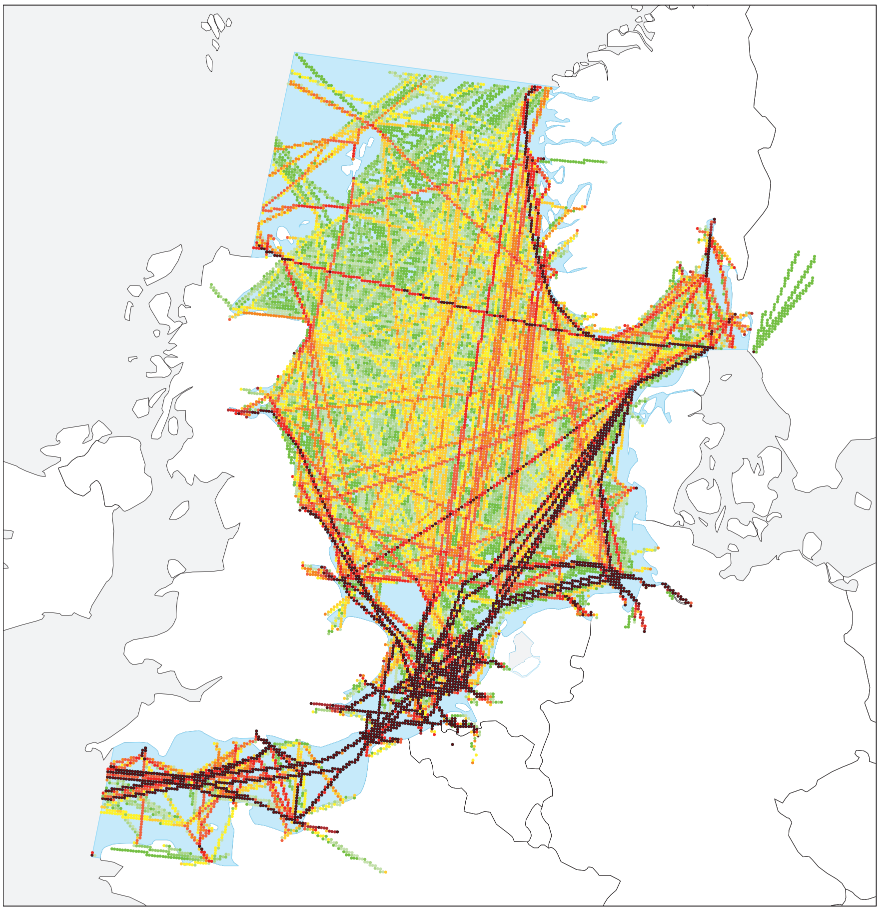
The Baltic Sea and the North Sea (including the English Channel) were designated as sulphur oxide emission control areas (SECA) in 2006 and 2007, respectively. The coastal countries of the Baltic Sea are currently involved in a decision-making process over an application to the IMO to designate the Baltic Sea as a nitrogen oxide emission control area. A North-American ECA for sulphur dioxide and nitrogen oxides (SECA and NECA) will become active on 1 August 2012.

In March 2011, the North Sea NECA Consultation Group commissioned an assessment of the environmental impacts and benefits of a nitrogen emission control area (this report) as well as the economic impacts (Danish EPA, 2012). The group consists of the eight coastal countries that surround the North Sea. The assessments aim to support the decision-making process of the North Sea countries for a common application to the IMO to designate the North Sea (including the English Channel) as a nitrogen emission control area.

Objectives based on IMO criteria

The objectives of the environmental impact and benefit assessment are based on the IMO criteria for designation of an emission control area by the IMO (Annex 1):
- estimate the contribution of North Sea shipping to air pollution within the coastal countries and beyond and to nitrogen deposition to the North Sea waters;

Figure 1
Nitrogen oxide emissions projected for the North Sea, 2030



Nitrogen oxide emissions (tonnes per grid cell of 5x5 km^2)

≤ 0.05	0.25 – 0.5	2.5 – 5	25 – 100	North Sea boundaries
0.05 – 0.1	0.5 – 1	5 – 10	> 100	
0.1 – 0.25	1 – 2.5	10 – 25		

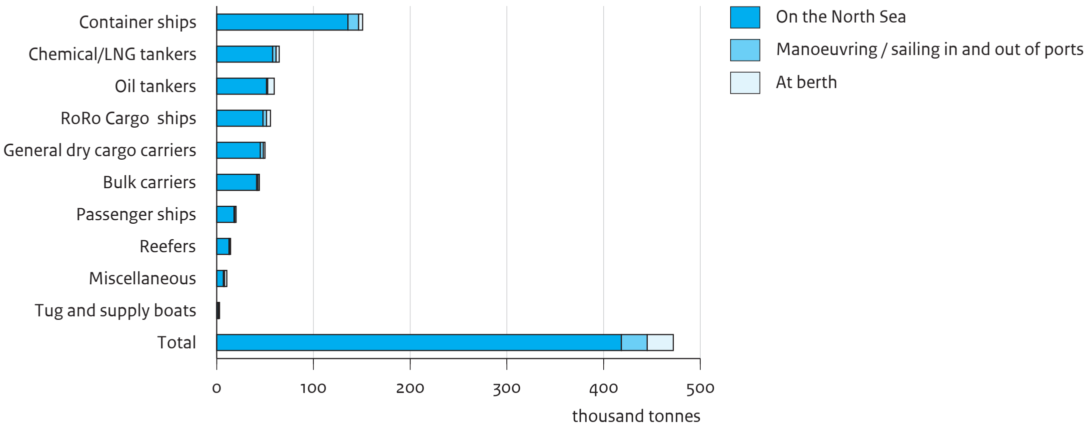
Source: PBL (based on MARIN 2011b)

- assess the environmental impacts and benefits of introducing a nitrogen oxide emission control area in the North Sea;
- compare the benefits of a nitrogen oxide emission control area in the North Sea with the costs, as presented by the economic impact assessment (Danish EPA, 2012);
- compare the cost-effectiveness of a nitrogen oxide emission control area with land-based emissions control measures.

Integrated assessment method aligned with other European air policy studies

Our integrated assessment method involved (see Section 1.3) the construction of emission baselines for North Sea shipping and scenarios describing the impacts of a nitrogen emission control area on emissions, air quality modelling, determining impacts on health and ecosystems through dose-response relationships, and estimating benefits by valuing health impacts. The comparison with land-based emission control measures was made using another cost-benefit assessment recently carried out within the framework of the revision of the national air pollutant emissions ceilings under the Gothenburg Protocol of the UNECE. To optimise the

Figure 2
Nitrogen oxide emissions over the North Sea, per type of vessel, 2009



Source: PBL (derived from MARIN 2011b)

comparison, we aligned our methods as much as possible with their well-accepted methods.

Harmonisation with economic impact assessment

The assessment of the environmental impacts and benefits of a nitrogen oxide emission control area in the North Sea as presented in this report has been developed and harmonised with the assessment of the economic impacts and costs by the Danish Environmental Protection Agency (2012).

Consortium

The assessment presented in this report was conducted by a consortium consisting of the PBL Netherlands Environmental Assessment Agency, the UK Ecometrics Research and Consulting, the European Monitoring and Evaluation Programme (EMEP) hosted by the Norwegian Meteorological Institute, the Dutch National Institute for Public Health and the Environment and the Dutch DCMR Environmental Protection Agency Rijnmond.

Emission inventories, baseline and scenarios

Busy shipping lanes in 2009 caused relatively high emissions along North Sea shores

The North Sea, including the English Channel, is one of the busiest seas in the world. The traffic intensity is particularly high in the southern section. Every day, 400 commercial vessels pass through the busiest seaway in the world, the Strait of Dover. The port of Rotterdam is the world's third port measured by total cargo volume in 2009 (AAPA, 2010). The busiest shipping lanes can be clearly identified in the spatial distribution of projected nitrogen oxide emissions from North Sea shipping in 2030 (Figure 1). Total nitrogen oxide emissions in the North Sea are estimated at 472 and 446 thousand tonnes in 2009 and 2030 respectively (see Section 2.1). Of these total ship emissions, 32% are released within 12 nautical miles of the shore, 89% within 50 nautical miles and 97% within 100 nautical miles. Almost 90% of the nitrogen oxide emissions take place at open sea and 10% in ports (Figure 2). Container ships are the largest single contributor to nitrogen oxide emissions in the North Sea and in ports (Figure 2), ranging from a 30% contribution in 2009 to 40% by 2030.

The emission inventory for 2009 by the Maritime Research Institute Netherlands (MARIN) was based on monitoring data from the Automatic Identification System (AIS) for 2008 and 2009, traffic data from the Lloyds Marine Intelligence Unit (LMIU) for 2008 and ship characteristics from the Lloyds List Group (LLG) database of October 2010. Emission factors were determined by the Netherlands Organisation for Applied Scientific Research (TNO) for the main and auxiliary engines. Different models were used to construct the emission inventory.

The MARIN inventory was validated with the emission inventory by the Finnish Meteorological Institute (FMI) that was used in the economic impact assessment (FMI, 2011). This showed that the ship activities of MARIN and

Table 1
Central assumptions in this assessment

Parameter	Assumptions
Growth in shipping 2009–2030	2.1%/year average (3.5% container ships, 1.5% other ship types)
Efficiency improvements 2009–2030	0.96%/year (through efficiency of scale, speed reductions and technological and operational improvements)
Share of LNG in 2030	25% in coastal shipping, 10% in oil, chemical and gas tankers
Shore-side electricity	applied to 5% of ships at berth
Emission standards	current IMO and EU legislation
Price year / discount rate	2012 euros, discount rate is 4%

Source: PBL

FMI compare reasonably well for 2009, but that the estimates for installed auxiliary engine power and fuel use and associated nitrogen oxide emissions differ substantially (by 38%; see Section 2.1). Since all experts at MARIN, TNO and FMI agree that these estimates are rather uncertain, we decided to include this uncertainty in a sensitivity analysis, summarised below and described in detail in Section 5.1. Another comparison was made with an inventory by the International Institute of Applied Systems Analysis (IIASA) that is currently widely used in European air policy studies (Wagner et al., 2010; Cofala et al., 2007). The comparison with the IIASA inventory showed that their nitrogen oxide emissions at sea are higher, mainly because of overestimated sailing speeds and higher growth assumptions.

Our emission baseline was based on the above emission inventory of shipping activities in 2009 (Chapter 2; MARIN, 2011a, b) and a number of assumptions (Table 1). Most of these assumptions were based on the Second IMO Greenhouse Gas Study (Buhaug et al., 2009). The year 2030 was chosen as the target year for our baseline mainly because the best available emission baselines for land-based emission sources also have 2030 as their target year. This allows for a sound assessment of the impacts of a nitrogen emission control area on the projected air quality in 2030 in the North Sea region.

Nitrogen oxide emissions on land will halve by 2030, whereas emissions on the North Sea will decrease only slightly
Based on the above emission inventory and assumptions, we calculated baseline emission growth from 2009 to 2030 for North Sea shipping (see Section 2.2). The baseline for land-based emissions was taken from the Primes 2009 scenario (Capros et al., 2008; CIAM, 2011a).

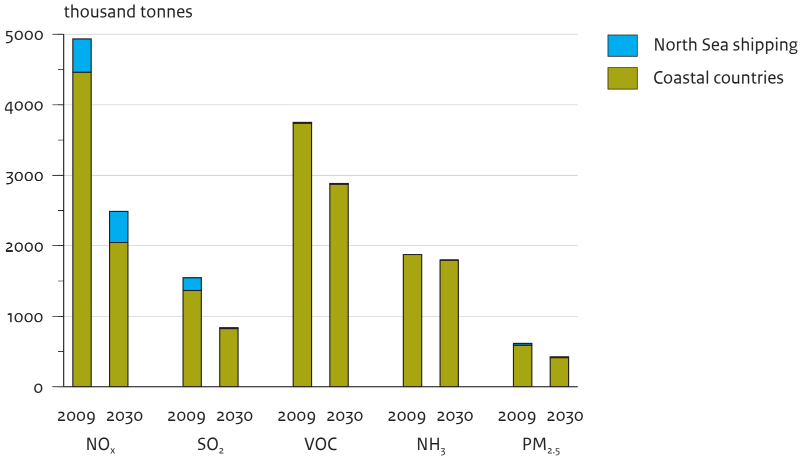
The land scenario estimates that most of the air polluting emissions in the countries surrounding the North Sea decrease substantially, with the exception of ammonia (Figure 3). In the North Sea, sulphur and particulate matter emissions are expected to decrease due to the use of cleaner fuels as enforced in the sulphur emission control area. Despite a moderate growth in shipping transport, we estimate that nitrogen oxide emissions decrease slightly between 2009 and the 2030 baseline. This is caused by the assumed efficiency improvements, the Tier II nitrogen oxide emission standards for ships and the higher assumed use of LNG as a clean fuel.

Policy scenarios for a nitrogen emission control area and contributions from shipping

Our main scenario is the nitrogen emission control area scenario (NECA), which simulates compliance with the IMO regulations in 2030 when only the new ships built after 2015 must meet the Tier III nitrogen oxide emission standards. A second scenario simulates a maximum feasible reduction at sea (MFR) where all the ships meet the Tier III emission standards in 2030. This scenario was only created to outline the long-term potential improvements in air quality, health and ecosystem impacts when all ships are equipped with the strictest nitrogen control measures. This MFR scenario was therefore not included in the cost-benefit analysis. The NECA and MFR scenarios reduce nitrogen oxide emissions by 129 and 300 thousand tonnes respectively in 2030 (a respective 30% and 67% reduction relative to the baseline).

The total contribution of air polluting emissions from North Sea shipping to air quality and deposition in 2030 was determined using two cases. In the first case, only nitrogen oxide emissions from North Sea shipping were set to zero. The other air polluting emissions on land and in other sea areas in 2030 were not changed in the air quality modelling. In the second case, all air polluting emissions from North Sea shipping were set to zero (nitrogen oxide, sulphur dioxide, particulate matter, carbon monoxide and volatile organic compounds). Again, air polluting emissions on land and in other sea areas were not changed.

Figure 3
Air pollutant emissions in the North Sea and the coastal countries, 2009 and 2030 baseline



Source: PBL (derived from MARIN 2011b and IIASA 2011)

Air quality, health and ecosystem impacts

Contributions from shipping vary by impact and distance to the North Sea and also depend on other contributing sectors

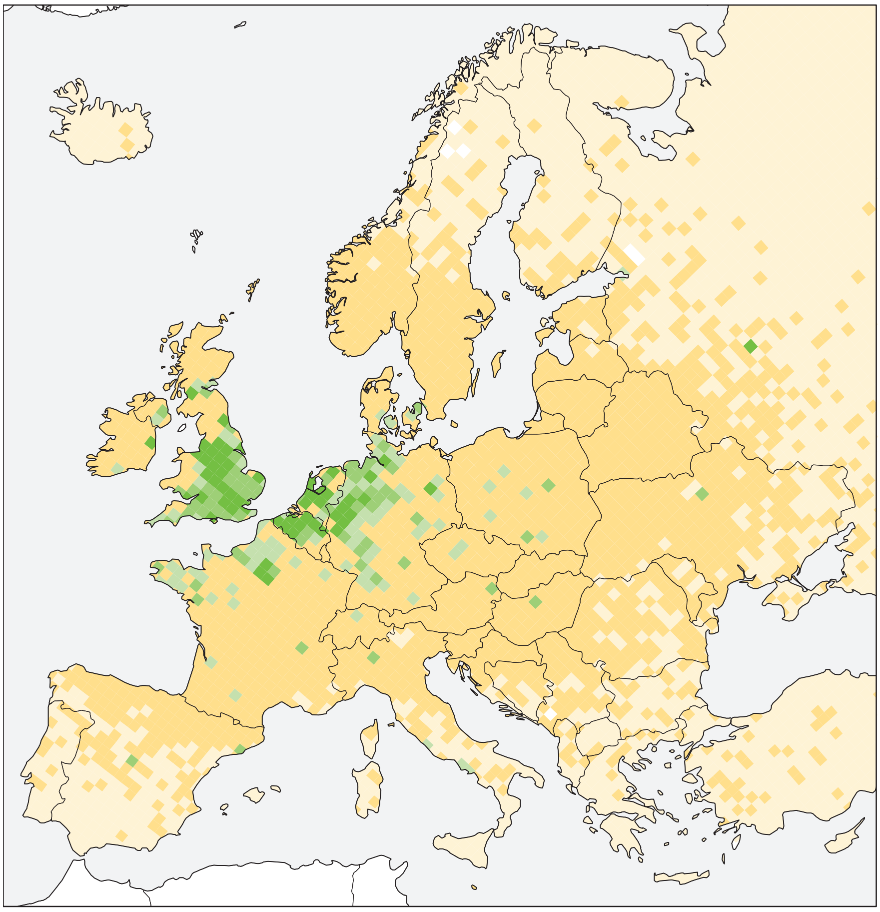
Based on the two 'contribution cases' as described above, we determined that nitrogen oxide emissions from ships are responsible, via atmospheric nitrate formation, for between one and five per cent of country-average particulate matter concentrations ($PM_{2.5}$) in 2030 (see Table 2 and Section 3.1). This contribution is significant in for example the Netherlands, where sectors such as road transport and industry make similar contributions in 2030 (Velders et al., 2012). The relative contributions to the estimated health effects (loss of life expectancy expressed as Years of Life Lost – YOLL) via exposure to $PM_{2.5}$ are somewhat larger (see Section 3.2). This indicates the presence of higher population densities near the North Sea.

The absolute contribution of nitrogen oxide emissions from North Sea shipping to the loss of life expectancy in Europe (via $PM_{2.5}$) is estimated at about 18 300 years. A nitrogen emission control area would prevent about 4 870 years of life lost in Europe in 2030. This amounts to 0.9% of the total life years lost in the North Sea coastal countries in 2030 (about 0.5 million years), and 0.5% of the total years of life lost in Europe (about 1 million years). These reductions would double after 2040, when all ships comply with the requirements of a nitrogen emission control area while assuming that other emissions sources in Europe do not change. An outline of such long-term health benefits in the MFR scenario is shown in Figure 4. Particulate matter is currently estimated to be associated with the highest disease burden in Western Europe, followed by second-hand smoke, traffic noise and radon (Hänninen O. and Knol A. (eds.), 2011).

Based on the two 'contribution cases' as described above, we determined that North Sea shipping contributes up to 25% of the nitrogen dioxide concentrations in certain coastal areas close to busy shipping lanes (see Section 3.1 and Figure 5). Contributions to country-average concentrations range from 7% to 24% in the North Sea coastal countries. Contributions to nitrogen deposition range from 2% to 5% (see Section 3.1). The contribution to nitrogen deposition above the critical load for eutrophication in ecosystems is a little higher (see Section 3.3), which indicates the relative higher contribution to ecosystems in the vicinity of the North Sea. Large parts of Europe are expected to face nitrogen depositions above the critical loads of ecosystems for nitrogen in 2030 (Figure 6). The largest reductions in an MFR scenario are seen east of the major shipping lanes.

Figure 4
Potential reduction in years of life lost under MFR scenario, 2030

Absolute reductions



Reduction in years of life lost

- 0
- 0 – 10
- 10 – 20
- 20 – 40
- 40 – 334

Source: PBL (based on NMI-EMEP and EMRC calculations)

A nitrogen emission control area in the North Sea in 2030 would reduce all the contributions mentioned in Table 2 by about one third. An MFR scenario would reduce the contributions by two thirds.
Nitrogen oxide emissions from North Sea shipping also contribute to higher ozone concentrations. The contribution of North Sea shipping in 2030 to a health-related and a crop-related ozone indicator is 4% and 11% respectively (see Section 3.1). Due to the non-linearity of atmospheric ozone formation, a nitrogen emission control area does not lead to a one-third reduction in the total contribution in 2030, but less.

Small contribution of a nitrogen emission control area to short-term eutrophication targets in North Sea

Eutrophication still posed a threat to North Sea ecosystems in coastal areas and a number of more distant offshore locations in 2009 (see Section 3.4). It has resulted in a range of undesirable disturbances in the

Table 2
Contributions of nitrogen oxide emissions from North Sea shipping to air quality and impacts in the 2030 baseline (derived using the contribution cases)

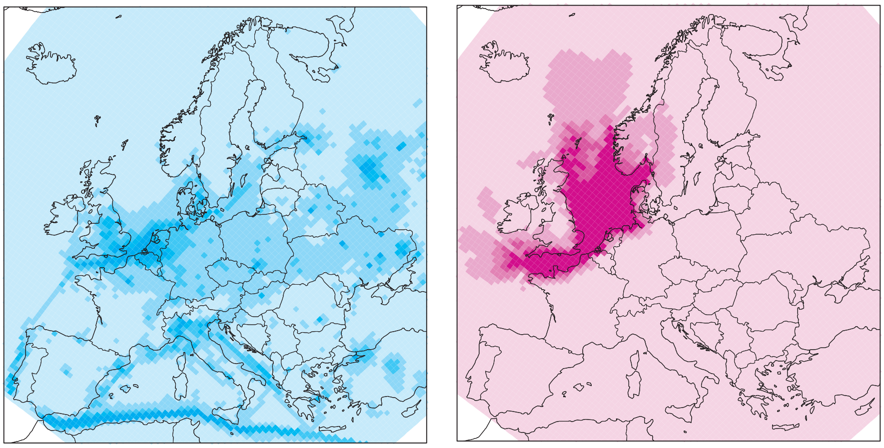
Country	Particulate matter ($PM_{2.5}$)	Health effects by $PM_{2.5}$ (years of life lost)	Nitrogen dioxide	Nitrogen deposition	Nitrogen deposition above critical loads
			%		
Belgium	3.4	3.7	15.4	3.2	11.2
Denmark	3.3	3.4	18.5	4.1	11.4
France	2.0	2.2	8.1	1.4	5.0
Germany	2.1	2.2	7.3	1.9	7.0
Netherlands	5.2	6.1	24.1	3.2	8.4
Norway	1.3	2.2	13.1	4.8	42.1
Sweden	1.1	1.5	8.9	3.5	16.0
United Kingdom	4.4	5.5	17.3	3.2	21.4
Average	**2.4**	**3.3**	**11.4**	**2.3**	**6.7**

Source: PBL (based on NMI-EMEP calculations)

Figure 5
Average annual nitrogen dioxide concentrations, 2030

Baseline

Contribution of NO_x from shipping to NO_2



Concentration (µg/m³): ≤ 2; 2 – 4; 4 – 6; 6 – 8; > 8

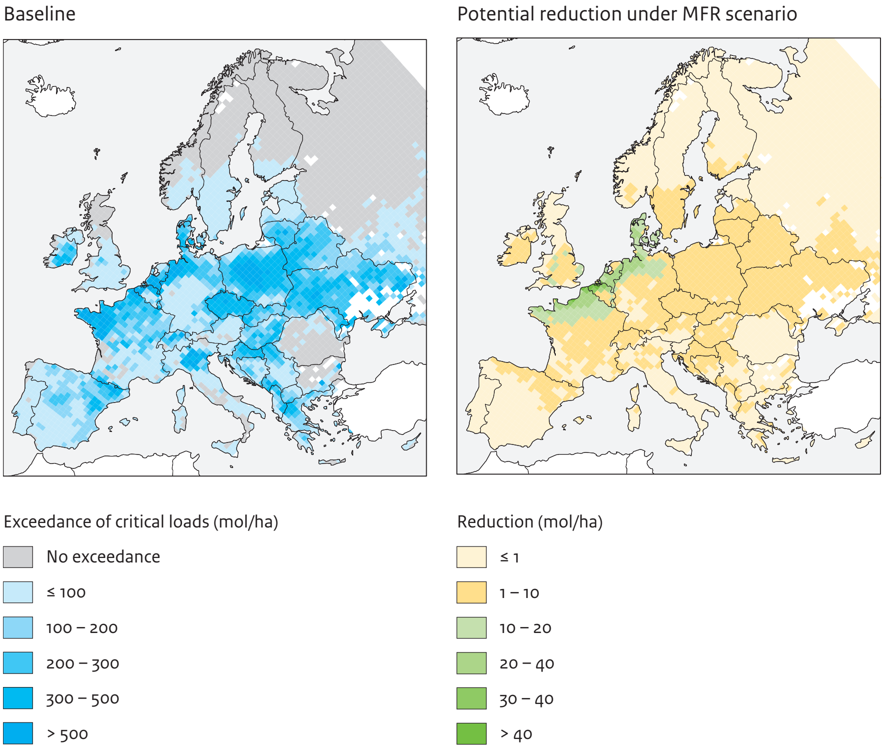
Contribution (%): ≤ 10; 10 – 15; 15 – 20; 20 – 25; > 25

Source: PBL (based on NMI-EMEP calculations)

marine ecosystem, including shifts in the composition of flora and fauna, which affects habitats and biodiversity, as well as oxygen depletion, which causes the death of fish and other species. Within the framework of the OSPAR Commission and the European Union, the North Sea countries aim to solve these eutrophication problems before 2020. These countries are therefore developing policies or support measures to reduce both riverine and atmospheric inputs of nitrogen to North Sea waters.

In 2009, rivers and direct tributaries discharged 814 thousand tonnes of nitrogen into the North Sea and atmospheric deposition contributed about 350 thousand tonnes in the same year. The total atmospheric

Figure 6
Average annual accumulated excess deposition of nitrogen loads, 2030



Source: PBL (based on NMI-EMEP and RIVM-CCE calculations)

deposition in 2030 is estimated to decrease to about 286 thousand tonnes. North Sea shipping will contribute 6% (16 thousand tonnes) to this deposition. This contribution can be reduced by an emission control area in 2030 by about one third. The contribution of an emission control area is much more limited in the period up to 2020 due to the slow replacement of current ships with new and cleaner ships.

Costs and benefits

Health benefits are largely determined by reduced particulate matter impacts

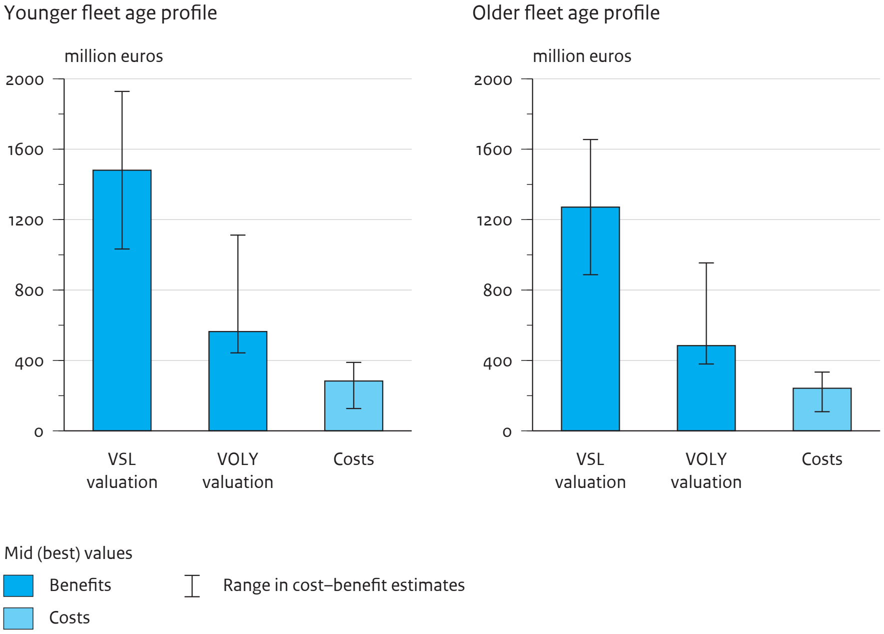
The total health benefits of a nitrogen emission control area were estimated at 484 million euros (2012 euros) with a range of 380 million to 954 million euros (see Section 4.1). These benefits may also be expressed in kilograms of reduced nitrogen oxide and amount to 3.9 euros per kilogram of reduced nitrogen oxide, with an uncertainty range of about 0.2 euros per kilogram (± 6%). Nearly 98% of the health benefits were related to mortality (69%) and morbidity (29%) caused by exposure to particulate matter, and 2% were related to ozone. Of the total benefits, 85% are seen in the North Sea coastal countries and 15% in other European countries.

The monetisation of health impacts from a nitrogen emission control area covers the:

- costs of pain, suffering, aversion to the risk of ill health or premature death;
- costs of medication and medical care;
- costs of lost productivity.

The main form of health damage in air pollution assessments, when impacts are converted to their monetary equivalent, concerns effects on mortality. This parameter was valued as the loss of life expectancy that results, using the value of a life year (VOLY). To reflect the importance of this element of the analysis, we performed a sensitivity analysis exploring the consequences of different positions for mortality valuation. We applied the European average value of 67,146 euros for the value of a life year (mortality), with a range of 47,120 to 156,674 euros. A sensitivity analysis based on a different valuation approach (Value of a Statistical Life – VSL) is reported briefly in Section 4.1 and summarised in the benefit to cost comparison and figures.

Figure 7
Costs and benefits of a nitrogen emission control area in the North Sea, 2030



Source: PBL (costs taken from Danish EPA 2012)

Ecosystem benefits not monetised

The monetary benefits of reduced terrestrial and marine ecosystem impacts and reduced impacts on crops due to a nitrogen emission control area were not, or only tentatively, estimated since sound methods and necessary data were lacking. However, it is clear from several studies that crops are affected and that people in the North Sea coastal countries are willing to pay for improved ecosystems. Nature areas on land are being restored and measures are being taken to reduce marine pollution and clean the seas. The lack of a proper quantification leads to a bias towards underestimation of the total benefits.

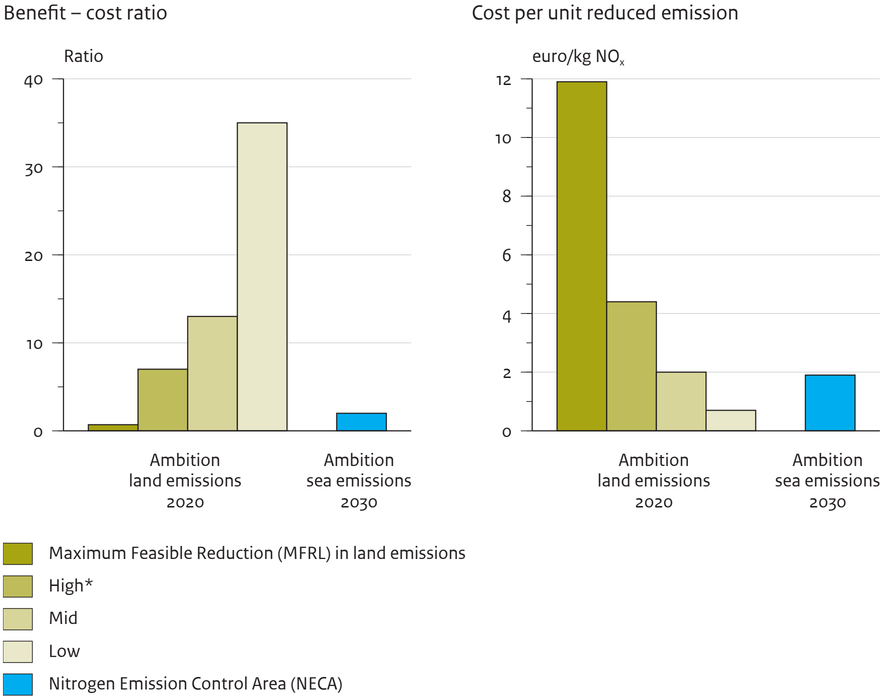
The costs of a nitrogen emission control area

The total costs of a nitrogen emission control area were estimated at 282 million euros for 2030, with a range from 127 million to 389 million euros, based on a low and high cost estimate (Danish EPA, 2012). The cost-effectiveness was estimated at 1.9 euros per kilogram of reduced nitrogen oxide, with a range of 0.8 to 2.6 euros per kilogram, based on a low and high cost estimate.

The above costs of a nitrogen emission control area in 2030 were calculated by the Danish EPA based on a future fleet age profile that was derived from specific ship age data for the North Sea in 2010. In this assessment study, we derived the future fleet age profile for container ships and other ship types by 2030 from current global ship data. This resulted in a somewhat older fleet age for this assessment, and therefore a somewhat smaller proportion of ships that must meet the nitrogen emission control area requirements by 2030 (see Section 2.2). A smaller share of Tier III compliant ships in 2030 would lead to a smaller reduction in nitrogen oxide emissions (about 16%), to lower nitrogen oxide abatement costs (about 16%), but also to a almost linear decrease in health benefits (also about 16%) (see Sections 4.4 and 5.1).

We therefore found that the benefit to cost ratio and the cost-effectiveness of a nitrogen emission control area do not change significantly under these different fleet age profile assumptions. Only the absolute costs and benefits would change under different fleet age profile assumptions for 2030 by about 16%. To compare the benefits and costs in this assessment we adjusted the above cost estimates of the Danish EPA downwards to account for the effect of the older fleet age profile used in this study. Vice versa, the benefits found in this study were adjusted upwards to account for the effect of the younger fleet age profile used in the Danish EPA study (see Section 4.1).

Figure 8
Comparison between air quality policy ambitions in the eight North Sea countries and for the North Sea



Source: PBL (ambitions on land derived from CIAM 2011a and Holland et al., 2011)

The benefits of a nitrogen emission control area exceed the costs

The monetised health benefits were compared with the costs of a nitrogen emission control area, while accounting for the applied ranges in the valuation of health impacts and the upper and lower range in cost estimates (see Section 4.5). Moreover, the impact of a relatively older or younger fleet on the benefits and costs is shown for 2030.

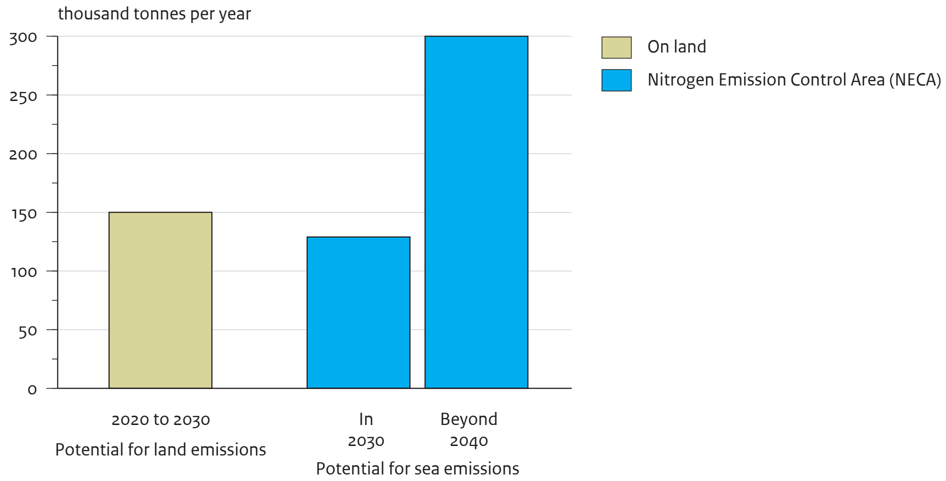
The benefits and costs show that the introduction of a nitrogen emission control area in the North Sea from 2016 onwards would be cost-effective as it would lead to net benefits by 2030 for Europe (Figure 7). These benefits would exceed the costs by a factor of two, based on an estimate towards the lower end of the range adopted here for mortality valuation (middle VOLY value) and a middle value for costs. The cost-benefit test is also passed in the least favourable situation (a factor of 1.1), with a low value attributed to health impacts and a high cost estimate. Much higher benefit-to-cost ratios were found in the most favourable situation, with a high value (VSL value) attributed to health impacts and a low cost estimate. The benefit-to-cost ratios do not change for a relatively older or younger fleet in 2030, only the absolute benefits and costs differ by about 16%. The above benefit estimates exclude benefits for ecosystems and crops.

Sea-based versus land-based air quality measures

Nitrogen oxide emission control at sea more cost-effective in the longer term

The costs and benefits and the cost-effectiveness of the nitrogen emission control area by 2030 could only be compared with those of recent European air policy scenarios with land-based emissions control measures for 2020 (see Section 4.6). These policy scenarios for land target not only nitrogen oxide reductions but also ammonia, particulate matter, sulphur dioxide and non-methane volatile organic compounds. The different target years and different pollutant control measures compel us to some caution with regard to drawing conclusions from the comparison. The European air policy scenarios on land emissions were recently explored in the context of the revision of the Gothenburg Protocol (GP) under the UNECE Convention on Long-Range

Figure 9
Potential nitrogen oxide reductions on land and at sea, applying an equal cost-effectiveness (1.9 euro/kg)



Source: PBL (Potential on land taken from IIASA 2011)

Transboundary Air Pollution (CLRTAP). The ambition levels of the land-based policy scenarios, aiming to improve health and ecosystem impacts by 2020, were positioned between the baseline, assuming current air policies, and the maximum feasible technical reduction (MFRL) from land-based sources. The ambition levels were indicated as low, medium and high.

The comparison of costs and health benefits between a nitrogen emission control area and additional land-based emission control measures indicates that there is still a substantial potential for land-based emission control measures that yield higher health benefits on land at lower costs (Figure 8, left). In particular, such land-based emission control measures include ammonia measures in agriculture, a limited number of relatively cheap nitrogen oxide measures in industry and some particulate matter measures in industry and agriculture. The low and medium ambitions for land-based emission control measures reduce the total years of life lost in the North Sea coastal countries in the short term (2020) by approximately 5 and 11 per cent respectively. As shown above, a nitrogen emission control area would reduce the total years of life lost due to air pollution in the North Sea coastal countries by almost one per cent by 2030, and even further in subsequent years.

A comparison of cost-effectiveness indicated that, if air policy aims to simultaneously abate eutrophication, acidification, ozone and health impacts, nitrogen control at sea is about as cost-effective[1] as nitrogen control in a medium air quality ambition for stationary land-based sources (Figure 8, right). This implies that a nitrogen emission control area fits a medium ambition for air quality improvement in Europe in addition to current legislation, or any higher ambition. A low ambition for air quality improvement would probably not include a nitrogen emission control area if cost-effectiveness was the only criteria.

Another comparison shows that a nitrogen emission control area in the North Sea provides a larger potential for relatively cheap[1] nitrogen oxide reduction in the longer term (2035–2045) if more and more old ships are gradually replaced with new ships with strict nitrogen control measures (Figure 9). The sooner a nitrogen emission control area is designated in the North Sea, the larger the reduction would be in subsequent years. The potential for relatively cheap[1] nitrogen oxide reductions by land-based control measures in the North Sea coastal countries is estimated to be more limited in the longer term.

A last comparison of the costs per unit nitrogen oxide reduction between specific land and sea-based control technologies shows that a number of mandatory technologies at existing and new land-based sources (in power production and traffic) are already more expensive than the technologies needed on ships in a nitrogen emission control area (see Section 4.6). Examples of the more expensive technologies are selective catalytic reduction at power plants fuelled by gas, biomass or heavy fuel oil, or nitrogen oxide abatement in Euro-6 diesel passenger cars.

Such more expensive land-based control measures could be defended for those emission sources that are closer to densely populated areas and ecosystems than shipping lanes. However, one could question the logic of more expensive land-based emission control measures for large-scale point sources that have high stacks and are located close to the shore and to shipping lanes. The above indicates that the air policies in the EU are not always designed in the most cost-optimal way. This is because other elements also play a role in policy development, such as a level playing field for land-based sources, the availability of technologies for sources on land and at sea, political support or the legal mandate of the various governments or intergovernmental organisations involved.

Uncertainties

Uncertainties in emission inventories and projections do not change the outcome of the cost-benefit analysis

This study examined the extent to which a number of identified uncertainties could change the outcome of the cost-benefit analysis (Chapter 5). Some of the identified uncertainties are described comprehensively in Chapter 2 and comprise uncertainties of 2009 emission inventories, auxiliary engine power estimates and related fuel use, younger or older fleet age profiles, higher or lower growth rates and efficiency improvements, and larger or smaller shares of LNG fuel use in 2030. All of these uncertainties can increase or decrease the nitrogen oxide reductions resulting from a nitrogen emission control area in the North Sea, while recognising that such a change would also result in an increase or decrease in abatement costs.

The important question now is whether a lower (or higher) projected nitrogen oxide reduction due to a nitrogen emission control area results in a linear decrease (or increase) in the monetised health benefits. Based on various baselines and nitrogen oxide reductions due to a nitrogen emission control area, we computed the resulting impacts on the health benefits. These results show that the relation between nitrogen oxide reductions at sea and health benefits on land is close to linear for a large number of these uncertainties (see Section 5.1). If nitrogen oxide reductions were to increase, benefits would increase, and vice versa. The maximum difference found in the relation was about 12%.

Under the fair assumption that a change in emission reductions at sea is linearly related to a change in costs, we find that the relation between the cost of nitrogen oxide abatement in the North Sea and the associated health benefits is close to linear. This means that the benefit to cost ratio of a nitrogen emission control area does not change significantly due to the above uncertainties. Only absolute costs and absolute benefits would increase at the same rate, for instance, as a result of a larger amount of installed auxiliary engine power or a larger share of cleaner ships in 2030.

Health benefits sensitive to assumptions on harmfulness of particulate matter and ozone

The above estimated health benefits are sensitive to the assumption that all particles, irrespective of source and chemical composition, are equally harmful (see Section 5.4). This assumption is currently advised by the World Health Organisation and accepted by the European Commission, and is central in European policy assessments. However, there are indications that some carbonaceous particles are more harmful than nitrate particles from nitrogen oxide emissions (from shipping and other sources). This could reduce the cost-effectiveness of nitrogen oxide measures compared with other measures. On the other hand, there are also indications that long-term exposure to low ozone concentrations is more harmful to human health than previously thought. In this situation, nitrogen oxide, as an ozone precursor, might become more important.

Health benefits in this study less sensitive to model resolution

The above estimated health benefits due to a nitrogen emission control area were found to be rather insensitive to the resolution of the air quality modelling (see Sections 3.1 and 5.2). A nitrogen emission control area contributes to less particulate matter through reduced secondary particulate matter. In contrast to primary particles, which are directly emitted by sources, secondary particles are formed by the chemical transformation of certain pollutants in the atmosphere. For instance, a part of the nitrogen oxide emissions from ships will be transformed into particulate nitrate (NO_3^-). Reductions in particulate nitrate explain how a nitrogen emission control area contributes to less particulate matter. Particulate nitrate has a relatively long lifetime in the atmosphere, which causes a relatively flat spatial distribution. This implies that a higher model resolution does not bring much more detail into the assessment of the impacts of a nitrogen emission control area on secondary particulate matter concentrations. This also means that the health impacts and benefits due to reduced human exposure to secondary particulate matter are relatively insensitive to a lower or higher model grid resolution.

On the contrary, the modelled nitrogen dioxide concentrations and nitrogen deposition were found to be rather sensitive to the model resolution. This means that a higher model resolution would provide a better picture in coastal areas and beyond of the reduced impacts due to a nitrogen emission control area.

Note

1 1.9 euros per kilogram of reduced nitrogen oxide.

FULL RESULTS

ONE

Introduction

1.1 Policy context

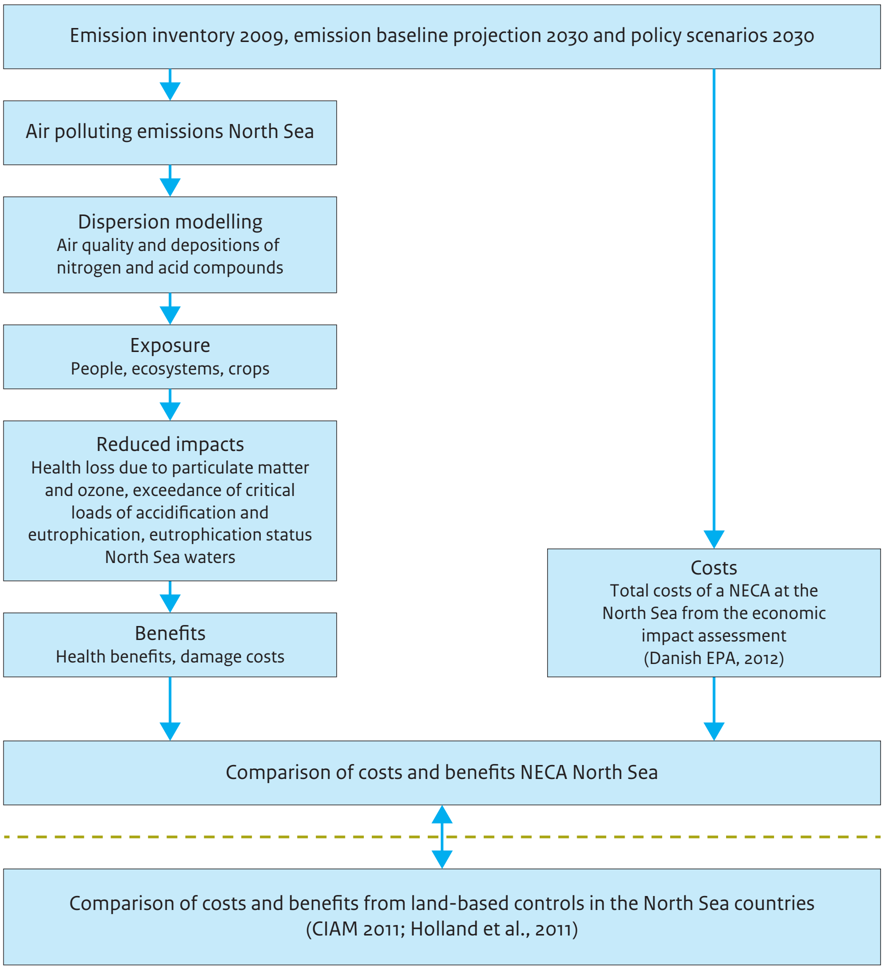
In the last five years, concerns about health and ecosystem effects due to air polluting emissions[1] from ships have magnified international policy debate regarding further emission control. The debate is taking place within a context where emission and fuel standards for international shipping lag behind those of land-based transport modes. As an outcome of the debate, the International Maritime Organisation (IMO) adopted more stringent requirements to further control air pollution from sea shipping in 2008 (IMO, 2008). The requirements apply to the sulphur content of fuels and maximum allowable emissions of nitrogen oxides. Particulate matter emissions are mostly co-reduced through the use of cleaner fuels containing less sulphur. The most stringent requirements for sulphur dioxide and nitrogen oxide are only mandatory in emission control areas (ECA). An ECA is an area where special mandatory measures apply that aim to reduce the exposure of sensitive ecosystems or urban areas to air pollution from international shipping.

Within Europe, the Baltic Sea and the North Sea (including the English Channel) were designated as sulphur oxide emission control areas (SECA) in 2006 and 2007, respectively. Since 2010, the coastal countries of the Baltic Sea have been involved in a decision-making process over an application to the IMO to designate the Baltic Sea as a nitrogen emission control area (NECA) (HELCOM, 2010a). The Baltic countries have invited the North Sea countries to consider establishing a NECA in the North Sea, as well. This would reduce air pollution in the Baltic Sea region and enhance the level playing field for ship owners and operators in European waters.

In March 2011, the coastal countries of the North Sea commissioned an environmental impact assessment (this report) and an economic impact assessment (Danish EPA, 2012). These studies are aimed to support a possible decision-making process in the North Sea countries concerning an application to the IMO to designate the North Sea (including the English Channel) as a nitrogen emission control area. The coastal countries of the North Sea are France, Belgium, the Netherlands, Germany, Denmark, Sweden, Norway and the United Kingdom.

The information from the above assessments is also valuable for the Oslo–Paris Commission for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) and the European Union. In September 2010, the OSPAR Commission called for an assessment of the contribution of a nitrogen emission control area to the eutrophication status of the North Sea (OSPAR, 2010). One of the objectives of the OSPAR Commission is to achieve and/or maintain the status of ‘non-problem area’ with regard to eutrophication, for all parts of the OSPAR maritime area, by 2020. The European Union’s Marine Directive has a similar goal, stating that human-induced eutrophication should be minimised before 2020, particularly regarding the adverse effects this has on the marine environment.

Figure 1.1
Overview of the applied method in this assessment



Source: PBL

Another relevant policy development in the context of this assessment is the recent adoption by the IMO of a package of mandatory technical and operational measures to reduce greenhouse gas (GHG) emissions from international shipping (IMO, 2011). These measures aim to improve the energy efficiency of marine transport, thus reducing fuel consumption which, in turn, yields the co-benefits of reducing emissions of local and regional air pollutants. Such measures also lead to cost reductions for ships in emission control areas.

The above developments have the interest of and are supported by the European Commission (EC), which has a limited jurisdiction to impose emission control measures on ships in the territorial waters of the Member States, ports and open seas. Emission control measures for land-based sources in Europe are regulated in a number of European Union (EU) directives and United Nations Economic Commission for Europe (UNECE) protocols. A relevant policy development in this context is the current revision of the national air pollutant emissions ceilings under the UNECE Gothenburg Protocol (GP) and the announced revision of the EU National Emission Ceilings Directive (NECD) in 2013. The revision of the GP aims to set national emission reduction obligations for air pollutants by 2020 relative to 2005. It is not clear yet whether the revision of the NECD in 2013 will aim to set such reduction obligations for the year 2020 or later (2025 or 2030). Results from the cost–benefit analysis of land-based emission control measures carried out for the GP revision are used here to indicate how the costs and benefits of a nitrogen emission control area in the North

Sea compare (CIAM, 2011a; Holland et al., 2011). The results of this study might therefore be useful as background material within the comprehensive review of European air policy by the EC that started in 2011 and should be finalised by 2013.

Finally, there has been a recent development outside Europe that is relevant to the above policy process of the eight North Sea countries. On 1 August 2011, an emission control area for sulphur dioxide and nitrogen oxide entered into force around the United States and Canada. The North American ECA will become active on 1 August 2012. Moreover, the United States has also submitted a proposal to the IMO to designate an area off the coasts of Puerto Rico and the US Virgin Islands as an ECA for nitrogen oxides and sulphur dioxide.

1.2 Objectives

The following objectives of this assessment of environmental impacts and health benefits were based on the IMO criteria for designation of an emission control area (Annex 1):

- estimate the contribution of North Sea shipping to air pollution in the coastal countries and beyond, and to nitrogen deposition to the North Sea waters;
- assess the environmental impacts and health benefits of introducing a nitrogen oxide emission control area in the North Sea;
- compare the benefits of a nitrogen oxide emission control area in the North Sea with the costs, as presented by the economic impact assessment (Danish EPA, 2012);
- compare the cost-effectiveness of a nitrogen oxide emission control area with land-based emission control measures.

1.3 Method

The integrated assessment method applied in this study is as much as possible aligned with the method used in recent integrated assessment studies that support the EU air policy developments (CIAM, 2011a, b; Holland et al., 2008, 2011) (Figure 1.1). The starting point here was an existing emission inventory for shipping activities on the open sea in 2009, complemented with data on port emissions. Based on this inventory, an emission baseline for 2030 and a number of nitrogen emission control scenarios for the North Sea were developed. Emission data on 2009 and projections for 2030 for land-based sources were taken from other recent integrated assessment studies (CIAM, 2011a; IIASA, 2011). Dispersion modelling of air polluting emissions subsequently was carried out to calculate changes in air quality and pollutant depositions. The modelling results were combined with maps for populations and ecosystems and dose–response relationships to derive impacts on health and ecosystem indicators. The impacts from air pollution on years of life lost, morbidity and damage to crops were monetised. Last but not least, the costs and benefits of the nitrogen emission control area were compared with the costs and benefits of air policy packages for land-based sources.

1.4 Reader

Chapter 2 discusses the emission inventory used in this study and describes how we derived the emission baselines for North Sea shipping and the policy scenarios for a nitrogen emission control area. It also presents the comparison between air polluting emissions at sea and on land. Chapter 3 presents the results from air quality modelling and impacts on health and marine and terrestrial ecosystems. Chapter 4 details the monetised health benefits of a nitrogen emission control area and presents information on benefits to crops and ecosystems. A summary is given of the cost estimates for a nitrogen emission control area from the economic impact assessment by the Danish EPA (2012). Subsequently, the cost-benefit analysis is presented. The costs and benefits at sea are compared with those of land-based air policy packages. Finally, Chapter 5 presents a discussion and summary of the uncertainties.

Note

1 Sulphur dioxide, particulate matter, nitrogen oxides and volatile organic compounds.

Emission inventory, baseline and scenarios

This chapter explains the emission inventory developed and validated for carbon dioxide and air polluting emissions. It describes the main assumptions that were used to derive the emission baselines for North Sea shipping considering current air policies only and the policy scenarios for a nitrogen emission control area. The baseline for land-based air polluting emissions is also discussed and compared with emissions at sea.

2.1 Emissions from North Sea shipping in 2009

The emission inventory for 2009 is based on the activities of international shipping in the North Sea (including the English Channel) and in ports. The inventory is provided by the Maritime Research Institute Netherlands (MARIN) and the emission factors by TNO (MARIN, 2011a, b), see Figure 2.1. These data include the number of kilometres travelled, sailing speeds and shipping routes, determined for 12 different ship types and 8 different ship size classes. The main data sources for these activities are monitoring data from the Automatic Identification System (AIS) for 2008 and 2009, traffic data from the Lloyds Marine Intelligence Unit (LMIU) for 2008 and ship characteristics from the Lloyds List Group (LLG) database of October 2010.

The AIS system is the preferred source for this type of study since it provides detailed information on shipping activities, such as ship name, IMO number, ship type, ship size, real-time position and course, speed and destination. However, MARIN only has access to AIS data on the Dutch part of the North Sea. The necessary activity data for the rest of the North Sea was therefore generated from LMIU data and the MARIN SAMSON ship traffic model (MARIN, 2011a). This model generates spatial activity data for the various ship types and sizes using LMIU data as input. LMIU data provide spatial and temporal information on port arrivals and departures. The incomplete LMIU data on ferries that cross North Sea waters more than once a day were supplemented with ferry data from the EU Marnis project (Marnis, 2008). A correction for ship type and size class was made for the change in activity between the year for which the LMIU data were available and the year of study. As well as ship activities, emission factors are also needed to calculate emissions of carbon dioxide and air pollutants from ships on the North Sea and in ports.

Emission factors for carbon dioxide and air pollutants have been determined by the Netherlands Organisation for Applied Scientific Research (TNO) for main and auxiliary engines (Annex 1 in MARIN, 2011a). The main engine propels a ship, whereas auxiliary engines provide the electrical power or heat to the ship's systems. Emission factors depend on variables, such as engine power, engine load, year of construction of the engine, engine type, engine speed and the type of fuel used. Emission factors for each air pollutant are determined for the main and auxiliary engines of ships in the ship

Figure 2.1
Nitrogen oxide emissions projected for the North Sea, 2030

Nitrogen oxide emissions (tonnes per grid cell of 5x5 km^2)

- ≤ 0.05
- 0.05 – 0.1
- 0.1 – 0.25
- 0.25 – 0.5
- 0.5 – 1
- 1 – 2.5
- 2.5 – 5
- 5 – 10
- 10 – 25
- 25 – 100
- > 100

North Sea boundaries

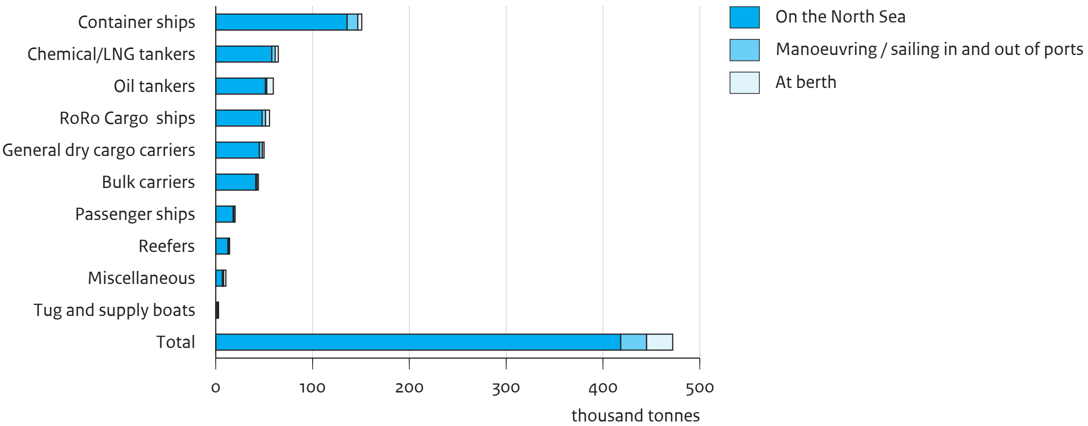
Source: PBL (based on MARIN 2011b)

characteristics LLG database. The scarce data on auxiliary engines in the database are supplemented with additional estimates based on empirical relationships between auxiliary and main engine power for the various ship types and sizes (Buhaug et al., 2009).

In addition to ship emissions on the open sea, emissions in ports from manoeuvring and while at berth have been estimated by MARIN using the aforementioned data sources and information or assumptions on the time at berth (MARIN, 2011b). When berthed, a ship's main engine is stopped although the auxiliary engines are generally kept in service. The use of shore-side electricity instead of auxiliary engines was limited in 2009 to a small number of North Sea ports.

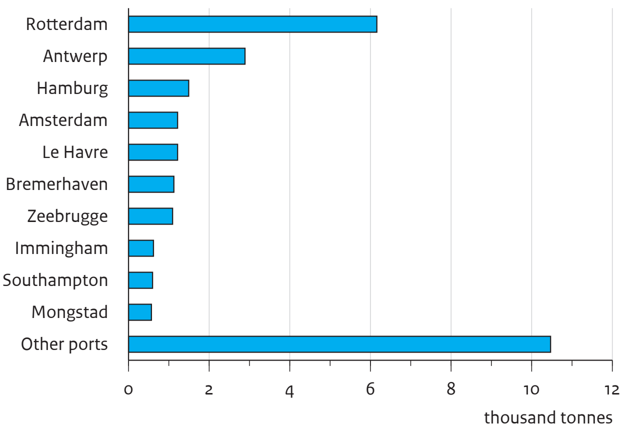
The complete emission inventory for 2009 for the North Sea and its ports includes emissions of carbon dioxide and air pollutants and their spatial distribution for 12 ship types and 8 size classes. The spatial resolution of the inventory at sea is 5x5 km^2 and within ports 0.5 x 0.5 km^2. The most concentrated shipping lanes with the highest nitrogen oxide emissions are located in the English Channel and in front of the coasts of Belgium and the Netherlands (Figure 2.1). Total nitrogen oxide emissions are estimated at 472 thousand tonnes in 2009 (Figure 2.2). It is estimated that 32% of the total ship emissions are released within 12 nautical miles of the shore, 89% within 50 nautical miles and 97% within 100 nautical miles. Almost 90% of the nitrogen oxide emissions take place at open sea and 10% in ports. Container ships are

Figure 2.2
Nitrogen oxide emissions over the North Sea, per type of vessel, 2009



Source: PBL (based on MARIN 2011b)

Figure 2.3
Nitrogen oxide emissions from vessels at berth in North Sea ports, 2009



Source: PBL (based on MARIN 2011b)

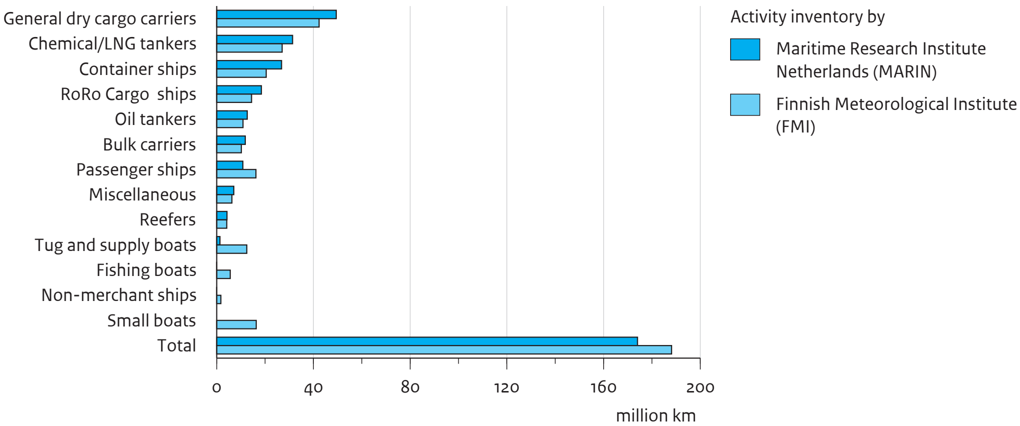
the largest single ship type contributor (30%) to the nitrogen oxide emissions in the North Sea and in ports. Rotterdam is the port with the highest nitrogen oxide emissions by ships at berth in 2009 (Figure 2.3). The total emissions of other air pollutants are given in Annex 3.

Validation of the MARIN emission inventory with other sources

The activity and emission inventory from MARIN has been validated in a number of comparisons with other data sources and studies. These comparisons support the usability of the MARIN inventory in this study but also highlight the need for an uncertainty analysis with regard to emissions from auxiliary engines.

In MARIN (2010), results from the SAMSON model for 2008 were compared with AIS monitoring data for the Dutch part of the North Sea. This comparison showed good agreement for emissions with differences of only a few per cent. However, the SAMSON model

Figure 2.4
Distances travelled on the North Sea, per type of vessel, 2009



Source: PBL (derived from MARIN 2011b and FMI 2011)

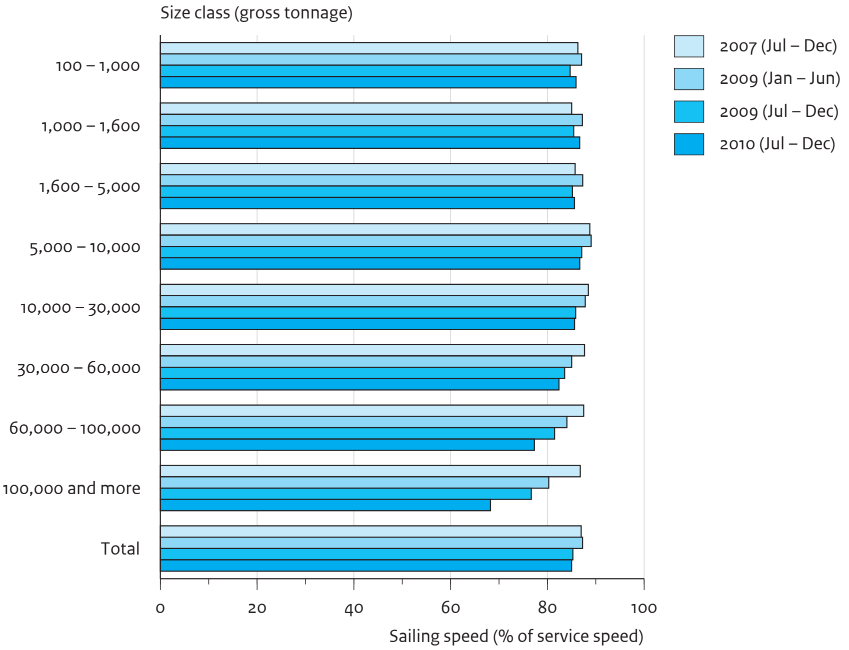
underestimated the number of smaller ships (pilot tenders, tugs, service vessels, dredgers) by more than 5%. The reason for this is the absence of these non-route bound ships in the LMIU data that is used as input for the SAMSON model. The effect on total emissions was found to be negligible.

The MARIN inventory for 2009 has also been validated. This inventory is based on their 2008 inventory and adjusted for changes in traffic volume and behaviour between 2008 and 2009. These changes were extracted from AIS monitoring data for the Dutch part of the North Sea. This assumes that the monitored traffic changes in the Dutch part of the North Sea are representative for the whole of the North Sea. This assumption could be validated using another recent inventory by the Finnish Meteorological Institute (FMI) that had AIS data for 2009 covering most of the North Sea (FMI, 2011). For instance, the total travelled distances in the North Sea compare reasonably well for the main ship types aggregated over all the size classes (Figure 2.4). The comparison confirmed the above finding that the SAMSON model underestimates the number of smaller ships. The ship activities from the FMI inventory are used as a base for the cost calculations in the economic impact assessment (Danish EPA, 2012) for the nitrogen oxide emission control area. The FMI inventory was created using the FMI Steam model (Jalkanen et al., 2009, 2011).

Although the estimated travelled kilometres were similar, there was a substantial difference in the estimates of total nitrogen oxide emissions from the North Sea over 2009. The FMI estimate (652 thousand tonnes) was 38% higher than the MARIN estimate (472 thousand tonnes). The main explanation was found in the different methodologies that were applied to supplement the scarce data on auxiliary engine power in the ship characteristics database. MARIN applied the aforementioned methodology of Buhaug et al. (2009), whereas FMI applied a detailed estimate of auxiliary engine power profiles per ship type and per operation mode as described in Jalkanen et al. (2009, 2011). The FMI methodology results in a fuel use for auxiliary engines in North Sea shipping that is roughly two times more than the fuel use estimated using the MARIN methodology. Since all experts at MARIN, TNO and FMI recognise that inventories on auxiliary engines are rather uncertain, the impact of this uncertainty on the final outcome of this study is analysed in Chapter 5.

In MARIN (2011b), a further comparison is made with other inventories and in more detail with the widely applied IIASA emission inventory for international shipping in EU seas (Cofala et al., 2007; Wagner et al., 2010). The IIASA inventory is an adjusted version based on earlier work by Entec (2002, 2005). The IIASA–Entec inventories have been used for several years now; for example, in major European air policy studies for the EC. Their most recent estimate for nitrogen oxide emissions in 2010 is 785 thousand tonnes, while MARIN estimates 472 thousand tonnes for 2009. Three causes have been identified that largely explain this difference.

Figure 2.5
Monitored sailing speeds of vessels on the North Sea



Source: PBL (based on MARIN 2011b)

The main cause is explained by the IIASA–Entec assumption that ships sail at their designed service speed[1], which does not agree with the AIS monitoring data for the period 2007–2010 (Figure 2.5). In the pre-crisis year 2007, ships sailed at speeds of about 87% of their service or design speed. A lower sailing speed leads to lower fuel use and nitrogen oxide emissions. In the first years (2009 and 2010) of the current economic crisis, larger ships in particular (e.g. container ships) reduced speed to save fuel. The abundant transport capacity in the marine market could also explain part of the reduction in sailing speeds in 2010.
Other causes that explain the higher IIASA–Entec emissions are the use of an average speed for all size classes within a ship type category and too high assumptions for the growth rate of shipping (fuel use) between 2000 and 2010. The comparison showed that emission factors do not differ significantly between the inventories. Overall, this comparison supports the credibility of the MARIN inventory.

2.2 Emission baseline for North Sea shipping in 2030

An emission baseline for ship emissions in the North Sea was developed for the year 2030. The year 2030 was chosen as this is a compromise between the following arguments:

- The impact of a nitrogen emission control area on nitrogen oxide reductions increases gradually as only new ships (built after 2015) need to comply with mandatory nitrogen oxide standards. Moreover, sea ships are replaced slowly due to an average lifetime of 25 to 30 years. The full effect of the control area is therefore reached beyond 2040, which pleads for a scenario year in the far future.
- To make reasonable estimates of the environmental impacts of a nitrogen emission control area in the North Sea, we also need projections for land-based emissions sources. Currently, the best available long-term scenarios for air emissions are made for 2030. Since these scenarios are also used as a base for European air policy studies, the application of these scenarios in this study enhances comparability between land and sea-based emission reduction measures.

Table 2.1
Average annual growth rates of shipping in the North Sea (2009–2030, tonne kilometres)

	Central case	Lower bound	Upper bound
Container shipping	3.5%	2.0%	5.0%
Other	1.5%	0.5%	2.5%
All ships total	**2.1%**	**1.0%**	**3.3%**

Source: PBL

The emission baseline for North Sea shipping was developed using a four-step approach, taking into account: 1) the future growth in trading volumes in the North Sea, 2) improvements in the energy efficiency of transport, 3) the effects of current IMO emission legislation and 4) the effects of an increased use of Liquefied Natural Gas (LNG) and shore-side electricity on energy use and emissions. The model, assumptions and relevant IMO legislation are described hereafter. More background information on the projections is provided in Annex 2.

Growth rates for trade volumes in the North Sea

Assumptions on the future growth of sea-borne trade in the North Sea were based on recent post-crisis studies of sea transport and other economic activities in the EU (Schade et al., 2010; Capros et al., 2010). These post-crisis studies expect economic growth and growth in sea-borne trade to catch up in the short-term (2011–2015) with pre-crisis levels (around 2% of GDP), reflecting the economic recovery after the 2008–2009 crisis. For subsequent years (> 2015/2020), the growth rates are expected to decline due to the dampening effects of high public debt, the ageing of the EU population and the resulting reduction in the labour force. These arguments support the use of lower growth rates for shipping compared with a number of pre-crisis scenario studies that apply annual growth rates of up to 5% (Buhaug et al., 2009; Cofala et al., 2007; Chiffi et al., 2008).

Based on the above studies and argumentation we assumed an average annual growth in overall North Sea shipping (in tonne kilometres) of about 2% for the central case (Table 2.1). To reflect the uncertainty in the future growth of shipping and the broad range in growth rates found in the literature, we used a bandwidth of 1% to 3%. The lower bound is based on the EU integrated transport and energy baseline until 2030 (i-TREN-2030) from Schade et al. (2010), while the upper bound is based on the second IMO greenhouse gas study (Buhaug et al., 2009). Different growth rates are used for container ships and for other ships, based on Buhaug et al, (2009).

Efficiency improvements of North Sea shipping

The assumptions on future improvements in transport energy efficiency of North Sea shipping in the current study (Table 2.2) are mainly derived from the second IMO greenhouse gas study (Buhaug et al., 2009). This study gives an overview of potential technological and operational measures for reducing fuel consumption and related emissions from maritime shipping. The projected development in the transport efficiency of international shipping is subdivided into three elements:

- Efficiency of scale: this relates to the size of the ships, with larger ships generally being more efficient per tonne kilometre than smaller ships. Due to the deployment of larger ships, transport efficiency is expected to improve by about 4% by 2030, compared to 2009, with a bandwidth of 0% to 14%.
- Speed: speed has a major influence on the fuel efficiency of ships. Sailing speeds are currently being reduced due to the economic crisis and the abundant transport capacity in the maritime market (see, for example, Figure 2.5). This might change to a pre-crisis situation again in future years if trade volumes grow and the oversupply in shipping capacity decreases. In the longer term, Buhaug et al. (2009) assume small speed reductions that reflect increasing bunker prices and energy and greenhouse gas policies to some extent. Based on their figures, we assumed a 7% reduction in fleet average operational speeds by 2030, compared with 2007 (pre-crisis) levels, with a bandwidth of 0% to 17%. This leads to a 10% decrease in energy consumption in the base case (bandwidth 0% to 22%). Annex 2 provides more details on these estimates.
- Improved ship design, technology and operation: improvements in ship design (e.g. optimised hull dimensions and form), technology (e.g. power and propulsion systems, renewable energy) and operations (e.g. fleet and ship management, voyage optimisation) can lead to substantial gains in fuel efficiency. In this study, we used cost-effective efficiency improvements of 10% up to 2030 (Buhaug et al., 2009) as the central estimate. This estimate, combined with the above assumptions for speed reductions (also 10%), corresponds reasonably well with the estimated impact of new IMO regulations on the energy efficiency of

Table 2.2
Assumed efficiency improvements between 2007 and 2030 in current study (fleet averages)

	Central case	Lower bound	Upper bound
Efficiencies of scale	-4%	0%	-14%
Speed	-10%	0%	-22%
Technological and operational improvements*	-10%	-2%	-14%
All ships total	**-22%**	**-2%**	**-42%**

**) Excluding changes in ship size and speed.*
Source: PBL (based on Buhaug et al., 2009)

Table 2.3
Air quality policies for international shipping in the baseline emission projection

Sulphur	• Worldwide reduction in maximum sulphur content in marine bunker fuels to 3.5% in 2012 and 0.5% in 2020. • Reduction in the sulphur content of marine fuels in all sulphur emission control areas (SECAs) down to 1.0% from July 2010 and down to 0.1% from 2015. • 0.1% sulphur fuel at berth in ports.
Nitrogen oxides	• Ships built between 2000 and 2010 need to meet Tier I emission standards that are up to 10% stricter than those for pre-2000 ships. • Post-2010 vessels need to meet Tier II standards that require a reduction of up to 15% compared with Tier I.

Source: PBL (based on IMO, 2011; EU, 2005)

ships (Bazari and Longva, 2011). Bazari and Longva (2011) estimate that improvements in ship design and technology (including design speed reductions) through the mandatory Energy Efficiency Design Index (EEDI) may reduce fuel use in 2030 by more than 10%. Operational measures (including operating speed reductions) initiated by the Ship Energy Efficiency Management Plan (SEEMP) may reduce fuel use further by just under 10% by 2030.

The combined assumptions for the efficiency improvements (central case: about 1% per year) and average annual growth in North Sea shipping (about 2% per year) lead to an overall growth in fuel use in the order of 1% per year between 2009 and 2030.

IMO and EU air quality and fuel quality legislation for international shipping

The 2009 emission inventory and the emission baseline for 2030 include current legislation on emission standards for sulphur and nitrogen oxides from the revised MARPOL Annex VI (IMO, 2008) and the EU (EU, 2005), see Table 2.3.

The impact of the IMO and EU emission legislation on the air polluting emissions of North Sea shipping was estimated using the Dutch Shipping Emission Inventory and Monitoring model (EMS) developed by TNO (Denier van der Gon and Hulskotte, 2010). No specific assumptions were made on the technologies used to meet the Tier II and Tier III nitrogen oxide emission standards.

In the economic impact assessment, the Danish EPA (2012) gives an overview of available nitrogen oxide abatement technologies to comply with Tier II and Tier III emission standards. They conclude that available information points to three technology routes to comply with Tier III: Selective Catalytic Reduction (SCR), Exhaust Gas Recirculation (EGR) or LNG. However, this study did not make specific assumptions on the technologies used to comply with Tier III. It is only assumed that the nitrogen oxide emissions of Tier III ships will be reduced by approximately 75% compared with Tier II emission levels, in line with the reduction required by the emission standards from Tier II to Tier III. Tier II nitrogen oxide emission levels are assumed to be 15% to 20% lower than Tier I emission levels, again in line with the reduction required by the IMO emission standards.

The future fleet is modelled using a stochastic approach with Weibull functions describing the share of different age classes in the fleet. These functions were estimated based on the Lloyd's world shipping characteristics database for 2008 and compare well with the more recent information on world ship age distributions given by UNCTAD (2011). Different functions are estimated, one for container ships and one for other ship types. Because of the higher growth rates for container shipping, it is assumed that the container fleet will expand faster in

Table 2.4
Assumptions on the market penetration of LNG as a fuel for North Sea shipping in 2030

	Central case	Lower bound	Upper bound
Short sea shipping[1]	25%	5%	50%
Oil, chemical and gas tankers[2]	10%	0%	20%

1) Short sea shipping was defined as all ship types with sizes below 10,000 GT.
2) Tankers over 10,000 GT.
Source: PBL (based on Buhaug et al., 2009)

future years and therefore the future container fleet will be relatively young compared with other ship types.

Comparisons between the future fleet as modelled by EMS and the fleet assumptions used in the economic impact assessment by the Danish EPA (2012) show that assumptions on the composition of the future container fleet are very similar, but assumptions on other ship types differ. The Danish EPA used specific ship age data for the North Sea in 2010 to derive their fleet age profile for 2030. The fleet as modelled by EMS (based on current global ship data) results in a somewhat older fleet with about 37% of other ships complying with Tier III standards in 2030, compared with about 50% in the model by the Danish EPA. A larger share of Tier III compliant ships in 2030 leads to a larger reduction in nitrogen oxide emissions (about 16%) and to higher nitrogen oxide abatement costs (about 16%), as well as an almost linear increase in environmental and health benefits (about 16%), see Sections 4.1, 4.4 and 5.1. Annex 2 provides more details on the differences between the fleet age profiles (distributions) between this assessment and the assessment by the Danish EPA (2012).

LNG fuel use and shore-side electricity in 2030

The share of ships that use LNG as a fuel instead of heavy fuel oil or marine gas oil is expected to increase. Ships that use LNG do not need any exhaust gas after-treatment in order to comply with future sulphur dioxide and nitrogen oxide emission control area regulations. LNG is thought to be most suitable for application in short sea shipping, where range is less of an issue, or for tankers that have enough space for the on-deck storage of LNG (EMSA, 2010). A literature review shows that any current assumption on the future market penetration of LNG in North Sea shipping is however very uncertain (Stuer-Lauridsen et al., 2010; Buhaug et al., 2009; MAGALOG, 2008; EMSA, 2010). We therefore used assumptions on the market penetration of LNG in short sea shipping and tankers derived from the IMO greenhouse gas study (Buhaug et al., 2009), as shown in Table 2.4. Short sea shipping (vessels below 10 000 GT) accounts for about 40% of fuel use in the North Sea in 2009 and about 30% of nitrogen oxide emissions.

These LNG assumptions are expected to result from the tightening of the maximum allowable sulphur content of marine fuels from 2015 onwards, due to the requirements of the sulphur emission control area. The costs of complying with these requirements are much higher than the costs of complying with nitrogen oxide emission control area requirements (Danish EPA, 2012). Therefore, the sulphur emission control area requirements, which are part of the baseline for 2030, are expected to be the main driver of the market penetration of LNG. No further market penetration is assumed as a result of the instalment of a nitrogen emission control area in the North Sea. Annex 2 provides more details on the way these assumptions were applied in the emission calculations.

Shore-side electricity is currently used in a limited number of North Sea ports, mainly by ferries and by some container ships that dock regularly in the same port. Ericsson and Fazlagic (2008) give an overview of existing installations in the ports of Sweden, Germany and Belgium. In Hoek van Holland, the Netherlands, the first connection for large sea-going ferries is expected to be completed in 2012. It is expected that the application of shore-side electricity will increase in the future to abate local air pollution and noise nuisance. To promote the application, Sweden and Germany recently obtained permission from the EU to apply reduced taxes to the electricity delivered to ships at berth. Despite these and other ongoing developments, it is not expected that a large share of ocean-going ships at berth will use shore-side electricity in 2030. It requires substantial investments in onshore infrastructure as well as onboard ships and is currently only applied in ports where the same ship docks regularly. Moreover, the lack of international standards for shore-side electricity systems onboard ships and at berth hampers the development. We assumed that, by 2030, 5% of the ships at berth will use shore-side electricity. In the uncertainty analysis we used a bandwidth of 1% to 10%.

Baseline emissions in 2030 for North Sea shipping

Based on the above-mentioned emission inventory for 2009 and assumptions, we calculated emissions for 2030 from North Sea shipping (Table 2.5). The carbon dioxide

Table 2.5
Air polluting emissions of international shipping in the North Sea and the ports

Thousand tonnes	CO_2	NO_x	SO_2	CO	NMVOC	NH_3	$PM_{2.5}$	PM_{10}
2009	20,671	472	177	82	14	0	25	26
2030 baseline	25,241	446	15	76	9	0	13	14
Trend 2009–2030	+22%	-6%	-92%	-7%	-36%	-	-47%	-47%

Source: PBL (2009 derived from MARIN 2011b)

emissions (and fuel use) increase from 2009 to 2030 by about 1% per year. The trend in nitrogen oxide emissions is the opposite, resulting from the current nitrogen oxide emission standards (up to Tier II) combined with the effects of the market penetration of LNG and the use of shore-side electricity in North Sea harbours. The assumed market penetration of LNG in the 2030 baseline leads to a nitrogen oxide emission reduction of approximately 41 thousand tonnes, whereas the application of shore-side electricity in North Sea harbours leads to an emission reduction of 1.4 thousand tonnes. Without LNG and shore-side electricity, nitrogen oxide emissions in the 2030 baseline would amount to 486 thousand tonnes, which is slightly higher than in 2009.

Sulphur dioxide emissions decrease strongly between 2009 and 2030 due to the stringent sulphur regulations for the North Sea that require ships to use low sulphur distillate fuels after 2015. These cleaner fuels also bring large reductions in particulate emissions (over 45%). Emissions of carbon oxide (CO) and non-methane volatile organic compounds (NMVOC) are also expected to decrease due to the expected improvements in engine environmental performance. We did not make any assumption on the use of biofuels in ships in 2030 and possible impacts on emissions.

Nitrogen oxide abatement technologies could result in small increases in carbon dioxide and ammonia emissions

Depending on the technologies applied, complying with Tier III nitrogen oxide standards can result in a small increase in fuel consumption and resulting carbon dioxide emissions. In the economic impact assessment study, the Danish EPA (2012) estimate the fuel impacts of applying either selective catalytic reduction or exhaust gas recirculation for two-stroke and four-stroke engines (Table 4.3 of their report). Based on these estimates and the assumptions on the technologies used on different ship types, the introduction of a nitrogen emission control area in the North Sea could lead to a small increase in carbon dioxide emissions of approximately 100,150 thousand tonnes (0.5%) by 2030, compared with the baseline.

Increases in ammonia emissions can occur if selective catalytic reduction with urea is used to reduce nitrogen oxide emissions from ships (or any other source). To prevent such ammonia slip, the injection of ammonia (urea) into the exhaust gas needs to be regulated as a function of the ship's engine load and speed (Fridell and Steen, 2007). Ammonia slip can also be prevented by applying an ammonia slip catalyst. It is currently unknown if and to what extent ammonia slip will be an issue when applying selective catalytic reduction on ships. However, to prevent excessive ammonia emissions from selective catalytic reduction use on heavy duty trucks, the European Euro VI emission standards also include an ammonia emission standard of 10 ppm. The IMO emission regulations do not include ammonia emission standards. A possible increase in ammonia emissions due to the appliance of selective catalytic reduction was not taken into account in this study.

2.3 Scenarios in 2030 for North Sea shipping

Two scenarios were developed to assess the environmental impacts of a nitrogen oxide emission control area in the North Sea, and two cases show the contribution of shipping to air quality (Table 2.6). The main scenario (NECA) simulates compliance with the IMO regulations in 2030. Only the ships built after 2015 have to meet the new nitrogen oxide limit values (Tier III). Taking into account the future fleet age profiles (Section 2.2), this results in a reduction in nitrogen oxide emissions of about 30% by 2030, compared with the baseline. All other emissions at sea and on land throughout Europe were kept the same in the scenarios.

The situation where all ships meet the Tier III standards and nitrogen oxide emissions are reduced by about 70% would be realised only beyond 2045. However, we lack suitable emissions scenarios for land-based sources beyond 2030 (Section 2.2). Therefore, a second scenario was developed that assumed that all ships in the North Sea meet the Tier III standards already in 2030. This scenario can be seen as a maximum feasible reductions scenario (abbreviated here as MFR). This enables us to

Table 2.6
Baseline, policy scenarios and cases for international shipping in the North Sea in 2030

Baselines, scenarios and cases	Max. sulphur content	NO_x standards	Nitrogen oxide emissions [thousand tonnes] central case (range)	Nitrogen oxide reduction relative to the baseline (thousand tonnes)
Baseline	0.1%	Tier I, II	446 (253–676)	-
NECA scenario	0.1%	Tier I, II, only new ships after 2015 meet Tier III	317 (185–471)	129 (67–205)
MFR Scenario	0.1%	All ships meet Tier III in 2030	146[1]	300[1]
Contribution I	0.1%	No NO_x emissions from ships	0	446
Contribution II	0.1%	No NO_x, SO_2, $PM_{2.5}$ and VOC emissions from ships	0	446

1) Since the MFR scenario is a hypothetical scenario for 2030, no range is specified.
Source: PBL

outline the potential improvements in air quality and deposition due to a fully implemented nitrogen oxide emission control area.

The total contribution of air polluting emissions from North Sea shipping to air quality and deposition was determined using two cases. In the first case (Contribution I or Contr.I), only nitrogen oxide emissions from shipping were set to zero. The other air polluting emissions on land and in other sea areas in 2030 were not changed in the air quality modelling. In the second case (Contribution II or Contr.II), all air polluting emissions from North Sea shipping were set to zero (nitrogen oxide, sulphur dioxide, particulate matter, carbon monoxide, and volatile organic compounds). Again, air polluting emissions on land and in other sea areas were not changed. A range in the estimated nitrogen oxide emissions was computed by combining the high growth assumptions (Table 2.1) with the low efficiency and low LNG share assumptions (Table 2.2 and 2.3), and the low growth assumptions with the high efficiency and high LNG share assumptions.

2.4 Emission baseline for other European seas

The best available emission baselines for international shipping in the other EU seas were taken from IIASA (CIAM, 2011a; Cofala et al., 2007) and include the current IMO air quality legislation. The emissions have been recalculated from 2000 to 2030 to take into account the downward adjusted growth expectations for shipping after the economic crisis. We assumed that the growth rate used for fuel use by North Sea shipping in the baseline (about 1% per year) also applies to the other EU seas. This includes the same assumptions on energy-efficiency improvements as used for the North Sea (Section 2.2). We did not include any assumptions on the use of LNG and shore-side electricity for other European seas. Emissions of nitrogen oxides for the Baltic in 2009 are based on Kalli et al. (2010). It is further assumed that the Baltic Sea is designated as a nitrogen oxide emission control area from 2016 onwards. The other seas around Europe are not assumed to be designated as nitrogen emission control areas. Emissions for each European sea are presented in Annex A4.2 for 2009 and A4.5 for 2030.

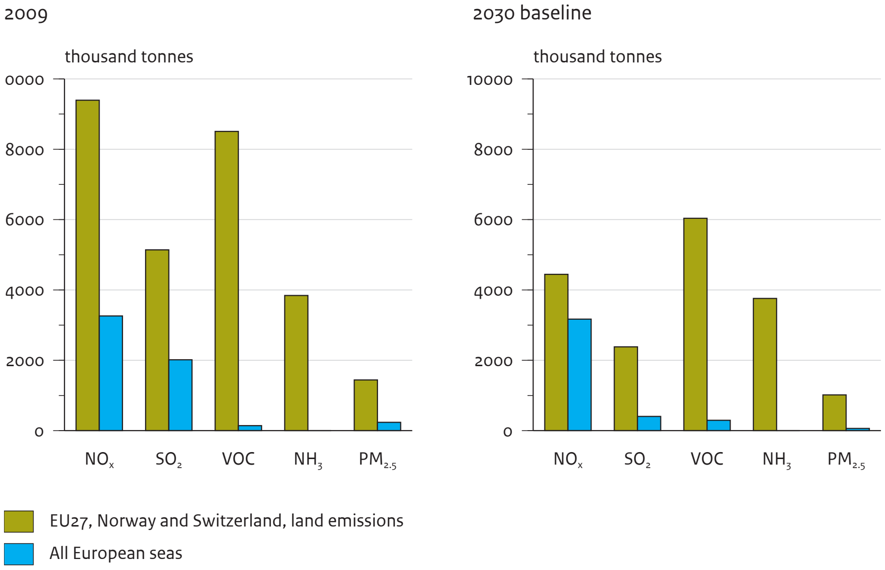
The baseline emissions of sulphur dioxide and particulate matter, summed over all European seas, will decrease substantially between 2009 and 2030 due to the cleaner fuels standards (Figure 2.6). Nitrogen oxide emissions will decrease only slightly between 2009 and 2030. This net decrease is the result of two counteracting effects: a limited growth in fuel use and hence nitrogen oxide emissions from EU shipping, on one hand (Tables 2.1 and 2.2), and the introduction of more stringent nitrogen oxide standards (Tier II) and the assumed nitrogen emission control area in the Baltic Sea, on the other. Despite the dramatic reduction in nitrogen oxide emissions towards 2030 in Europe, land emissions are still projected to exceed those at sea. The baseline for land emissions is further described in the next section.

2.5 Emissions for land-based sources

The emissions from land-based sources in 2009 and 2030 were based on the Primes July 2009 baseline (Capros et al., 2009), as implemented in the GAINS model by IIASA (CIAM 2011a; IIASA, 2011). That baseline is also used as a reference in the current revision of the Gothenburg Protocol, which aims to set new national air pollutant emission ceilings for EU countries for 2020. The baseline incorporates assumptions on the impacts of the recent economic recession on economic growth up to 2030. The annual change in GDP in Europe in 2009 was -4% but is projected to grow by 2.2% on average between 2010 and

Figure 2.6

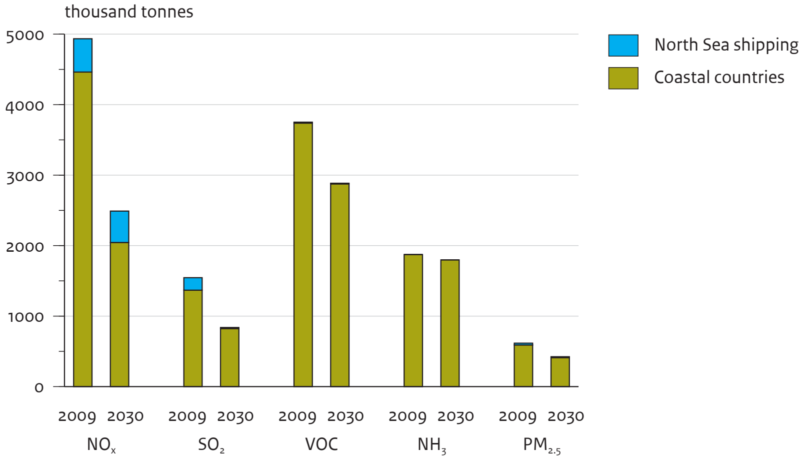
Air polluting emissions on land and above sea, in Europe



Source: PBL (land-based emissions taken from CIAM 2011a)

Figure 2.7

Air pollutant emissions in the North Sea and the coastal countries, 2009 and 2030 baseline



Source: PBL (land-based emissions taken from CIAM 2011a)

2020 and by 1.7% between 2020 and 2030. Projections for other European countries outside the EU27 are based on trends from the IEA World Energy Outlook 2009.

The Primes 2009 baseline includes the climate, energy and air quality policies in the EU27 as of 2010 (CIAM, 2011/4). Greenhouse gases are reduced in this baseline by about 14% by 2020, compared with 1990 levels, nearly 15% of the gross final energy demand is met by renewable energy sources, and 7.5% of the energy demand in transport is met by biofuels. More details on the baseline can be found online in the IIASA GAINS model (IIASA, 2011).

Table 2.7
Emissions on land and the North Sea in 2009 and the 2030 baseline

Thousand tonnes	NO_x		SO_2		VOC		NH_3		$PM_{2.5}$	
	2009	**2030**	**2009**	**2030**	**2009**	**2030**	**2009**	**2030**	**2009**	**2030**
Belgium	254	150	103	80	146	129	76	79	24	19
Denmark	139	64	12	11	108	66	62	52	28	16
France	1,038	414	322	174	951	645	647	625	268	189
Germany	1,152	568	391	306	1,151	959	572	550	106	81
Netherlands	293	139	47	38	196	159	133	129	21	13
Norway	171	126	23	26	169	126	22	24	41	28
Sweden	172	76	30	28	169	118	51	44	24	17
United Kingdom	1,244	506	439	160	848	674	311	294	79	48
Total land	4,463	2,044	1,368	824	3,738	2,876	1,874	1,797	591	411
North Sea	***472***	***446***	***177***	***15***	***14***	***9***	***0***	***0***	***25***	***13***

Source: PBL (emissions North Sea countries taken from IIASA, 2011)

The land-based emissions for the eight North Sea countries are presented in Table 2.7, together with the emissions in the North Sea. The emissions of most pollutants, except for ammonia (NH_3), are expected to decrease substantially due to current air, climate and energy policies. Figure 2.7 shows how the baseline emissions on land and at sea relate for the eight North Sea countries and the North Sea. Figure 2.6 shows how the baseline emissions on land and at sea relate for the whole of Europe.

Note

1 The average speed maintained by a ship under normal load and weather conditions.

Air quality, health and ecosystem impacts

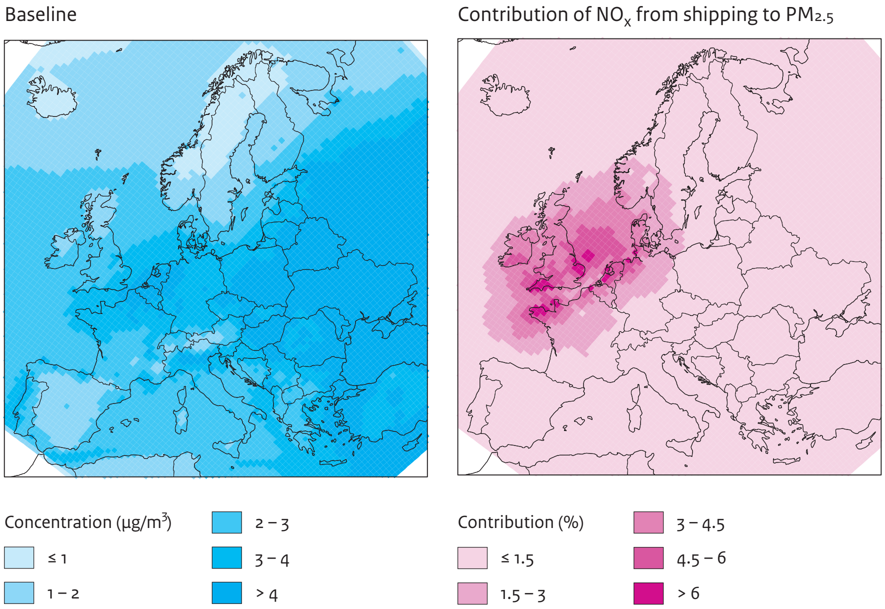
This chapter presents the results of air quality modelling. It shows the impacts on air pollutant concentrations, deposition, health, marine and terrestrial ecosystems. The chapter focuses on the environmental impacts of a nitrogen emission control area in the eight North Sea countries and specifically in the Rotterdam port area within the Netherlands. These countries are selected since this is where most of the impacts occur. Impacts in the other European countries are presented in Annex 5, 6 and 7, and are described here if relevant.

3.1 Air quality and deposition impacts

The applied air quality model is the EMEP model of the European Monitoring and Evaluation Programme of the UNECE. The model is designed to calculate air concentrations and deposition fields for major acidifying and eutrophying pollutants, ozone and particulate matter. The model resolution and domain are flexible, so that the model can be used on applications ranging from global to local. Particulate matter is modelled for primary and secondary aerosols. Primary particles are directly emitted by sources, whilst secondary particles are formed by the chemical transformation of certain pollutants in the atmosphere. For instance, a part of the nitrogen oxide emissions (from ships and other sources) will be transformed into particulate nitrate (NO_3^-) aerosols. Reductions in modelled particulate nitrate aerosols explain how a nitrogen emission control area contributes to less particulate matter. Organic secondary particles from anthropogenic sources are not included in the model because their contribution is relatively small and the formation pathways are rather uncertain. Most particles from natural sources, except for fine sea salt particles, are not included here because of the uncertainty in their emission quantification and the fact that they are not controllable using policy measures. A detailed description of the EMEP model is given in Simpson et al. (2012). The EMEP model was run by the Norwegian Meteorological Institute.

The EMEP model results are constantly evaluated with measurements and other models, both in the annual EMEP reports (see www.EMEP.int) and in peer-reviewed publications (Jonson et al., 2010; Fagerli and Aas, 2008; Bartnicki and Fagerli, 2008; Tsyro et al., 2011; Aas et al., 2012). The EMEP model is the reference atmospheric dispersion model used in the integrated assessment model (GAINS) supporting the development of air policy in the EU. Here the air quality calculations were carried out using a horizontal resolution of 50×50km^2 and an average of the meteorological conditions for 1996, 1997, 1998, 2000 and 2003. Such averaging of meteorology is a usual procedure in scenario studies where we want to exclude the influence of meteorological fluctuations on the outcome of the analysis. The above main starting points are equal to those used in other recent integrated assessment studies (CIAM, 2011a; Holland et al., 2011). This approach allows us to make a sound comparison between our results on cost-benefits with those of other

Figure 3.1
Average annual particulate matter concentrations ($PM_{2.5}$), 2030



Source: PBL (based on NMI-EMEP calculations)

studies dealing with land-based policies. In addition, the above model study set-up is especially suitable for showing the impact of a policy measure on the change in air quality (and benefits), rather than providing absolute air concentrations that can be compared with measurements and air quality limit values. Such a comparison would require actual meteorology data and higher modelling resolutions.

To examine the impacts of model resolution on the environmental impacts and the outcome of this study, we set up an additional but limited model study in which we modelled the impacts of a nitrogen emission control area at a higher resolution in the port of Rotterdam. For that purpose, we applied the Operational Priority Substances (OPS) model from the Netherlands Institute of Public Health and Environment (Van Jaarsveld, 2004) at a resolution of 0.5 x 0.5 km², with the same meteorological years as mentioned above. Only the dispersion and atmospheric transformations of ship emissions in the Rotterdam port were modelled at a higher resolution. The dispersion and atmospheric transformations of all other emissions (excluding the ships emissions in the Rotterdam port) were calculated using the EMEP model at the more coarse resolution. Subsequently, we combined the high and low resolution air quality and deposition maps for the Rotterdam port area for $PM_{2.5}$, nitrogen dioxide and nitrogen deposition. The OPS model runs were performed by the DCMR Environmental Protection Agency Rijnmond.

Impacts on particulate matter concentrations ($PM_{2.5}$)

The projected anthropogenic particulate matter ($PM_{2.5}$) background concentrations in the 2030 baseline are highest in North-West Europe, northern Italy and Eastern Europe (Figure 3.1, left). The anthropogenic $PM_{2.5}$ background concentrations around the North Sea range from 1 µg/m³ in northern Scandinavia to around 5 µg/m³ in the Netherlands and Belgium. It is also clear that the particulate matter concentrations are higher over land than over sea. This caused by the larger density of land sources that contribute to these particulate matter concentrations.

In the port of Rotterdam, these anthropogenic $PM_{2.5}$ concentrations can be as high as 5.8 µg/m³ (Figure 3.2, top). The highest concentrations in the Rotterdam map are caused by primary particulate matter that is directly emitted by ships. The indirect, secondary, contribution of nitrogen oxide and sulphur dioxide emissions from ships to particulate matter is much less pronounced in the Rotterdam harbour. This is explained by the relatively long lifetime of secondary particulate matter and the relatively large contribution from long-range transport outside the Rotterdam harbour area.

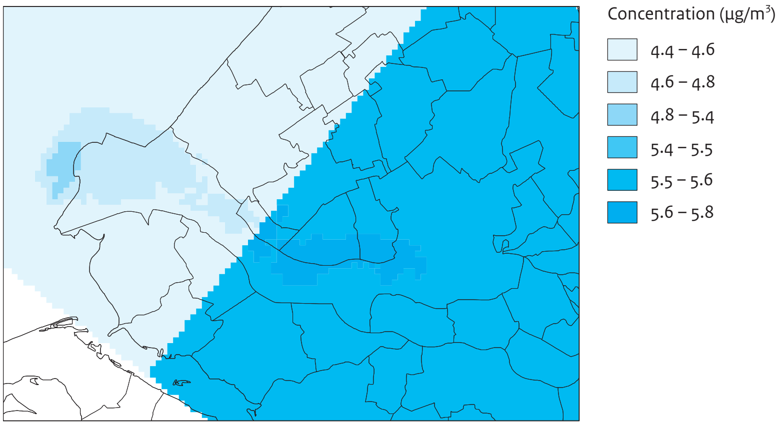
Table 3.1
Average annual anthropogenic $PM_{2.5}$ concentrations[1]

Countries	2009	2030 baseline	2030 scenarios and cases: NECA	MFR	CONTR.I	CONTR.II	Reductions relative to the baseline: NECA	MFR	CONTR.I	CONTR.II
	µg/m³		µg/m³				%			
Belgium	7.68	5.10	5.05	4.99	4.93	4.87	0.9	2.2	3.4	4.6
Denmark	4.70	3.03	3.00	2.97	2.93	2.90	0.9	2.1	3.3	4.5
France	4.90	3.06	3.04	3.02	3.00	2.99	0.6	1.3	2.0	2.5
Germany	5.76	3.74	3.71	3.68	3.66	3.64	0.6	1.4	2.1	2.6
Netherlands	7.29	4.64	4.58	4.49	4.40	4.30	1.3	3.3	5.2	7.3
Norway	1.18	0.94	0.94	0.93	0.93	0.93	0.4	0.9	1.3	1.8
Sweden	1.53	1.18	1.17	1.17	1.16	1.16	0.3	0.7	1.1	1.5
United Kingdom	3.77	2.44	2.41	2.37	2.33	2.30	1.1	2.8	4.4	5.8
Average	**3.59**	**2.37**	**2.36**	**2.34**	**2.32**	**2.30**	**0.6**	**1.5**	**2.4**	**3.1**

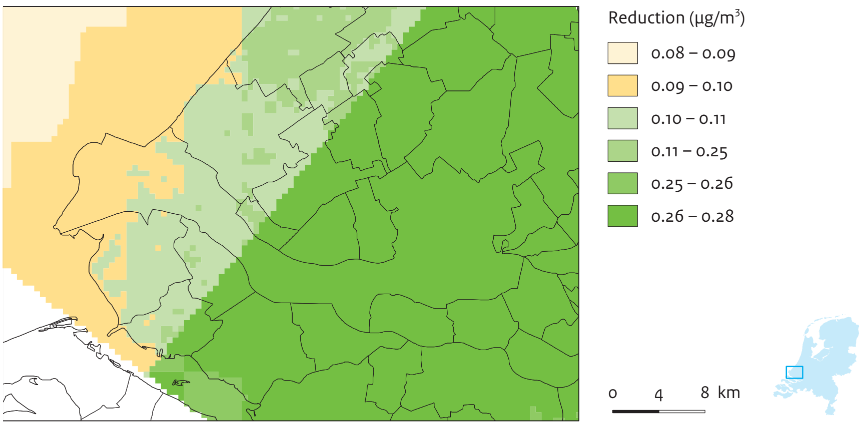
1) *Concentrations are not population weighted.*
Source: PBL (based on NMI-EMEP calculations)

Figure 3.2
Average annual particulate matter concentrations ($PM_{2.5}$) in the Rotterdam port area, 2030

Baseline

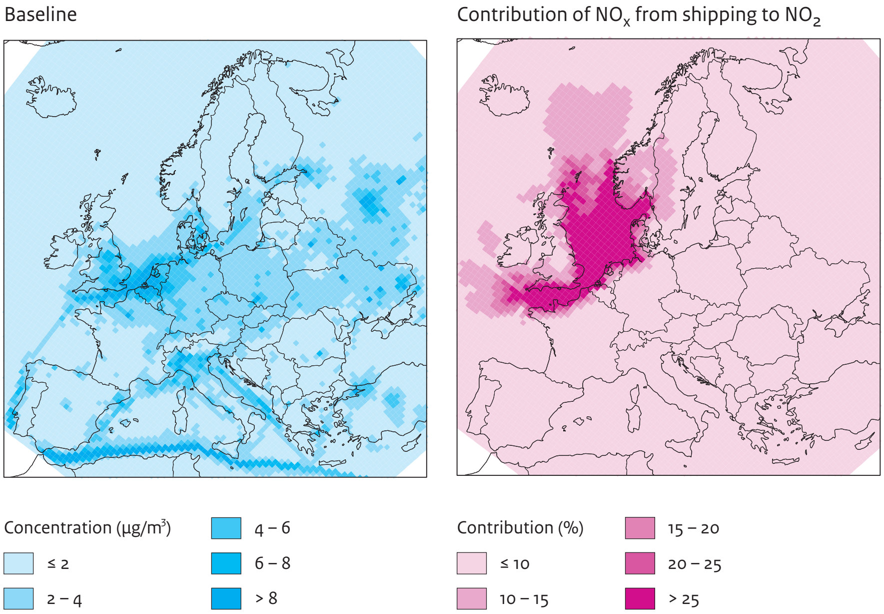


Potential reduction under MFR scenario



Source: PBL (based on NMI-EMEP and DCMR Rijnmond calculations)

Figure 3.3
Average annual nitrogen dioxide concentrations, 2030



Source: PBL (based on NMI-EMEP calculations)

The contribution of nitrogen oxide emissions from North Sea shipping to $PM_{2.5}$ concentrations can be derived from the Contribution-I case and the 2030 baseline scenario. This contribution depends on the proximity of a country to the North Sea and the busy shipping lanes and can be as high as 7% in certain coastal areas (Figure 3.1, right). The contribution to country averages is the highest in the Netherlands and the United Kingdom with 5% and 4%, respectively, and the lowest in Sweden and Norway with about 1% (Table 3.1). The contribution in Luxembourg and Switzerland is about 2% and 1%, respectively (Annex 5). The NECA scenario (i.e. normal Tier III penetration rate from 2016 onwards) reduces these contributions by about one third; the MFR scenario (all ships meet Tier III standards in 2030) reduces them by about two thirds.

Under the MFR scenario, the highest concentrations in the port of Rotterdam are reduced by 0.2–0.3 µg/m³ (a reduction of 4.6% to 4.8% relative to the baseline) (Figure 3.2, bottom). The reductions in secondary particulate matter concentrations as a result of a nitrogen emission control area are higher over Rotterdam than at the coast. It is clear that the concentration gradients due to the reduction of secondary particulate matter are small. This indicates that a higher model resolution does not bring substantially more detail into the assessment of the impacts of a nitrogen emission control area on secondary particulate matter concentrations. This also implies that the impacts on human health (Sections 3.2) from exposure to secondary particulate matter are probably not much influenced by taking either a lower or higher model grid resolution. It also means that the health benefits in this assessment (Section 4.1) are not very sensitive to model grid resolution.

The overall contribution from North Sea shipping (including all air polluting emissions) to $PM_{2.5}$ concentrations can be derived from the Contribution-II case and the baseline scenario in 2030. The highest contribution is found in the Netherlands and the United Kingdom with 7% and 6%, respectively, and the lowest in Sweden and Norway with less than 2% (Table 3.1). The contribution from North Sea shipping to particulate matter concentrations in the Netherlands in 2030 is about the same as the projected contributions from for example Dutch road transport or industry, but only half of the contribution of the Dutch agricultural sector (Velders et al., 2012).

Impacts on nitrogen dioxide concentrations

The projected anthropogenic nitrogen dioxide background concentrations (NO_2) in the 2030 baseline are the highest in North-West Europe, northern Italy and Eastern Europe (Figure 3.3, left). Shipping lanes can be clearly identified in the North Sea, the English Channel, the Mediterranean and the Adriatic Seas and along the

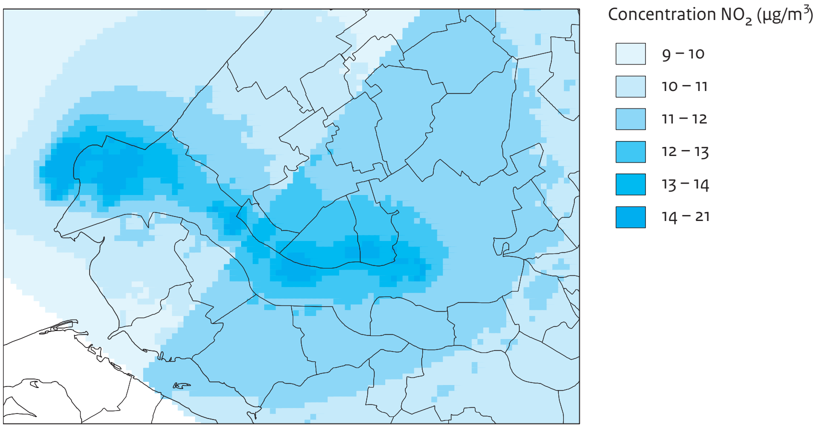
Table 3.2
Average annual nitrogen dioxide concentrations

Countries		2030	2030 scenarios and cases			Reductions relative to the baseline		
	2009	baseline	NECA	MFR	CONTR.I	NECA	MFR	CONTR.I
	µg/m³		µg/m³			%		
Belgium	14.92	7.23	6.89	6.46	6.12	4.6	10.6	15.4
Denmark	6.56	3.33	3.15	2.91	2.72	5.5	12.6	18.5
France	5.06	2.15	2.10	2.03	1.98	2.5	5.7	8.1
Germany	9.08	4.04	3.95	3.84	3.75	2.2	5.0	7.3
Netherlands	15.65	7.82	7.26	6.53	5.94	7.2	16.5	24.1
Norway	1.30	0.77	0.74	0.70	0.67	3.9	9.0	13.1
Sweden	2.13	1.11	1.08	1.04	1.01	2.7	6.1	8.9
United Kingdom	6.75	3.33	3.16	2.94	2.76	5.3	12.0	17.3
Average	4.99	2.34	2.26	2.15	2.07	3.4	7.8	11.4

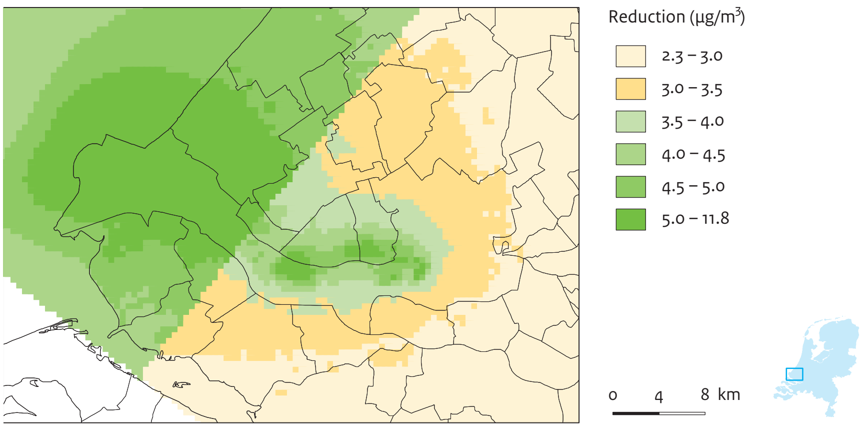
Source: PBL (based on NMI-EMEP calculations)

Figure 3.4
Average annual nitrogen dioxide concentrations in the Rotterdam port area, 2030

Baseline



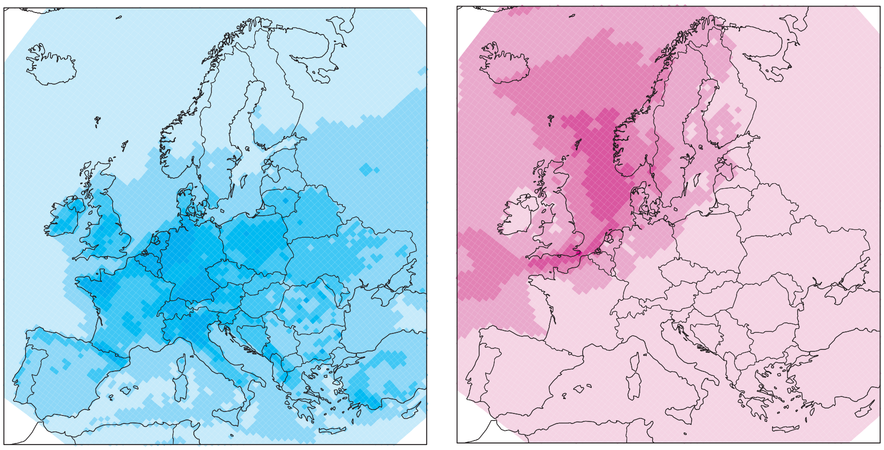
Potential reduction under MFR scenario



Source: PBL (based on NMI-EMEP and DCMR Rijnmond calculations)

Figure 3.5
Average annual nitrogen depositions, 2030

Baseline | Contribution of NO_x from shipping to N deposition



Deposition (mol/ha): ≤ 200; 200 – 400; 400 – 600; 600 – 800; > 800

Contribution (%): ≤ 2; 2 – 4; 4 – 6; 6 – 8; > 8

Source: PBL (based on NMI-EMEP calculations)

coasts of Spain and France. The nitrogen dioxide concentrations around the North Sea range in the 2030 baseline from a few µg/m³ in Scandinavia to more than 7 µg/m³ in the Netherlands and Belgium. Concentrations can be as high as 21 µg/m³ in the port of Rotterdam (Figure 3.4, top). Figure 3.4 (top) shows that the nitrogen dioxide concentrations are higher over land than over the sea. This is caused by the larger density of land sources that contribute to these nitrogen dioxide concentrations.

The contribution from North Sea shipping to nitrogen dioxide concentrations can be higher than 25% in certain coastal areas (Figure 3.3, right). The contribution to country averages is the highest in the Netherlands and Denmark with 24% and 19%, respectively, and the lowest in Germany and France with 7% and 8%, respectively (Table 3.2). The contribution to the country average concentrations in Ireland is around 7%, but absolute concentrations are relatively low (Annex 5). The NECA scenario reduces these contributions by about one third; the MFR scenario reduces them by about two thirds.
Under the MFR scenario, the highest concentrations in the port of Rotterdam are reduced by about 4 µg/m³ to 12 µg/m³ (a reduction of 25% to 50% relative to the baseline) (Figure 3.4, bottom). The reductions in nitrogen dioxide concentrations are higher over sea than over land. This is logical since nitrogen dioxide (NO_2) is quickly formed in the atmosphere from the ship's nitrogen oxide emissions. The maps show that a higher model resolution enables a more detailed analysis of the impacts of a nitrogen emission control area on the nitrogen dioxide concentrations.

Impacts on nitrogen deposition

The projected anthropogenic nitrogen deposition in the 2030 baseline is highest in the Netherlands, Belgium, parts of Germany, Brittany (France), Switzerland and northern Italy (Figure 3.5, left). The nitrogen depositions around the North Sea range from a few hundred moles per hectare in the south of Scandinavia to around a thousand moles per hectare in the Netherlands and Belgium. Depositions can be as high as about 1 850 moles per hectare around the port of Rotterdam (Figure 3.6, top). The much higher depositions of nitrogen over land than over the sea are caused by the large contributions of ammonia from agriculture and nitrogen oxides from road transport and industry.
The contribution from North Sea shipping to nitrogen deposition can be up to 8% in certain coastal areas (Figure 3.5, right). The contribution to country averages is the highest in Norway and Denmark with 5% and 4%, respectively, and the lowest in Germany and France with less than 2% (Table 3.3). The contribution to the country average deposition in Finland and Estonia is around 2% (Annex 5). The NECA scenario reduces these contributions by about one third; the MFR scenario reduces them by about two thirds.

Table 3.3
Average annual nitrogen deposition

Country	2009	2030 baseline	2030 scenarios and cases NECA	MFR	CONTR.I	Reductions relative to the baseline NECA	MFR	CONTR.I
	mol N/ha/yr		mol N/ha/yr			%		
Belgium	1,120	967	959	947	936	0.9	2.1	3.2
Denmark	602	476	471	463	457	1.2	2.8	4.1
France	687	574	572	569	566	0.4	1.0	1.4
Germany	1,021	842	838	831	826	0.6	1.3	1.9
Netherlands	1,300	1,149	1,140	1,126	1,113	0.8	2.0	3.2
Norway	151	114	112	110	108	1.4	3.3	4.8
Sweden	220	164	162	160	158	1.0	2.4	3.5
United Kingdom	588	491	487	480	475	0.9	2.1	3.2
Average	550	452	449	445	442	0.7	1.6	2.3

Source: PBL (based on NMI-EMEP calculations)

Under the MFR scenario, the highest depositions in the port of Rotterdam are reduced by 70 moles per hectare to 170 moles per hectare (a reduction of 2% to 10% relative to the baseline) (Figure 3.6, bottom). The map indicates that a higher model resolution enables a more detailed analysis of the impacts of a nitrogen emission control area on nitrogen deposition.

Impacts on ozone

Ozone is formed in the atmosphere from nitrogen oxide (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight. The lifetime of ozone in the lower parts of the atmosphere is a few days, which allows ozone to be transported over large distances. Due to the complex non-linear atmospheric photochemistry and the dependence on the ambient concentration levels of nitrogen oxide and volatile organic compounds, a reduction in nitrogen oxide emissions does not always result in less ozone formation. Reductions in local nitrogen oxide emissions can even lead to an increase in ozone due to the 'nitrogen oxide titration effect'. This effect is only noticed for the NECA and MFR scenarios for the Netherlands and Belgium (Annex 5, Table A5.4).

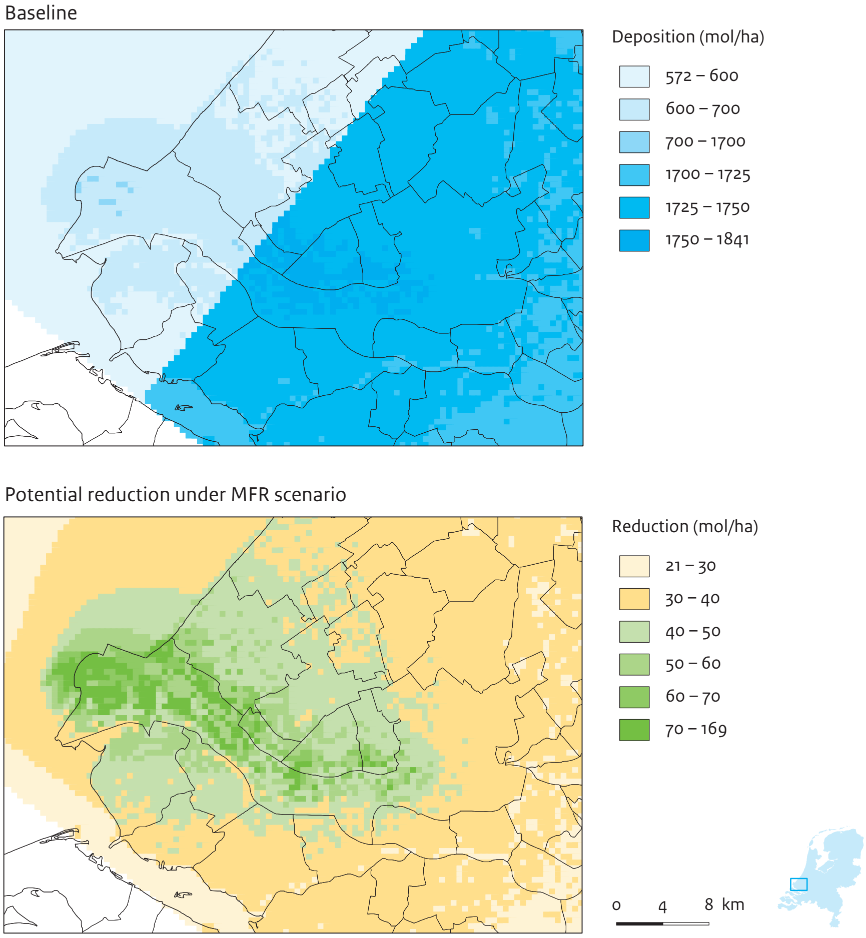
SOMO35 is an ozone indicator recommended for health impact quantification by the World Health Organization (WHO). This indicator is based on an accumulation of 8-hourly mean ozone concentrations over a threshold of 35 ppb (=70 µg/m³) during a year. It should not be interpreted as implying a threshold for ozone effects at 35 ppb, rather as a level above which the quantification of ozone health effects can be performed with higher confidence than below. The NECA and MFR scenarios result in reductions in the average SOMO35 by 2030 of less than 1% and 2%, respectively. The contribution of all nitrogen oxide emissions from North Sea shipping to the average SOMO35 in the eight North Sea countries is less than 4% (Annex 5, Table A5.4). The SOMO35 values are used in the next section for the assessment of health impacts. Valuation of these impacts is presented in Section 4.1.

The current indicator for the exposure to and potential damage to crops by ozone is the AOT40. This indicator is based on the accumulation of hourly mean ozone concentrations over a threshold of 40 ppb (= 80 µg/m³) during the three summer months. The NECA and MFR scenarios result in reductions in the average AOT40 by 2030 of 2% and 6%, respectively (Annex 5, Table 5.5). Turning off all nitrogen emissions from shipping by 2030 would reduce the AOT40 by 11% in the North Sea countries (Annex 5, Table A5.5). The impact of the scenarios on the reduction in the AOT40 is larger than on the SOMO35. This is an indication that shorter periods of high ozone levels are more sensitive to the NECA scenarios in this study. The AOT40 values are used in Section 4.2 for the valuation of reduced crop damage due to the NECA scenarios and cases.

3.2 Health impacts

The focus in this section is on the health impacts of human exposure to particulate matter and ozone. Exposure to particulate matter was estimated to be a leading cause of the environmental burden of disease in a recent study in six selected European countries (including France, Belgium, the Netherlands and Germany), followed by passive smoking, traffic noise, indoor radon, lead, dioxins, ozone, benzene and formaldehyde exposures (Hänninen and Knol, 2011). Their results suggest that 3% to 7% of the standard WHO burden of disease in the

Figure 3.6
Average annual nitrogen depositions in the Rotterdam port area, 2030



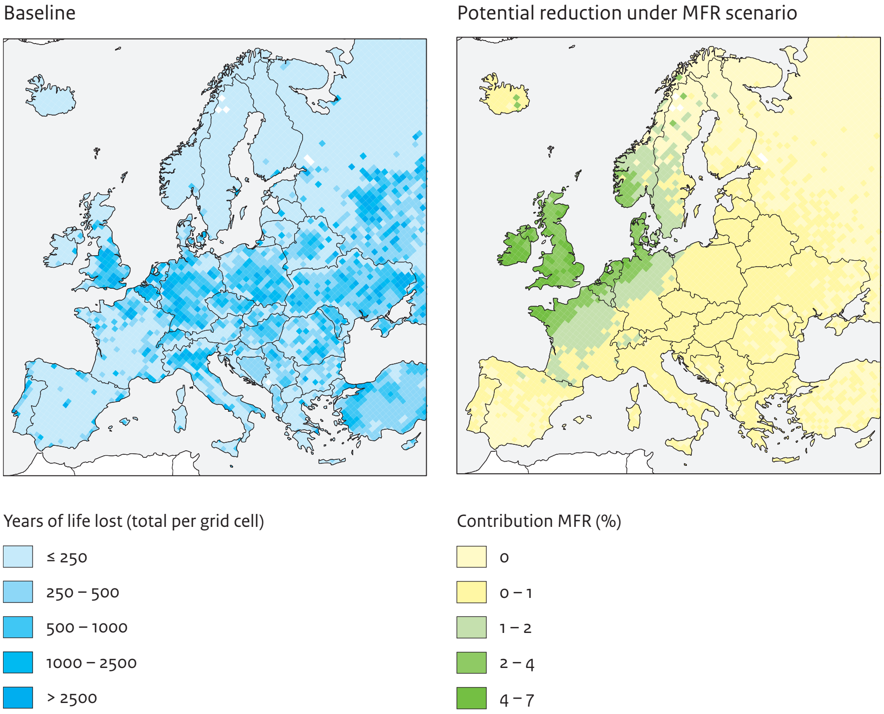
Source: PBL (based on NMI-EMEP and DCMR Rijnmond calculations)

selected European countries is associated with exposure to the above environmental stressors. Particulate matter ($PM_{2.5}$) is estimated to be responsible for approximately two thirds of this standard environmental burden of disease.

Health impacts were calculated here using the modelled concentrations of particulate matter and ozone (previous section), population density maps and exposure-response relationships. The applied method is described in detail in Holland et al. (2011). The population distribution and the effects of demographics up to 2030 within the population, such as numbers of children, the elderly and those of working age, are also taken into account. Incidence rates considered representative of the rate of occurrence of different health conditions across Europe are used to modify the population at risk for each type of impact quantified.

In line with WHO advice, we treat all particles, irrespective of source and chemical composition, as equally harmful. Particles from natural sources are not included in the modelling as they are not controllable using policy measures for emission sources. Additional views on the harmfulness of certain particulate matter fractions and their impacts on the outcome of this study are dealt with in the chapter on uncertainties (Chapter 5). Only quantifying the impacts of exposure to ozone and $PM_{2.5}$ does not mean that we consider that there are no effects of exposure to NO_2 and SO_2 on health. However, it is felt that the separate inclusion of functions for these pollutants would incur a risk of double counting the effects quantified when using the functions based on $PM_{2.5}$ exposure, so it is not done. Health impacts were expressed using the indicator Years of Life Lost (YOLL) and a series of other indicators. These indicators are also used in the valuation of health impacts in Section 4.1.

Figure 3.7
Years of life lost, 2030



Source: PBL (based on NMI-EMEP and EMRC calculations)

Impacts on Years of Life Lost

The YOLL indicator describes the health impact in terms of the loss of life expectancy attributable to the exposure of the population to particulate matter ($PM_{2.5}$). The YOLL is linearly related to the $PM_{2.5}$ concentrations (Section 3.1). The highest YOLL in 2030 is expected to occur in urbanised areas of North-West Europe, northern Italy and Eastern Europe (Figure 3.7, left). The relative reductions around the North Sea in the MFR scenario range from 2% to 7% (Figure 3.7, right). The potentially highest reductions in absolute YOLL in the MFR scenario are located in North-West Europe (See Findings, Figure S4).

The contribution of nitrogen oxide emissions from North Sea shipping to the loss in life expectancy in Europe is estimated at about 18,300 years, annually, by 2030. A nitrogen emission control area would prevent about 4,870 years of life lost, annually, in Europe, by 2030. A nitrogen emission control area would reduce the total years of life lost by 0.5%, annually, in Europe, by 2030, and by more than 0.9% in the North Sea coastal countries. The sulphur and particulate matter emissions from North Sea shipping with current legislation are estimated to cause 6,050 years of life lost in the coastal countries by 2030.

Country-wide reductions in total estimated YOLL by 2030 under an MFR scenario range from 3% to 4% in the United Kingdom and the Netherlands, to 1% to 2% in Sweden, Norway, Germany and France (Table 3.4). The YOLL prevented by NECA and MFR scenarios in the coastal countries in 2030 are estimated at a respective 4,000 and 10,000 YOLL, annually. The YOLL prevented by the NECA and MFR scenarios in other European countries in 2030 are estimated at a respective 750 and 1,800 YOLL, annually (Annex A6.1). We estimated that 85% of the YOLL improvements due to a nitrogen emission control area are seen in the countries that surround the North Sea and 15% in other European countries.

Impacts on other health indicators

Besides loss in life expectancy from particle exposure, we analysed a number of other health impacts due to the exposure of the population to $PM_{2.5}$ and ozone (Table 3.5). The table indicates substantial health effects, with nearly half a million life years being lost per year under the baseline scenario, with some improvements from the policies under debate. There are many more cases of hospital admissions, chronic bronchitis and various effects that may be minor at the level of the individual but which could affect a very large number of people.

Table 3.4
Years of life lost due to exposure to particulate matter

Countries	2009	2030 baseline	2030 scenarios and cases NECA	MFR	CONTR.I	CONTR.II	Reductions relative to the baseline NECA	MFR	CONTR.I	CONTR.II
	years		years				%			
Belgium	52,540	33,500	33,189	32,703	32,250	31,737	0.9	2.4	3.7	5.3
Denmark	15,589	9,056	8,980	8,855	8,752	8,654	0.8	2.2	3.4	4.4
France	203,849	121,649	120,899	119,880	118,978	118,152	0.6	1.5	2.2	2.9
Germany	298,736	168,793	167,742	166,321	165,038	164,034	0.6	1.5	2.2	2.8
Netherlands	72,120	42,679	42,047	41,076	40,084	38,945	1.5	3.8	6.1	8.7
Norway	5,070	3,539	3,519	3,490	3,462	3,424	0.6	1.4	2.2	3.2
Sweden	13,306	9,205	9,169	9,109	9,063	8,997	0.4	1.0	1.5	2.3
United Kingdom	152,945	89,205	87,960	86,099	84,268	82,372	1.4	3.5	5.5	7.7
Total	**814,155**	**477,626**	**473,505**	**467,533**	**461,895**	**456,315**	**0.9**	**2.1**	**3.3**	**4.5**

Source: PBL (based on NMI-EMEP and EMRC calculations)

Table 3.5
Annual health impacts in the eight North Sea countries

Health impact (population at risk, unit)	2009	2030 baseline	2030 NECA	2030 MFR	2030 CONTR.I	2030 CONTR.II
Quantification against ozone exposure						
Acute mortality (all ages, premature deaths)	10,326	9,592	9,584	9,508	9,310	9,300
Respiratory hospital admissions (65yr +, cases)	9,779	10,827	10,816	10,731	10,507	10,497
Minor restricted activity days (15–64yr)	25,803,511	19,027,407	19,015,835	18,870,509	18,472,195	18,454,047
Days with respiratory medication use (adults 20yr +)	9,275,656	7,773,478	7,767,710	7,707,539	7,545,699	7,538,333
Quantification against $PM_{2.5}$ exposure						
Exposure chronic mortality (life years lost)	814,156	477,625	473,504	467,532	461,895	456,315
Infant mortality (0–1yr, deaths)	131	70	69	68	67	66
Chronic bronchitis (27yr +, new cases)	36,607	24,675	24,465	24,161	23,875	23,593
Respiratory hospital admissions (all ages, cases)	14,536	9,492	9,410	9,293	9,182	9,072
Cardiac hospital admissions (all ages, cases)	8,965	5,854	5,804	5,731	5,663	5,595
Restricted activity days (15–64yr)	76,599,920	44,180,383	43,799,243	43,246,987	42,725,761	42,209,317
Days with respiratory medication use (children 5–14yr)	949,792	484,982	480,754	474,617	468,821	463,043
Days with respiratory medication use (adults 20yr +)	6,676,935	4,414,222	4,376,562	4,322,091	4,270,736	4,220,078
Days with lower respiratory symptoms (5–14yr)	39,635,935	24,922,672	24,705,423	24,390,029	24,092,180	23,795,280
Days with lower respiratory symptoms (15yr +)	68,139,507	44,750,090	44,367,836	43,814,818	43,293,388	42,778,703

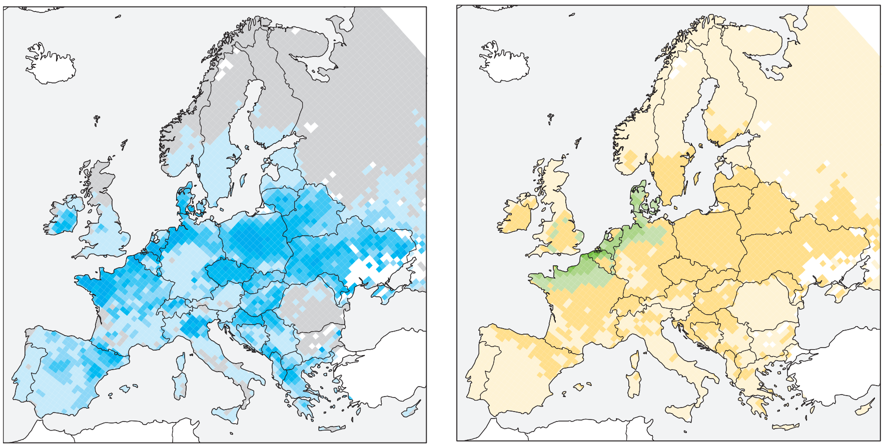
Source: PBL (based on EMRC calculations)

The analysis indicates that the health impacts of $PM_{2.5}$ are much larger than those of ozone. Unlike particulate matter related mortality effects, which are related to long-term exposure in the methodology used, the effect of ozone on mortality is presently only quantified for short-term exposure. For this short-term exposure to ozone, there is some consensus that the shortening of life will be small, perhaps a year on average, and in many cases much less. There is also some evidence of the effects of long-term exposure to ozone (Jerrett et al., 2009), though these have yet to be factored into the agreed methodology as adopted for analysis to support decision-making by the European Commission.

An indication of the impacts of an ageing European population can be seen in the increase in respiratory hospital admissions due to ozone exposure of people over 65 years between 2009 and 2030. The trend is determined despite the fact that ozone concentrations were projected to decreased over this period.

Figure 3.8
Average annual accumulated excess deposition of nitrogen loads, 2030

Baseline | Potential reduction under MFR scenario



Exceedance of critical loads (mol/ha)

- No exceedance
- ≤ 100
- 100 – 200
- 200 – 300
- 300 – 500
- > 500

Reduction (mol/ha)

- ≤ 1
- 1 – 10
- 10 – 20
- 20 – 40
- 30 – 40
- > 40

Source: PBL (based on NMI-EMEP and RIVM-CCE calculations)

The health impacts in all European countries (see Annex 6) are used in Section 4.1 for the valuation of health benefits due to the NECA scenarios and the cases.

3.3 Terrestrial ecosystem impacts

Impacts on terrestrial ecosystems were calculated using the modelled ecosystem-specific depositions of eutrophying and acidifying compounds (Section 2.2), maps of critical loads and other information on dose-response relationships. A critical load is defined as 'the highest deposition of eutrophying or acidifying compounds below which harmful effects in ecosystem structure and function do not occur according to present knowledge' (Nilsson and Grennfelt, 1988). The basic idea behind the critical load concept is to balance the depositions that an ecosystem is exposed to with the capacity of this ecosystem to buffer the input (e.g. the acidity input buffered by the weathering rate), or to remove it from the system (e.g. nitrogen by harvest) without harmful effects within or outside the system.

Critical loads have been computed and mapped for forests, semi-natural vegetation and surface waters in Europe by Hettelingh et al. (2008). Surface waters only have critical loads for acidification, assuming that the atmospheric deposition of nitrogen does not contribute significantly to eutrophication in these ecosystems. The focus in this section is on eutrophication (nitrogen impacts) since this remains the larger problem in 2030 compared with acidification, and our study examines a nitrogen oxide measure. Indicators for the acidification of forests, freshwater ecosystems and catchment areas are given in Annex 6. Tentative results are presented of areas where the change in biodiversity caused by excessive nitrogen deposition in the 2030 baseline is significant.

Excess deposition of nitrogen

The average accumulated excess deposition of nitrogen (AAE-N) is the total excess deposition of nutrient nitrogen (above the critical loads) accumulated in all ecosystems in a certain area (Posch et al., 2001). Areas with high excess deposition in the 2030 baseline are projected in the Netherlands, Belgium, part of Germany, Brittany (France), Poland and northern Italy (Figure 3.8, left). The country average excess deposition is the highest in the Netherlands and Denmark (Table 3.6) due to the combination of high nitrogen deposition and sensitive ecosystems in these countries. Norway, Sweden and the

Table 3.6
Average accumulated excess deposition of nitrogen loads in 2030

Countries	Total eco-system area	2009	2030 baseline	2030 scenarios and cases			Reductions relative to the baseline		
				NECA	MFR	CONTR.I	NECA	MFR	CONTR.I
	1,000 km^2	Mol N/ha/yr		Mol N/ha/yr			%		
Belgium	6.3	315.6	165.9	160.6	153.4	147.3	3.2	7.5	11.2
Denmark	3.6	410.2	228.6	221.0	211.0	202.7	3.3	7.7	11.4
France	180	265.0	140.4	138.4	135.7	133.4	1.5	3.4	5.0
Germany	103	222.7	109.0	106.7	103.8	101.4	2.1	4.8	7.0
Netherlands	4.4	571.3	387.8	378.9	366.2	355.1	2.3	5.6	8.4
Norway	136	4.6	0.4	0.4	0.3	0.2	15.0	30.8	42.1
Sweden	151	43.0	12.6	11.9	11.2	10.6	5.0	11.1	16.0
United Kingdom	92	23.7	6.1	5.7	5.2	4.8	6.8	14.8	21.4
Average		**127.0**	**63.0**	**61.7**	**60.1**	**58.8**	**2.0**	**4.5**	**6.7**

Source: PBL (based on NMI-EMEP and RIVM-CCE calculations)

United Kingdom have relatively low exceedances of critical loads for nutrient nitrogen and thus low excess deposition.

North Sea shipping contributes nearly 7% to the total excess deposition of nitrogen in 2030 in the North Sea coastal countries (see Contr.I scenario). The NECA and MFR scenarios reduce this contribution by about one third and two thirds, respectively. Under the MFR scenario, maximum reductions amount to over 40 moles nitrogen per hectare in 2030 along the North Sea coast (Figure 3.8, right). The country average excess deposition is reduced by 7% and 8% in Belgium and Denmark and around 5% in the Netherlands and Germany. The relatively low excess deposition in Norway, Sweden and the United Kingdom is reduced by more than 10%.

Change in biodiversity

Tentative results were calculated of areas where the change in biodiversity caused by excessive nitrogen deposition in the 2030 baseline is significant, as it exceeds 5%. The change in biodiversity is an indicative estimate of the effect of the nitrogen deposition in the 2030 baseline on:

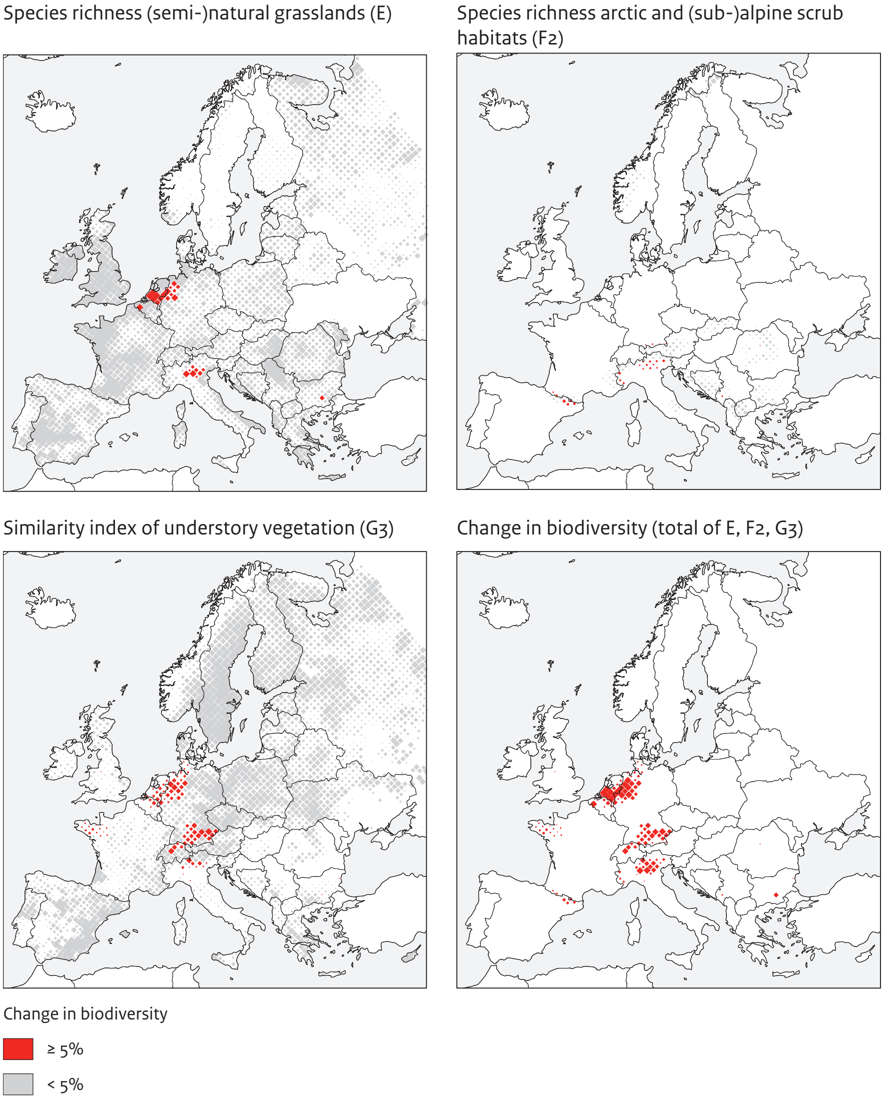
- the species richness of natural and semi-natural grasslands (Classification E according to the European Nature Information System – EUNIS);
- the species richness of the arctic and alpine and sub-alpine scrub habitats (EUNIS class F2);
- the Sorensen's similarity index of the understory vegetation of coniferous boreal woodlands (EUNIS class G3 A-C).

The analysis is based on dose-response relationships (Bobbink, 2008; Hettelingh et al., 2008; Bobbink and Hettelingh, 2011) for these three classes, using the European harmonised land cover map (Chapter 2 in Hettelingh et al., 2009). The uncertainties of this analysis are rather important (see Hettelingh et al., 2010). The dose-response information was only available for a relatively small number of non-randomly chosen sites in Europe. Nevertheless, it was assumed to be representative at the European scale, while such relationships between dose and response may vary geographically. Moreover, the dose-response curves were only available for three classes that make up only half of the European natural area. The latter implies that the indicative changes in biodiversity are likely to be an underestimate.

To account for some of the uncertainties, the computed change in biodiversity in 2030 was only accounted for if the indicator changed significantly, this means by more than 5% relative to the anthropogenic nitrogen deposition that would not cause adverse effects (Figure 3.9). The areas with a potential risk of change in the species richness of natural or semi-natural grasslands (upper left) are concentrated in the Netherlands, western parts of Germany and northern Italy (shown in red). The species richness of the arctic and alpine and sub-alpine scrub habitats (upper right) might be endangered in the Alps and the Pyrenees. The biodiversity of the understory vegetation of coniferous boreal woodlands (bottom left) might be at risk in the Netherlands, Belgium, Brittany, parts of Germany, Switzerland and northern Italy. The combined change in biodiversity is presented in the bottom right of Figure 3.9.

Grey areas indicate areas with modelled changes in biodiversity below 5% that are considered not significant. Compared to computations made for 2000 (Posch et al., 2011), changes in biodiversity using currently available dose-response curves for selected ecosystems (Bobbink and Hettelingh, 2011) indicate that the potential risks

Figure 3.9
Biodiversity changes in nature areas, baseline, 2030



Source: PBL (based on NMI-EMEP and RIVM-CCE calculations)

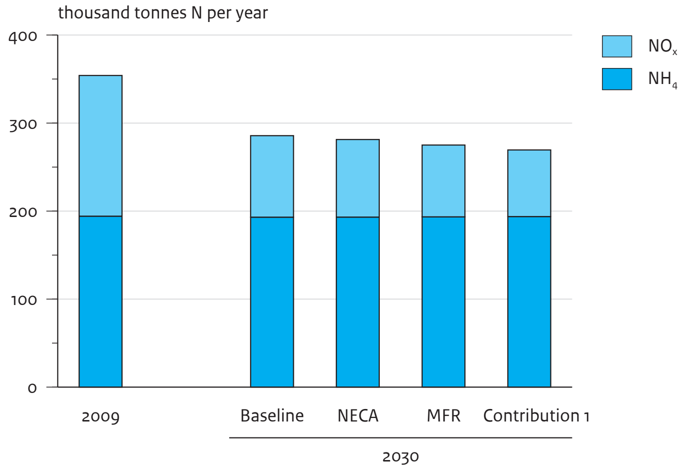
decrease when emissions are sufficiently reduced. This decrease is consistent with the decrease in excess nitrogen loads as indicated in Table 3.6.

3.4 Marine ecosystem impacts

Despite substantial reductions in nutrient inputs to the North Sea over the last decades, eutrophication still poses a threat to the ecosystems in coastal areas and a number of more distant offshore areas (OSPAR, 2009a). In these areas, increases are observed in the accelerated growth of algae in the water column and higher forms of plants living on the sea floor. This has resulted in a range of undesirable disturbances in the marine ecosystem. This includes shifts in the composition of the flora and fauna, which affects habitats and biodiversity and depletes oxygen levels, causing the death of fish and other species.

Coastal eutrophication problems are not only caused by increased nutrient loads (nitrogen and phosphorus) but also by imbalances in the available nitrogen, phosphorus and silica (Turner et al., 1998). These imbalances favour the growth of certain algae species. The observed nitrogen excess with respect to phosphorus possibly

Figure 3.10
Nitrogen deposition in the North Sea



Source: PBL (based on NMI-EMEP calculations)

explains the successful development of species such as Phaeocystis (associated with foam events) and Chrysochromulina (producing toxins) in the North Sea (Lancelot et al., 1987; Dahl et al., 2005). This imbalance has increased over the last decade due to the successful abatement of phosphorus through waste water treatment and the less successful abatement of nitrogen due to the insufficient implementation of agro-environmental measures (Billen and Garnier, 2007).

Eutrophication problems in the North Sea are tackled by the Oslo–Paris commission for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) and the European Union's Marine Strategy Framework Directive (EU, 2008). One of the objectives of the OSPAR Commission is to achieve and maintain by 2020 that all parts of the OSPAR maritime area have the status of non-problem area with regard to eutrophication. To achieve its objectives, the OSPAR Commission focuses on monitoring the ecological status of marine waters, evaluating the effectiveness of mitigation measures and identifying further actions needed to achieve non-problem status. The European Union's Marine Strategy Framework Directive has a similar goal, stating that human-induced eutrophication should be minimised, and in particular the adverse effects it has on the marine environment. To do so, the EU has taken steps to reduce nitrogen and phosphorus loads in the environment, notably through the adoption of several crucial pieces of legislation such as the Nitrate Directive, the Urban Waste Water Treatment Directive and the Water Framework Directive.

Due to EU policies or those induced by the OSPAR Commission, the atmospheric deposition of nitrogen decreased by about 15% in the North Sea over the 1995–2006 period (OSPAR, 2009b). The annual riverine nitrogen input to the North Sea decreased by 20% over the 1990–2006 period (OSPAR, 2009c). In 2009, rivers and direct tributaries discharged 814 thousand tonnes nitrogen into the North Sea (OSPAR, 2011), and atmospheric deposition contributed about 350 thousand tonnes in the same year (Figure 3.10, Table 3.7). A substantial amount of nutrients also enters the North Sea through the English Channel boundary (Troost and Los, 2011). Nitrogen outputs occur through biochemical processes (denitrification and the sedimentation of detritus and algae) and at the northern boundary with the Atlantic Ocean. The exchange of waters between the North Sea and the Baltic Sea is limited due to geomorphological and climatological reasons. The limited exchange leads to a long residence time of waters in the Baltic Sea, which is one of the causes that explains the high sensitivity to eutrophication there.

A recent study by Troost and Los (2011) suggests that atmospheric deposition may be important with respect to eutrophication in North Sea waters. Their model analysis for 2002 estimates that about 5% of the total nitrogen and 7% of the algal nitrogen in the whole North Sea originates from atmospheric deposition. The atmospheric contribution to these parameters can be as large as 15% for areas further away from the shore and from the influences of rivers and land-based emission sources, such as the sensitive Dutch 'Oystergrounds' area.

Table 3.7
Reductions in average annual nitrogen deposition at the sea surface

Pollutant		2030	Reduction by 2030 in the scenarios and a case		
	2009	baseline	NECA	MFR	CONTR.I
	thousand tonnes per year		%		
Oxidised nitrogen	160	93	-4.9	-11.9	-18.3
Reduced nitrogen	194	193	0.1	0.2	0.3
Total nitrogen	**354**	**286**	**-1.5**	**-3.7**	**-5.7**

Source: PBL (based on NMI-EMEP calculations)

Looking at a larger scale may thus lead to an underestimate of the importance of atmospheric deposition in some sensitive areas. Troost and Los further show that atmospheric nitrogen deposition does indeed affect the ecosystem functioning. Not only nitrate concentrations in winter are increased, but concentrations of organic substances (algae, detritus) in summer are also higher. The algal system is thus effectively consuming the atmospheric nitrogen and its inputs are not competing with other nitrogen sources but supplementing them. The largest effects were found in offshore areas and areas just outside the most productive coastal regions.

This study shows that the atmospheric deposition of nitrogen on the North Sea and also on the Baltic Sea is projected to decrease under current air policies by about 20% between 2009 and 2030 (Figure 3.10, Table 3.7). Most of the reductions will be achieved by nitrogen oxide reductions in Europe, while ammonia emissions will be reduced only a little without new policies for agriculture (Figure 2.6, Table 2.7). The deposition of nitrogen on North Sea waters in 2030 ranges from 500–600 moles per hectare per year along parts of the North Sea coast to a few hundred moles further north in the area (Figure 3.5, left).

The total nitrogen deposition on the North Sea can be further reduced by about 2% (5 thousand tonnes) and 4% (10 thousand tonnes) in the NECA and MFR scenarios, respectively. The contribution of North Sea shipping to total nitrogen deposition in 2030 (286 thousand tonnes) is estimated at about 6% (16 thousand tonnes). The contribution of shipping in 2009 is lower as land emissions are now relatively higher. The contribution of North Sea shipping to total nitrogen deposition is highest in the English Channel, along the coasts of Belgium and the Netherlands and in the middle of the North Sea (where land sources contribute less) (Figure 3.5, right). North Sea shipping contributes about 2.5% (3 thousand tonnes) to the nitrogen deposition on the Baltic Sea. The NECA and MFR scenarios reduce this contribution by 1 and 2 thousand tonnes, respectively.

The current analysis is too limited to assess the impact of a nitrogen emission control area in the North Sea on the eutrophication status in 2030. This would at least require scenarios for 2030 for riverine inputs and inputs and fluxes over the North Sea boundaries, as well as a suitable North Sea ecosystem model. Also, one has to consider that the objectives of the OSPAR Commission and the EU Marine Strategy Framework Directive are to solve the eutrophication problems before 2020. From the above, it is clear that the contribution of a nitrogen emission control area to less nitrogen deposition in the North Sea will be limited. The nitrogen emission control area does contribute to an improved balance between nitrogen and phosphorus which may counteract the growth of non-siliceous algae. In addition, a nitrogen emission control area reduces the input of nitrogen in more remote North Sea areas, where the primary production of phytoplankton is more limited by nitrogen (Skogen et al., 2004).

FOUR

Costs and benefits

This chapter first presents an estimate of the monetised health benefits of a nitrogen emission control area and information on benefits to crops and ecosystems. A summary is given of the cost estimate of a nitrogen emission control area from the economic impact assessment made by the Danish EPA (2012). A cost-benefit analysis is subsequently presented. The costs and benefits of the NECA sea-based air policy scenario are compared with those of land-based air policy scenarios.

4.1 Health benefits

The monetisation of the health impacts of the nitrogen emission control area scenarios seeks to account for a number of factors relevant to the specific effect under consideration (for more information see Hurley et al., 2005):

- costs of medication and medical care;
- lost productivity;
- cost of pain, suffering, aversion to the risk of ill health or premature death.

The first element is quantified using data on the costs of medicines, hospital stays, and so on. The second element is based on data from companies indicating average productivity per worker. The third element is quantified from the perspective of willingness to pay (WTP) to reduce risk or willingness to accept (WTA) money to compensate for added risk. WTP and WTA are standard economic concepts – indeed, no legal economic activity can exist without two parties, one willing to pay a certain amount and another willing to accept that amount in exchange for goods of some description. A variety of techniques have been used to quantify this element including questionnaire-based surveys and market analysis. An example of the latter concerns wage-risk studies, which consider the additional wages paid to workers in risky occupations relative to wages for workers with similar skills but operating in safer environments.

The main form of health damage in air pollution assessments, when impacts are converted to their monetary equivalent, concerns effects on mortality (see, for example, Holland et al., 2011). This parameter can be valued in two ways, either as the number of deaths linked to a particular cause using the 'value of a statistical life' (VSL) or the resulting loss of life expectancy using the 'value of a life year' (VOLY). The text box below goes into more detail on the derivation of the VSL and the VOLY. Preference here, for the most part, goes to the VOLY as we regard air pollution at levels typical in the North Sea region to be a contributing factor to death (albeit, potentially, an important factor rather than the principal cause). However, effects on infant mortality quantified for children aged between one month and one year are valued using the VSL. Sensitivity analysis based on the use of the VSL for effects of $PM_{2.5}$ on mortality is also reported briefly below. To reflect the importance of this element of the benefits analysis, we performed a further sensitivity analysis exploring the consequences of the various different valuations of mortality.

Box 1. Deriving the Value of a Statistical Life or the Value of a Life Year

For many years the Value of a Statistical Life (VSL) has been used as a measure of preference for options that change the risk of a fatality. The VSL has been derived using a number of techniques, of which the most prominent are wage-risk (revealed preference) and contingent valuation (stated preference) methods. Wage-risk studies consider the wage premium paid to workers in occupations where there is a heightened risk relative to workers with a similar skill level in less risky occupations. The VSL is calculated by dividing the wage differential by the risk differential. Contingent valuation (CV) studies take a questionnaire-based approach to elicit an individual's willingness to pay (WTP) for an increased level of protection against the risk of death, with VSL calculated by dividing WTP by the change in risk considered.
In the United States there is preference for the results of the wage-risk studies, whilst in Europe, Canada and Australia the CV approach is more widely followed. As a result, US valuations tend to be significantly higher than those used in Europe and elsewhere. Both types of study have been reviewed in a recent report for OECD (2012). There is an implied preference in the OECD report for the CV studies.

In the early 1990s, European experts working on the EC-funded 'External costs of Energy' project (ExternE, 1995–2005) became concerned about the application of the VSL for air pollution mortality for several reasons. First, those whose deaths were associated with short-term exposure to air pollution at levels typical in Europe at the time were thought unlikely to have long to live in any event. Secondly, deaths linked with longer-term exposure were considered unlikely to be due to air pollution alone, but only one of several stresses on the body. Therefore, whilst the loss of life expectancy could be significant and clearly required valuation, the ExternE team concluded that the use of a full VSL was neither appropriate nor in the wider interests of society. They therefore developed the concept of the value of a life year (VOLY).

The VOLY is derived from CV studies in which individuals are asked how much they are willing to pay to avoid a risk of losing some quantity of life expectancy (for instance three or six months). WTP is, as for the VSL, then divided by the risk to quantify the VOLY. Methods used to construct questionnaires and interview participants have evolved substantially over the years to mitigate biases that could influence the results. The VOLY concept is not universally accepted as it is, for example, not used by USEPA, and it is the subject of a substantially smaller literature than exists for the VSL. However, it has been used extensively for analysis to support decision-making by the EC, who have used it alongside the VSL. Some governments, for example in the United Kingdom, use only the VOLY valuation. A prominent recent example of calculation of the VOLY is a paper by Desaigues et al. (2011). Their values are also included in this assessment of costs and benefits.

The following data (Table 4.1) for the valuation of health impacts have been used by Holland et al. (2011) to inform the revision of the Gothenburg Protocol by the UNECE and for the EU NEC Directive. One additional estimate has been added for mortality valuation – the lower bound of our range of 40,000 euros for the VOLY, taken from Desaigues et al. (2010). This is included to supplement the other VOLY estimates on the basis that there is as yet rather limited literature on this parameter (though it should be added that the VOLY estimates are broadly consistent with the much more extensive literature on VSL).

These values were applied to the impacts described above to generate the monetised annual health benefits for the EU27, Norway and Switzerland (Tables 4.2 and 4.3), per European country or aggregated for the eight North Sea countries (Annex 7). We estimated that 85% of all health benefits due to a nitrogen emission control area are seen in the North Sea coastal countries. The countries with the largest health benefits (in order of decreasing magnitude) are the United Kingdom, Germany, France and the Netherlands. Belgium and the Scandinavian countries receive relatively smaller benefits. This is of course driven to a significant degree by differences in national population. Almost 70% of the health benefits are related to chronic mortality through exposure to particulate matter and almost 30% to morbidity due to particulate matter (Figure 4.1). Only a few per cent of the health benefits are related to ozone impacts on mortality and morbidity.

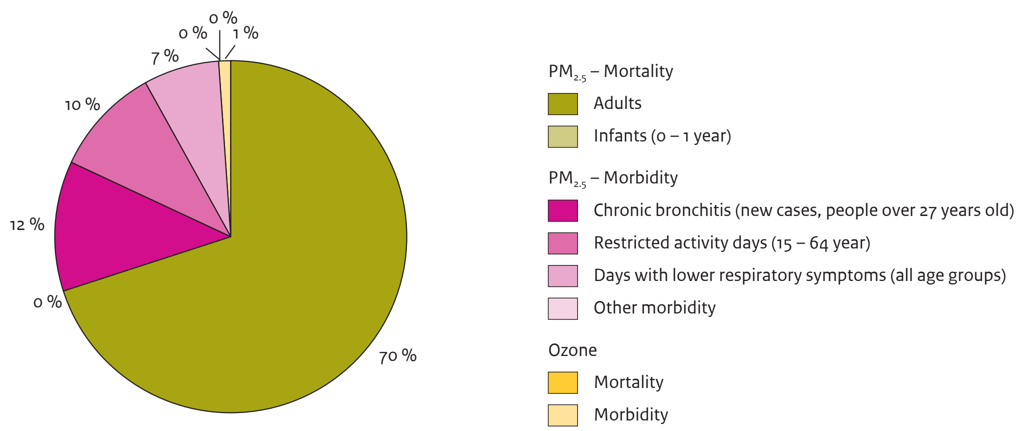
The above benefits were calculated based on a relatively older fleet age profile in 2030 that was derived from current global ship data (Section 2.2). The fleet age profile in 2030 derived by the Danish EPA was based on specific data for the current North Sea fleet and a different approach to modelling fleet renewal. The latter profile results in a somewhat younger fleet, therefore a somewhat larger share of ships that must meet the nitrogen emission control area requirements in 2030. A larger share of Tier III in 2030 leads to a larger reduction in both nitrogen oxide emissions (about 16%) and the related costs of nitrogen oxide abatement (about 16%).

Table 4.1
European average monetary values used for health impacts in the analysis (price year 2012)

Health impact	Value	Euros
Mortality (life years lost, VOLY valuation: low, mid and high)	47,120 / 67,150 / 156,670	per case
Mortality (deaths, VSL valuation: low and high)	1,280,490 / 2,613,980	per case
Infant mortality (1–12 months: low and high)	1,920,700 / 3,920,970	per case
New incidence of chronic bronchitis	245,024	per case
Respiratory and cardiac hospital admissions	2,615	per case
Restricted activity days, working age population, per day	108	per day
Respiratory medication use, per day	1	per day
Days of minor restricted activity	49	per day
Lower respiratory symptoms, per day	49	per day

Source: PBL (based on Holland et al., 2011)

Figure 4.1
Contribution to health benefits from a nitrogen oxide emission control area, 2030 NECA



Source: PBL (based on EMRC calculations)

This leads to an almost linear increase in environmental and health benefits (about 16%), see Section 5.1. The monetised health benefits of a nitrogen emission control area in 2030, assuming a relatively younger fleet, are given in Table 4.4.

4.2 Benefits to crops

Benefits will also accrue through reduced damage to building materials (stone, metals, etc.) and to crops through reduced ozone exposure. The latter effect may be partly compensated for by reduced crop growth as a consequence of reduced nitrogen deposition, though this is dependent on farming practice and the extent to which nitrogen fertilizer is applied.

Neither effect has been considered in detail here as past analysis has strongly suggested that damage to materials and crops is substantially less important than effects on health, as described above. For the scenarios investigated here, where only nitrogen oxides are abated, associated benefits for materials seem likely to be negligible given that response functions developed by the UNECE Task Force on Materials over many years demonstrate a far more important role for sulphur dioxide than nitrogen oxides (see the functions listed by Tidblad and Kucera, 2007).

Table 4.2
Monetised annual health impacts in the EU27 and Norway and Switzerland

Health impact	Mortality valuation	2009	2030 baseline	2030 NECA	2030 MFR	2030 CONTR.I	2030 CONTR.II
Quantification against ozone		**million euros per year**					
Acute mortality (all ages, premature deaths)	Low	1,231	1,048	1,046	1,039	1,027	1,026
	Mid	1,776	1,511	1,509	1,500	1,481	1,481
	High	4,270	3,634	3,627	3,605	3,560	3,559
Respiratory hospital admissions (65yr+, cases)		61	62	62	62	61	61
Minor restricted activity days (15–64yr)		3,203	2,166	2,163	2,150	2,123	2,122
Days with respiratory medication use (adults 20yr+)		27	21	21	21	20	20
Quantification against $PM_{2.5}$		**million euros per year**					
Exposure chronic mortality (years of life lost)	Low	84 434	48,153	47,923	47,592	47,290	47,005
	Mid	121,796	69,460	69,129	68,653	68,214	67,803
	High	292,774	166,969	166,173	165,027	163,976	162,987
Exposure chronic mortality (deaths)	Low	215,889	156,705	155,971	154,914	153,948	153,049
	High	439,700	319,160	317,664	315,513	313,547	311,715
Infant mortality (0–1yr, deaths)	Low	644	300	299	297	296	293
	High	1,330	620	616	613	609	605
Chronic bronchitis (27yr+, new cases)		14,536	9,492	9,410	9,293	9,182	9,072
Respiratory hospital admissions (all ages, cases)		79	51	51	49	49	49
Cardiac hospital admissions (all ages, cases)		48	31	31	31	31	31
Restricted activity days (15–64yr)		17,658	10,065	10,017	9,946	9,882	9,822
Days with respiratory medication use (children 5–14yr)		2	1	1	1	1	1
Days with respiratory medication use (adults 20yr+)		16	11	11	11	11	11
Days with lower respiratory symptoms (5–14yr)		3,851	2,407	2,394	2,376	2,360	2,343
Days with lower respiratory symptoms (15yrs+)		7,049	4,535	4,513	4,481	4,452	4,425
Total damage (with VOLY low)		136,378	80,998	80,619	80,060	79,527	79,061
Total damage (with VOLY mid)		174,931	103,070	102,586	101,877	101,202	100,608
Total damage (with VOLY high)		349,087	203,020	202,066	200,672	199,356	198,181
Total damage (with VSL low)		269,023	190,314	189,427	188,140	186,936	185,854
Total damage (with VSL high)		496,013	355,212	353,557	351,158	348,927	346,909

Source: PBL (based on EMRC calculations)

Table 4.3
Monetised health benefits in 2030, relative to the baseline for the EU27, Norway and Switzerland

Total benefits by valuation	NECA	MFR	CONTR.I	CONTR.II
	million euros per year			
Total benefits (VOLY, low)	380	938	1,471	1,937
Total benefits (VOLY, mid)	484	1,192	1,868	2,462
Total benefits (VOLY, high)	954	2,348	3,665	4,839
Total benefits (VSL, low)	887	2,176	3,379	4,461
Total benefits (VSL, high)	1,655	4,052	6,285	8,303

Source: PBL (based on EMRC calculations)

Table 4.4
Monetised health benefits of the NECA scenario in 2030 relative to the baseline for the EU27, Norway and Switzerland, adjusted for a younger fleet age profile in 2030 (see Section 2.2)

Total damage per valuation	NECA
	million euros per year
Total damage (VOLY, low)	443
Total damage (VOLY, mid)	564
Total damage (VOLY, high)	1,112
Total damage (VSL, low)	1,033
Total damage (VSL, high)	1,928

Source: PBL (based on EMRC calculations)

Table 4.5
Benefits to arable crop production from reduced ozone exposure in the North Sea countries

Countries	NECA	MFR	CONTR.I
	2012, million/year		
Belgium	0.2–0.5	1.4–2.1	3.5–5.4
Denmark	0.7–1.8	1.9–4.9	3.4–8.8
France	3.4–8.1	9.0–21	15–38
Germany	3.2–6.8	8.7–19	15–32
Netherlands	-0.4– -0.5	1.6–2.5	8.6–13
Norway	-0.4–0.1	0.1–0.2	0.2–0.5
Sweden	0.0–0.6	0.4–1.5	0.6–2.5
United Kingdom	1.6–2.8	4.9–8.8	10–18
Total	9.1–20	28–60	58–118

Source: PBL (based on EMRC calculations)

For the effects of ozone on crops we have applied the percentage change in AOT40 concentrations in each country (using data from Table A5.5) to the range of crop damage estimates presented for different scenarios, from current legislation to maximum feasible reduction, by Holland et al. (2006). Whilst the Holland et al. scenarios are different from those considered here, being focused on 2020 rather than 2030, they do at least provide a range for which a rough estimate of possible benefits can easily be generated. Results for the North Sea countries are shown in Table 4.5; results for other European countries are presented in Annex 7. Total benefits in all European countries are equivalent to between 3% and 7% of the quantified health benefits in the NECA scenario (using VOLY mid). In view of the rough estimate, results on crops impacts have not been factored directly into the comparison of costs and benefits. However, their effect on results is discussed in Chapter 5, 'Uncertainties'.

4.3 Benefits to marine and terrestrial ecosystems

The visibility of the ecological benefits of environmental measures in a cost-benefit analysis is important since neglecting it could lead to policy decisions that degrade ecosystem services and biodiversity further and thereby negatively impact a range of economic and social objectives. Examples of such ecosystem services are food and fish, nutrient regulation, air quality and climate, drinking water, recreation on land and in water.
Several attempts have been made to quantify the welfare effects of ecological changes (TEEB, 2010), but no standard methodology for the monetisation of these types of welfare effects is yet available. In recent literature, the links between nature and the economy are often described using the concept of ecosystem services (MA, 2005) or the benefits humans obtain from the goods and services provided by ecosystems. Following this concept, nitrogen deposition results in changes in the generation of ecosystem services and biodiversity that in turn lead to welfare effects. Ideally, the valuation of such welfare effects of changes in ecosystem services is based on the willingness to pay of consumers and firms to protect or enhance biodiversity. Unfortunately, scientifically sound methods and data for quantifying the benefits of pollution control measures to ecosystem services are lacking. Benefits to marine and terrestrial ecosystems have therefore not been factored into the comparison of costs and benefits. This leads to a bias to underestimate the total benefits of a nitrogen emission control area compared with the costs (see Chapter 5, 'Uncertainties'). A limited overview is given of recent information on the subject below.

Benefits to marine ecosystems

With regard to marine ecosystems, limited information is available, for example, on the willingness to pay for a clean Baltic Sea and for clean coastal waters in the Dutch delta. The willingness to pay for a clean Baltic Sea was estimated in Söderqvist and Hasselström (2008). People in the Baltic countries were sent a questionnaire from which it was possible to infer the respondent's willingness to pay for measures that would reduce eutrophication to a sustainable level in the Baltic Sea. Despite several assumptions and other methodological shortcomings, Söderqvist and Hasselström state that their results for this 'willingness to pay' are a rough indication of the substantial benefits that society would receive from achieving an undisturbed Baltic Sea. The estimated willingness to pay ranged between 650 and 800 euros per household for Denmark, Sweden and Germany, which also border the North Sea. Based on the 'willingness to pay' analysis by Söderqvist and Hasselström, Gren et al. (2008) report a range in unit damage costs of between 12 and 24 euros per kilogram of nitrogen for the whole Baltic basin, using different discount rates. A nitrogen emission control area would avoid part of such damage costs.

In Aquamoney (2009), Dutch respondents were questioned about their willingness to pay for measures that would lead to a good ecological status in the Dutch part of the Scheldt river basin, in comparison with the status quo (poor status). The Scheldt river basin is part of the Dutch delta, is openly connected to the North Sea and can be regarded as part of the Dutch coastal waters. For the Dutch study, three sites in the lower Scheldt sub-basin were chosen: the beaches near Breskens, Braakman creek and the nature area 'Drowned Land of Saeftinghe'. The inferred mean willingness to pay for these sites ranged from 121 to 188 euros per household per year. Moreover, the study found that the respondents' willingness to pay decreased with increasing distance to the site (distance decay). This observed site dependency related to the willingness to pay for clean waters in the Dutch delta probably also applies to a clean North Sea.

The above studies show that people in the North Sea countries are willing to pay for a clean or cleaner North Sea. However, the available information is insufficient to be able to estimate reliable benefits related to avoided ecosystem damage due to a nitrogen emission control area.

Benefits to terrestrial ecosystems

Information on the willingness to pay for restoring biodiversity in eutrophic terrestrial ecosystems is lacking. However, there are examples of countries that are willing to pay for restoring such eutrophic terrestrial ecosystems. One example is the Dutch 'Programme Approach to Nitrogen' (PAS). This programme aims to improve or maintain the biodiversity inside Nature 2000 areas while allowing for growth in regional agricultural activities. The programme focuses on the abatement of nitrogen emissions and the restoration of habitats and species threatened by nitrogen deposition in Nature 2000 areas. The national abatement measures in the programme focus mainly on additional ammonia emission reductions in agriculture. The restoration measures will be specific for each Nature 2000 area and could include measures such as reducing nitrogen by mowing, sod cutting or digging off soil layers, changing groundwater levels or improving groundwater quality. A budget of 120 million euros has been set aside by the Dutch government and provinces for the programme in the period 2011 to 2014 (EL&I, 2011).

As an alternative to information on 'willingness to pay', other studies sometimes use information on unit cost estimates of terrestrial ecosystem damage due to reactive nitrogen. With such information, the benefits of a nitrogen emission control area should be seen as prevented damage costs. In Brink and Van Grinsven (2011), the Braat and Ten Brink (2008) TEEB–COPI study is referred to in which a damage unit cost of 2.2 euros per kilogram of deposited nitrogen was estimated for the ecosystem service 'water purification and waste management', both for scrubland and grassland. Based on a study by Pretty et al. (2003), Brink and van Grinsven inferred a damage unit cost of 0.3 euros per kilogram of deposited nitrogen for freshwater eutrophication in England and Wales. Another reference to such damage unit costs is the NEEDS study by Ott et al. (2006). They present a European approach in which the welfare effect of an increase in biodiversity (due to less nitrogen deposition) is approximated by means of restoration costs: what would it cost to restore a unit of land area with a lower biodiversity value to a unit with a higher biodiversity value? A number of simplifications and rough assumptions were made in the study to derive restoration costs related to excess nitrogen oxide depositions. Their estimates of the unit damage cost due to nitrogen deposition (causing eutrophication) for the EU-25 range from 0.4 to 10 euros per kilogram, with an average of 2.5 euros. A benefit of a nitrogen emission control area would be that fewer costs are required to restore biodiversity to a desired level.

The above information shows that countries may be willing to spend money to protect terrestrial ecosystems, also against the damage to biodiversity caused by excess nitrogen inputs. The available information and methods are however insufficient to estimate reliable benefits for all North Sea coastal countries related to the nitrogen emission control area.

4.4 Costs of a nitrogen oxide emission control area

The economic impacts, including total costs, of a nitrogen emission control area were examined in the economic impact assessment study by the Danish EPA (2012). Other aspects that were examined relate to the cost-effectiveness of different nitrogen oxide reduction technologies for sea shipping that meet the nitrogen emission control area requirements and indirect economic impacts, such as potential modal shift and economic impacts on shipping companies.

The basis of the Danish EPA cost assessments are the unit cost estimates for all relevant technologies complying with the Tier III nitrogen oxide emission standards. They found that both the Selective Catalytic Reduction (SCR) and Exhaust Gas Recirculation (EGR) technologies are able

Table 4.6
Costs and cost-effectiveness of the nitrogen emission control area in the North Sea in 2030 under different fleet age profiles (in 2012 euros, 4% discount rate)

	Fleet age profile	Nitrogen oxide reduction NECA 2030 – central case (thousand tonnes)	Cost NECA (million euros)	Cost-effectiveness (euros per kg reduced nitrogen oxide)
This report	Older	129	243[1] (109–334)[1]	1.9 (0.8–2.6)
Danish EPA, 2012	Younger	150[2]	282 (127–389)	

1) Costs based on the Danish EPA, 2012 and adjusted downwards to account for a relatively older fleet age profile.
2) Reduction based on this report and adjusted upwards to account for the younger fleet age profile used by the Danish EPA (2012).
Source: PBL and Danish EPA, 2012.

to meet these nitrogen oxide standards. The unit costs were derived based on interviews with key industry experts and existing studies. From these unit costs, the most cost-efficient technology choice was identified for different ship engine types and sizes. The analysis shows that EGR is a more cost-efficient solution for two-stroke main engines while SCR is more cost-efficient for four-stroke main engines and four-stroke auxiliary engines. This information was combined with the Danish EPA fleet projection for 2030 to derive the total cost of a nitrogen emission control area.
The total cost of a nitrogen emission control area was estimated at to be 282 million euros in 2030, with a range from 127 to 389 million euros, based on a low and high cost estimate (2012 prices, Danish EPA, 2012). The cost-effectiveness was estimated at 1.9 euros per kilogram reduced nitrogen oxides, with a range of 0.8 to 2.6 euros per kilogram, based on a low and high cost estimate.

The above costs were calculated by the Danish EPA based on a fleet age profile in 2030 that was derived from ship age data specific to the North Sea in 2010. In this assessment study, we derived the fleet age profile for container ships and other ship types in 2030 from current global ship data, which results in a somewhat older fleet age profile. This in turn results in a somewhat smaller share of ships that must meet the nitrogen emission control area requirements in 2030. A smaller share of Tier III in 2030 leads to a smaller reduction in nitrogen oxide emissions (about 16%) and related nitrogen oxide abatement costs (about 16%), as well as to an almost linear decrease in environmental impacts and benefits (about 16%), see Sections 2.2 and 5.1.

We therefore found that the benefit to cost ratio and the cost-effectiveness of a nitrogen emission control area do not change significantly under these different fleet age profile assumptions. Only the absolute costs and benefits would change under different fleet age profile assumptions in 2030, by about 16%. To compare the benefits and costs in the next section we adjusted the above cost estimates downwards by 16% (Table 4.6). Vice versa, the benefits were also adjusted upwards in Table 4.4 in order to compare the benefits based on a younger fleet age profile with the above costs.

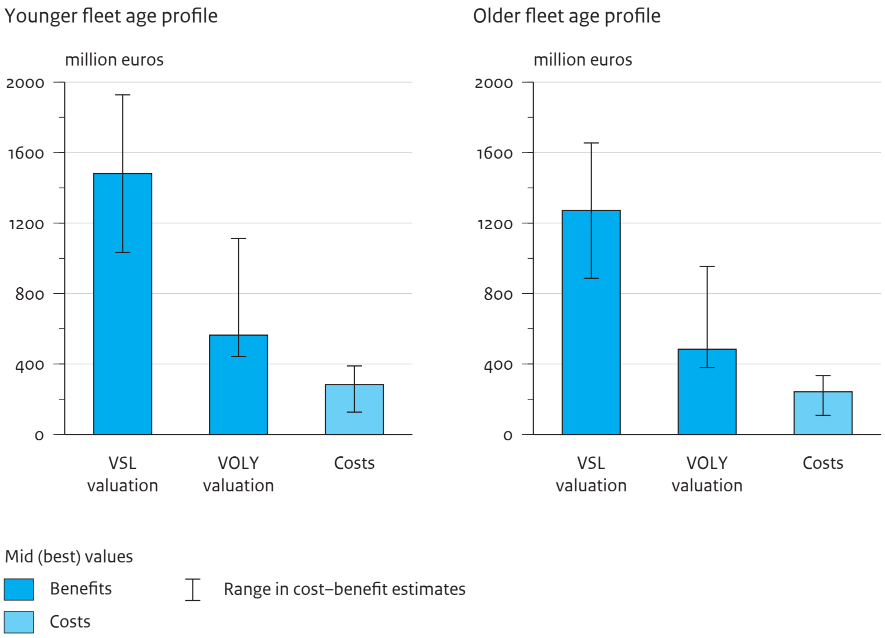
The economic assessment study did not make cost estimates for the maximum feasible reduction (MFR) scenario in this report (Section 2.3). In this scenario, all ships in 2030 (built before or after 2016) must comply with the nitrogen oxide Tier III emission standards. In reality, this would involve installing (retrofitting) nitrogen oxide reduction equipment on a significant number of older ships that were built before 2016. Retrofitting is in general more costly than installing such equipment on new ships.

Danish EPA (2012) also show interesting results on how the relative cost per unit reduced nitrogen oxide of an emission control area in the North Sea increases if there is no such emission control area in the Baltic Sea. In this situation, all the investment costs for nitrogen emission control on ships that enter both seas would be assigned solely to the North Sea. This also implies that the costs for the North Sea would decrease if more sea areas around the EU were designated nitrogen emission control areas. The total cost of all the considered nitrogen emission control areas would of course increase as a result.

4.5 Comparing costs and benefits of a nitrogen oxide emission control area

The monetised health benefits (Section 4.1) were compared with the costs (Section 4.4) of a nitrogen emission control area, see Figure 4.2. The applied ranges in the valuation of health impacts and the upper and lower range in cost estimates were also taken into

Figure 4.2
Costs and benefits of a nitrogen emission control area in the North Sea, 2030



Source: PBL (costs taken from Danish EPA 2012)

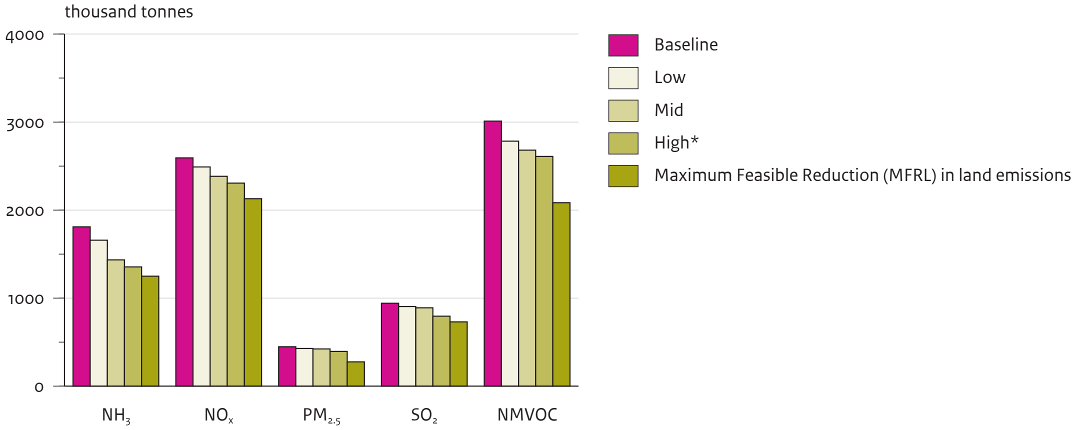
account. Moreover, the impact on the benefits and costs is shown for a relatively older or younger fleet in 2030. The benefits and costs show that the introduction of a nitrogen emission control area in the North Sea from 2016 onwards is cost-effective as it leads to net benefits in 2030 in Europe (Figure 4.2). The benefits exceed the costs by a factor of two, based on an estimate towards the lower end of the range adopted here for mortality valuation (middle VOLY value) and a middle value for costs. The cost-benefit test is also passed in the least favourable situation (factor of 1.1), with a low value attributed to health impacts and a high cost estimate. This excludes benefits to ecosystems and crops. Much higher benefit to cost ratios were found in the most favourable situation, with a high value (VSL value) attributed to health impacts and a low cost estimate. The benefit to cost ratios do not change for a relatively older or younger fleet in 2030, although the absolute benefits and costs differ by about 16%.

The health benefit assessment above was carried out using the same methods and models as those that are used to support the developments in air policy in the EU and the UNECE region. This has been done to enhance the comparability of this study with recent studies dealing with land-based air policy measures. The costs and benefits of the 'land' studies are explored hereafter and, where possible, a comparison is made between the costs and benefits of land and sea-based air policy measures.

4.6 Costs and benefits of land-based air quality measures

Costs and benefits of land-based policy scenarios
The costs and benefits and the cost-effectiveness of the nitrogen emission control area in 2030 could only be compared with those of European policy scenarios with land-based emission control measures in 2020 (Holland et al., 2011). As mentioned before, the methods used here in the cost-benefit analysis for a nitrogen emission control area were as much as possible aligned with the methods used in the cost-benefit analysis for the land-based policy scenarios (Section 1.3). It is important to mention that these methods take into account the location of emissions and reductions through measures and the distance to sensitive receptors such as densely populated areas and ecosystems. In other words, these methods reveal how efficiently the health and ecosystem effects can be reduced per unit cost of emission control measures. The policy scenarios for land-based sources not only include emission control measures for nitrogen oxide, but also for ammonia, particulate matter, sulphur dioxide and non-methane volatile organic compounds.

Figure 4.3
Total emissions according to the air policy ambitions that were considered in the Gothenburg protocol revision for the North Sea countries, 2020



Source: PBL (based on CIAM 2011a)

The different target years and different pollutant control measures compel us to some caution with regard to drawing too strong conclusions from the comparisons made.

Information on land-based measures has recently been updated in CIAM (2011a) to serve as an input to the revision of the Gothenburg Protocol (GP) under the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP). This revision aims to set new emission reduction obligations for 2020, relative to 2005, for nitrogen oxides, sulphur dioxide, ammonia, non-methane volatile organic compounds and particulate matter ($PM_{2.5}$). The Gothenburg Protocol is an important element in European air quality policy (for land-based sources). The analysis done in the revision of the Gothenburg Protocol also serves as an input to the upcoming revision in 2013 of the National Emission Ceilings Directive (NECD) of the EU. It is not clear yet whether the revision of the NECD will aim to set such reduction obligations for the year 2020 or afterwards (2025 or 2030).

Policy scenarios representing different ambition levels aimed at improving health and ecosystem impacts in 2020 were explored in the context of revising the Gothenburg Protocol, using the GAINS model. The potential for improvements ranges from impacts caused by the air quality in the baseline situation (emissions under Current Legislation, CLE) and an improved situation in which all available technical reduction measures have been implemented at stationary land-based sources. The latter situation is referred to in this report as the maximum feasible reduction scenario on land (MFRL). Within this range, five policy ambition levels were chosen, Low, Low*, Mid, High* and High, each leading to additional improvements in health and/or ecosystem impacts relative to the previous ambition. The higher the ambition level, the higher the reductions in air polluting emissions (Figure 4.3). For practical reasons we have included only the Low, Mid and High* scenarios in the comparisons made here.

The average (or quasi-marginal) benefit to cost ratios of the policy scenarios in the Gothenburg Protocol revision range from 35 for the Low scenario to 7 in the High* scenario (Table 4.7). The extra costs for the MFRL scenario exceed the extra benefits, which results in a ratio below one. The variation in ratios between the countries in the scenarios is relatively large, with higher ratios in Germany and France and lower ratios in the Scandinavian countries and the Netherlands. The Mid scenario shows that the costs are expected to exceed the benefits in a number of countries.
Up to the High* ambition, the estimated benefit to cost ratios averaged over the eight North Sea countries exceed the estimated ratio of two resulting from a nitrogen emission control area in 2030 (Figure 4.4). This indicates that there is still a potential for land-based emission control measures that yield higher benefits on land at lower costs, at least in the shorter term. This is most likely explained by the more cost-effective reductions in health impacts through ammonia measures in agriculture, in particular, a limited amount of relatively cheap nitrogen

Table 4.7

Benefit-to-cost ratio of air quality scenarios for 2020 in the Gothenburg Protocol revision, relative to the preceding scenario (quasi-marginal analysis)[1]

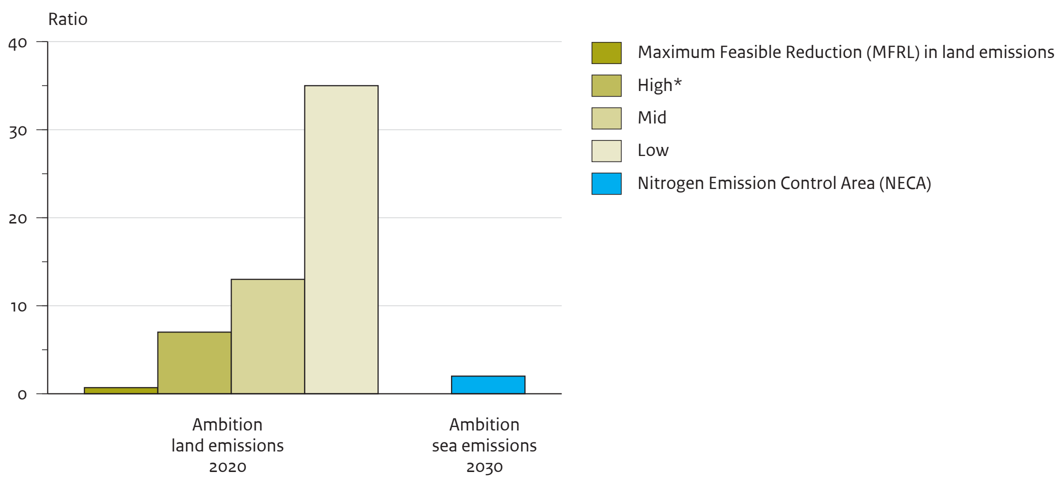
Countries	LOW	MID	HIGH*	MFRL
Belgium	37.6	5.0	9.9	0.9
Denmark	9.0	6.2	2.3	0.4
France	49.4	16.5	9.1	0.7
Germany	46.7	20.6	8.7	0.9
Netherlands	13.7	0.6	3.0	0.7
Norway	5.4	0.4	0.8	0.3
Sweden	9.3	0.5	2.9	0.4
United Kingdom	26.8	9.9	7.0	0.6
Average	**35**	**13**	**7**	**0.7**

1) Mortality valued using the median VOLY from the NEWEXT study. EU average Power Purchasing Parities (PPP) values and all health impacts in the EU from national emissions reductions were accounted for

Source: derived from Tables A3.2 and A4.9 from Holland et al., 2011

Figure 4.4

Comparison between cost–benefit ratios of air quality policy ambitions in the eight North Sea countries and for the North Sea



Source: PBL (ambitions on land emissions derived from CIAM 2011a and Holland et al., 2011)

oxide measures in industry, and, to a lesser extent, particulate matter measures in industry and agriculture. A similar comparison with benefit to cost ratios related to nitrogen deposition in North Sea waters could not be made.

The low and medium ambitions for land-based emission control measures reduces the total years of life lost in the North Sea coastal countries in the short term (2020) by approximately 5 and 11 per cent, respectively. As shown in Section 3.2, a nitrogen emission control area would reduce nearly 1 per cent of the total years of life lost from air pollution in the North Sea coastal countries by 2030, and would continue to have an increasing share in the years after 2030.

Cost-effectiveness of land-based policy scenarios

The cost-effectiveness of the nitrogen emission control area by 2030 may also be compared with the cost-effectiveness of the nitrogen oxide measures that are taken in the above policy scenarios of the Gothenburg Protocol revision for 2020 (CIAM, 2011a). It should be noted that those policy scenarios aim at simultaneously abating eutrophication, acidification, ozone and health impacts. The data were taken from the GAINS online

Table 4.8

Cost-effectiveness of nitrogen oxide measures in policy scenarios from the Gothenburg Protocol revision

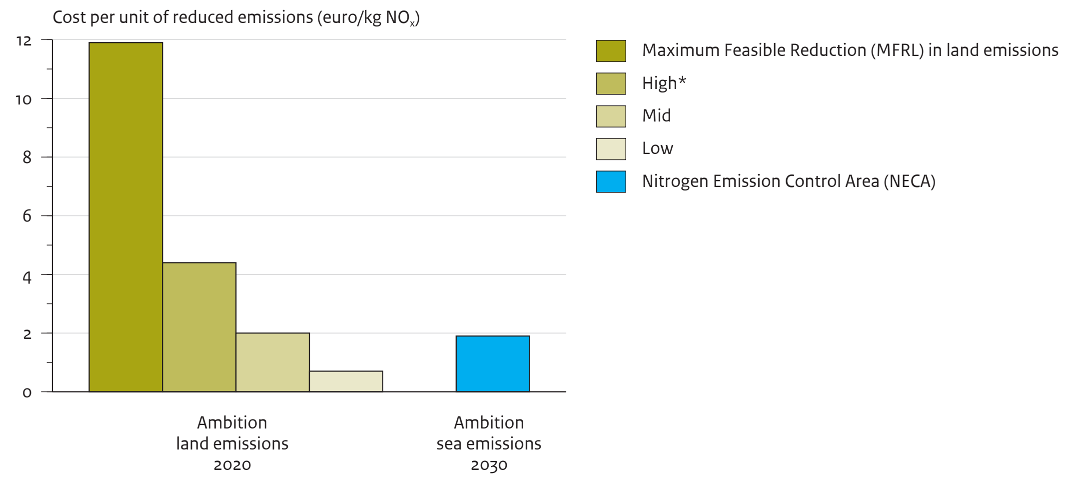
	Cost-effectiveness NO_x measures in 2020, euros[1]/kg			
Country	**Low**	**Mid**	**High***	**Maximum reduction**
Belgium	0.4	0.9	2.5	11.0
Denmark	0.6	2.1	5.2	13.7
France	0.9	3.5	6.5	21.6
Germany	1.2	1.9	5.2	10.5
Netherlands		1.2	2.0	6.7
Norway	0.5	2.0	4.6	9.3
Sweden	0.7	2.1	5.7	12.4
United Kingdom	0.5	1.4	2.8	10.1
Average	**0.7**	**2.0**	**4.4**	**11.9**

1) In 2012 euros

Source: PBL (based on CIAM, 2011a)

Figure 4.5

Comparison between the cost-effectiveness of air quality policy ambitions in the eight North Sea countries and for the North Sea

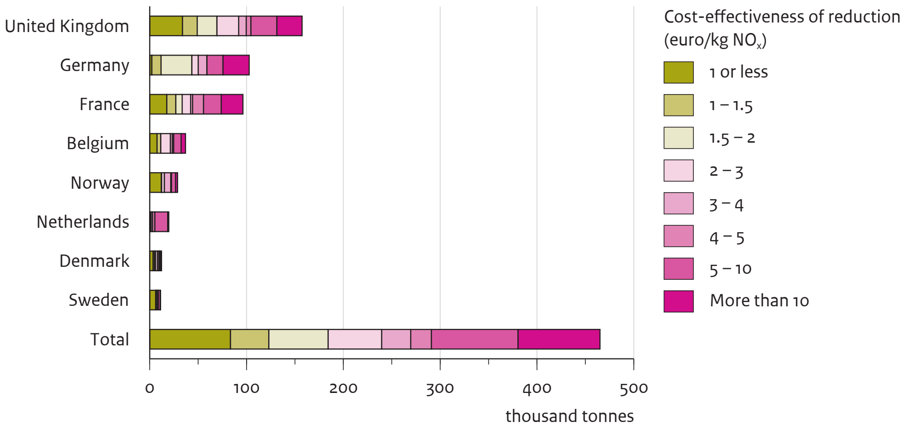


Source: PBL (ambitions on land emissions derived from CIAM 2011a and Holland et al., 2011)

model (IIASA, 2011) and the cost-effectiveness increases from the Low scenario with less than 1 euro per kilogram of reduced nitrogen oxide emissions to about 12 euros per kilogram in the MFRL scenario (Table 4.8).

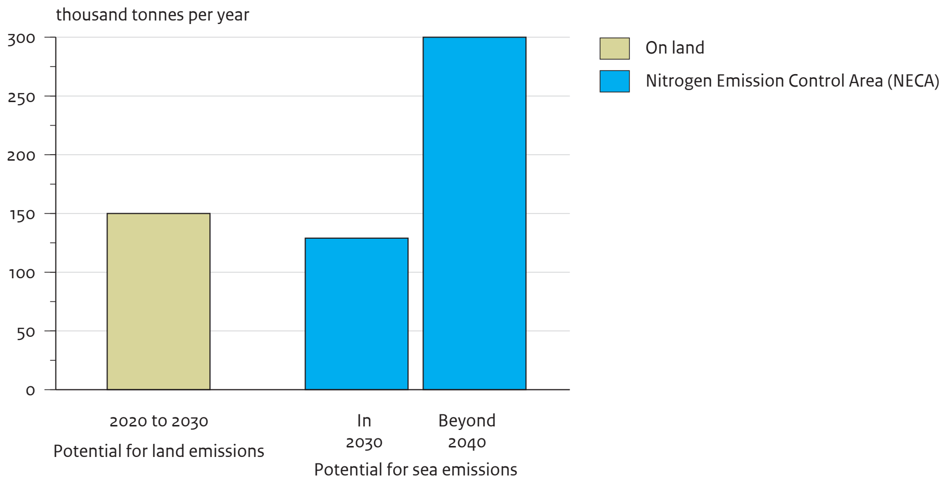
The cost-effectiveness of the nitrogen oxide measures due to the nitrogen emission control area by 2030 (Section 4.4) would be comparable with the value of the Mid policy scenario for land-based sources for 2020 (Figure 4.5), and both values amount to about 1.9 euros per kilogram of reduced nitrogen oxide. This is an indication that a nitrogen emission control area in the North Sea could enter a cost-optimal regional air policy with a medium ambition that aims at simultaneously abating eutrophication, acidification, ozone and health impacts. However, this indication is only valid under the assumption that the costs of abatement technologies and total emission levels on land and at sea will not change, substantially, between 2020 and 2030. A low ambition for air quality improvement in Europe would probably not include a nitrogen emission control area if cost-effectiveness would be the only criteria.

Figure 4.6
Potential NO_x reductions from stationary sources in North Sea countries, 2030



Source: IIASA (2011), PRIMES 2009 current legislation scenario, recalculated with a price level of 2012.

Figure 4.7
Potential nitrogen oxide reductions on land and at sea, applying an equal cost-effectiveness (1.9 euro/kg)



Source: PBL (Potential on land taken from IIASA 2011)

Potential and costs of nitrogen measures for land-based sources in 2030

An estimate of the potential reduction in nitrogen oxide due to measures at stationary sources in European countries in 2030 and the associated costs and cost-effectiveness are included in the GAINS model (IIASA, 2011). The maximum reduction on land is 465 thousand tonnes in the eight North Sea countries in 2030 relative to the 2030 baseline (Figure 4.6). The largest potentials on land are found in the United Kingdom, Germany and France. The total cost of this maximum reduction amounts to over 2.5 billion euros. The average cost of all available measures in 2030 is about 5.5 euros per reduced kilogram of nitrogen oxide, with individual measures ranging from 1 to over 30 euros per kilogram. For individual measures under 1 euro per kilogram, the potential reduction is estimated at about 80 thousand tonnes of nitrogen oxide, under 1.5 euros per kilogram the total potential is 120 thousand tonnes, and under 4 euros this is 270 thousand tonnes.

Table 4.9
Cost-effectiveness for nitrogen oxide reduction using selective catalytic reduction at large point sources in the North Sea countries[1]

Measure	BEL	DNK	FRA	DEU	NLD	NOR	SWE	UK
	Euros per kg reduced nitrogen oxide							
New coal-fired power plant with SCR	2.5	2.5	2.6	1.9	2.5	2.5	2.5	2.5
New gas-fired power plant with SCR	9.4	5.7	9.4	12.5	5.9	10.5	9.4	9.4
New heavy fuel oil-fired power plant with SCR	2.5	6.0	3.9	13.0	2.2	7.4	5.7	7.4
New biomass-fired power plant with SCR	5.8	1.8	5.8	5.8	6.2	5.8	7.4	3.4

1) *Recalculated with 2012 prices.*
Source: CIAM (2011a)

If we apply the average cost-effectiveness of the nitrogen emission control area as a threshold for land-based reduction measures (1.9 euros per kg, Section 4.4), the potential reduction on land would be in the order of 150 thousand tonnes by 2030. This is a similar potential to the reduction in the NECA scenario, which amounts to 129150 thousand tonnes in 2030 (Sections 2.3 and 4.4). A larger potential for relatively cheap nitrogen oxide emission reductions in the North Sea becomes available in the situation in which all ships meet the requirements of a nitrogen emission control area (Figure 4.7). Due to the long lifetimes of ships, such a situation could be expected somewhere around 2040, and the associated nitrogen oxide emission reductions could be in the order of 300 thousand tonnes. The actual reductions by then will depend on a large number of developments – in growth rates of sea-based transport, efficiency improvements, climate and energy policies and the share of LNG as fuel.

Cost-effectiveness of mandatory nitrogen oxide measures under current legislation

The cost-effectiveness of the nitrogen emission control area in 2030 can also be compared with the cost-effectiveness of similar nitrogen oxide measures for existing or new land-based sources that are already mandatory under current European or national legislation. One has to realise that in contrast to the above comparison on a benefit to cost basis (see Figure 4.4), a comparison based on cost per reduced kilogram of nitrogen oxide does not take into account the location of nitrogen oxide reductions and the distance to sensitive receptors such as densely populated areas and ecosystems. This limits the value of such a comparison to some extent.

For the comparison based on cost-effectiveness, estimates for the cost-effectiveness of SCR at stationary point sources and in passenger cars were examined. SCR is required in the EU as a Best Available Technology (BAT) for a number of existing and most new stationary point sources in for example the industrial and power sectors. The cost-effectiveness in the power sector ranges from 2 to 13 euros per kilogram of reduced nitrogen oxide (Table 4.9). The estimated cost-effectiveness of nitrogen oxide reductions resulting from the mandatory Euro-6 standards for diesel passenger cars is around 10 euros per kilogram (Smeets et al., 2007). This estimate was based on the extra cost as estimated in the impact assessment by the European Commission in 2006. At that time, it was expected that the Euro-6 emission limits would also be met using SCR. A recent study by AEA (2011) states that the 2006 estimate is probably the high end estimate as new technologies become available and the prices of such equipment often drop due to mass production and enhanced integration with engine technology.

The above data show that a number of mandatory nitrogen emission control measures for land-based sources are more expensive than the nitrogen emission control measures necessary in a nitrogen emission control area (Section 4.4, 1.9 euros per kg reduced nitrogen oxides). Such more expensive land-based control measures could be defended for emission sources that are closer to densely populated areas and ecosystems compared with shipping lanes. However, one could argue about the logic of more expensive land-based emission control measures for large-scale point sources that have high stacks and are located close to the shore and shipping lanes.
The data above indicate that air policies in the European Union do not always comprise the most cost-optimal measures because other elements also play a role, such as a level playing field for large combustion plants, the availability of technologies for sources on land and at sea, political support or the legal mandate of the various governments or intergovernmental organisations involved.

Uncertainty analysis

Uncertainties are present in both the cost and benefit assessments of an emission control area in the North Sea. It is therefore necessary to ask whether uncertainties so far unaccounted for could change the outcome of the cost-benefit assessment made in the previous chapter. We therefore explore the sensitivity of the benefits to uncertainties related to assumptions on emission inventories, projections and scenarios and the air quality model resolution. A number of uncertainties are also discussed that could potentially increase or decrease benefits.

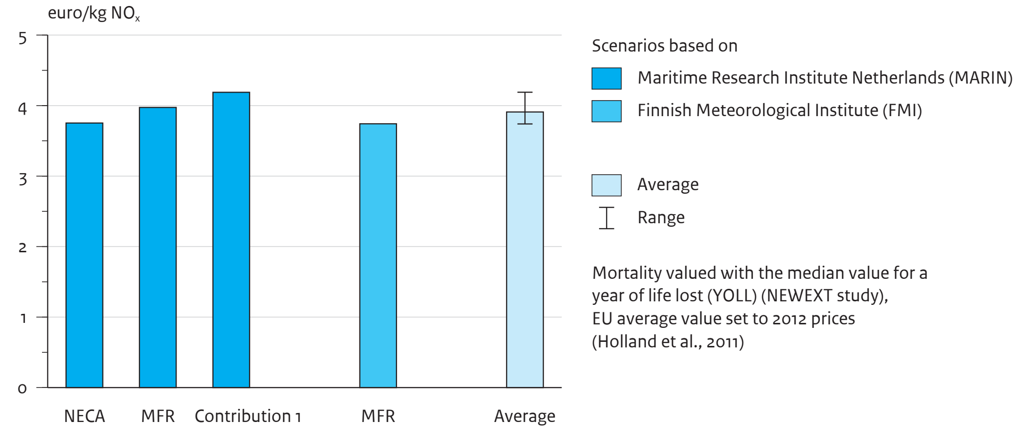
5.1 Emission inventory, projection and scenario assumptions

The above results on the environmental and economic benefits of a nitrogen emission control area were based on, amongst other data, the validated MARIN emission inventory and projections using central scenario assumptions agreed upon by the North Sea countries. However, both the emission inventory and the scenario assumptions contain significant uncertainties. Some of these were discovered during this study and some were quantified based on literature or expert judgements. A large uncertainty that was discovered during this study concerns the much higher estimates of the auxiliary engine power and the associated fuel consumption by North Sea ships in an inventory over 2009 by the FMI (FMI, 2011). Their activity inventory was used as a base in the economic cost assessment study. The FMI estimated that nitrogen oxide emissions from North Sea ships were 38% higher in 2009 than in the MARIN inventory. Since all experts at MARIN, TNO and FMI recognise that inventories of auxiliary engines are rather uncertain, a specific analysis was set up to assess the impacts on the outcome of this study.

We therefore constructed a new emission baseline and MFR scenario for 2030 based on the FMI inventory for 2009. We used the same developments in baseline emissions and reduction impacts due to a nitrogen emission control area as in our main baseline and scenarios (Sections 2.2 and 2.3). This resulted in an 'FMI baseline' for nitrogen oxide emissions of 614 thousand tonnes for 2030 (compared with 446 thousand tonnes based on MARIN). The impacts of a nitrogen emission control area relative to this 'FMI baseline' were shown in an 'FMI MFR' scenario as 201 thousand tonnes (compared with 146 thousand tonnes based on MARIN). Subsequently, we computed the impacts of this 'FMI MFR' scenario on air quality and especially health benefits using the same methods as used to compute the health benefits for the scenarios based on MARIN (Section 4.1).

With all this information, we derived the monetised health benefits per reduced kilogram of nitrogen oxide (Figure 5.1). The comparison teaches us that the relationship between changes in nitrogen oxide emissions in the North Sea (differences in the order of hundreds of thousand tonnes) is almost linearly related to changes in health benefits in the coastal countries and

Figure 5.1
Monetised health benefits in Europe, per unit of reduced nitrogen oxide over the North Sea, 2030



Source: PBL (based on NMI-EMEP calculations and FMI data)

beyond. The maximum uncertainty in this relationship is about 12%. In other words, if we were to use the larger nitrogen oxide reductions resulting from a nitrogen emission control area based on the FMI inventory, health benefits would increase accordingly. Assuming that the change in emission reductions at sea is linearly related to the change in costs, we find that the relationship between the cost of nitrogen oxide abatement in a nitrogen emission control area and the associated health benefits is close to linear.

This almost linear relationship also applies to the uncertainties in other scenario assumptions (e.g. low and high growth assumptions, EEDI/SEEMP efficiency improvements and fleet age profiles) used to derive the baseline emissions and nitrogen emission control area impacts in 2030 (Sections 2.2 and 2.3). The limited uncertainty of 12% is the result of the non-linear behaviour of atmospheric chemistry in relation to atmospheric transport and air pollutant deposition. The average monetised health benefits per reduced kilogram of nitrogen oxide in the North Sea were estimated at 3.9 euros per kilogram of nitrogen oxide.

5.2 Air quality model resolution

The estimated health benefits (Section 4.1) of a nitrogen emission control area were found to be rather insensitive to the resolution of the air quality modelling (Section 3.1). A nitrogen emission control area contributes to less particulate matter through reduced secondary particulate matter. In contrast to primary particles that are directly emitted by sources, secondary particles are formed by the chemical transformation of certain pollutants in the atmosphere. For instance, a part of the nitrogen oxide emissions from ships will be transformed into particulate nitrate (NO_3^-). Reductions in particulate nitrate explain how a nitrogen emission control area contributes to less particulate matter. Particulate nitrate has a relatively long lifetime in the atmosphere, resulting in a relatively flat spatial distribution. This implies that a higher model resolution does not bring much more detail into the assessment of the impacts of a nitrogen emission control area on secondary particulate matter concentrations. This also means that the health impacts and benefits due to reduced human exposure to secondary particulate matter are relatively insensitive to a lower or higher model grid resolution.

On the contrary, the modelled nitrogen dioxide concentrations and nitrogen deposition were found to be rather sensitive to the model resolution. This means that a higher model resolution would provide a better picture in coastal areas and beyond of the reduced impacts due to a nitrogen emission control area.

5.3 Uncertainties that have the potential to increase benefits

The first factor that would increase benefits would be to account for the unquantified monetary benefits, in particular increased protection for terrestrial and marine ecosystems, resulting from reduced nitrogen oxide deposition and reduced exposure to ground-level ozone.

However, the available approaches for estimating such benefits are currently not scientifically sound enough to be used.

The second factor is related to the treatment of time in the comparison of economic costs and benefits of pollution control measures. Both data for costs and benefits have to be annualised or expressed as the net present value of a policy over an extended period. Due to the annualised results from air quality modelling, benefits data were also annualised. In the above analysis we have generated annual estimates of health impacts by integrating a one-year pulse of pollution with the life tables used for mortality quantification. Hurley, Miller and Shafrir (2011) have now addressed the sensitivity of results to the duration of the pulse change. They found that taking a 30-year pulse and scaling back would provide an 11% increase in annual impacts compared with a 1-year pulse. For the purpose of the present analysis this is noted as a likely source of underestimation of mortality impacts.

The third factor is related to the results of recent US research that provide stronger evidence of the effects of long-term exposure to ozone on mortality (Jerrett et al., 2009) than was previously available. However, within the revision of the Gothenburg Protocol, it was concluded that it would be premature to use the relationships from Jerrett et al. for the present study, though this effect could add significantly to the more modest health and economic impacts quantified so far for ozone compared with $PM_{2.5}$. In this assessment we quantified the benefits of reduced ozone exposure only in relation to short-term exposure to ozone.

5.4 Uncertainties that have the potential to decrease benefits

The first factor that could reduce benefits would be to account more precisely for the speciation of particulate matter in the dose-response functions used. Particulate matter is a complex mixture, varying in composition and particle size, which is dependent to a large degree on source. In targeting control measures, it would be important to know if particulate matter from certain sources or of a certain composition gave rise to a particular health concern, for example owing to high toxicity. If, as some have speculated, nitrogen oxide-derived particles are less toxic than particles of average toxicity, the health benefits associated with the introduction of a nitrogen emission control area would be lower than indicated here.

The few epidemiological studies that have addressed this important question specifically suggest that combustion sources are particularly relevant to health (WHO, 2007). Toxicological studies have also pointed to primary combustion-derived particles as having a higher toxic potential. By contrast, several other single components of the particulate matter mixture (e.g. ammonium salts, chlorides, sulphates, nitrates and wind-blown dust such as silicate clays) have been shown to have a lower toxicity in laboratory studies. However, Smith et al. (2009) found that sulphate aerosols were of higher toxicity than average particles in an epidemiological study. This suggests that the laboratory studies may not be a reliable indicator of the response of the population as a whole, which is of course composed of individuals of varying health, who are exposed over a lifetime rather than for the duration of an experiment. It is therefore currently not possible to approximate the contributions from different sources and different particulate matter components to the effects on health caused by exposure to ambient particulate matter (WHO, 2007). Therefore, WHO advises treating all particles, irrespective of source and chemical composition, as equally harmful. This advice has for some time been adopted in the European cost-benefit analysis of the policy scenarios within the revision of the Gothenburg Protocol (Holland et al., 2011) commissioned by the EC.

Given the limited sizes of the benefit to cost ratios described above, the assumed harmfulness of particle species can change the conclusions reached as to whether a nitrogen emission control area would pass a cost-benefit analysis test. On the other hand, long-term exposure to low concentrations of ozone might prove to be more harmful to human health than currently assumed (see above). This would give more emphasis to nitrogen oxide reductions as this pollutant is an ozone precursor, together with volatile organic compounds (Section 3.1).

The second factor that could reduce the benefits of a nitrogen emission control area is the application of a lower valuation of the health benefits – the value of a life year lost (VOLY). In the above cost-benefit analysis we argued that the best available estimates for a life year lost range between 47,120 and 156,674 euros, with a mid-value of 67,146 euros. This mid-value and the upper value are also used in current cost-benefit analyses for EC air policies (Holland et al., 2008 and 2011). The more recent value of a life year lost of 47,120 euros from Desaigues et al. (2010), expressed in 2012 prices, was added here on the basis that there is as yet rather limited literature on this value. In addition, one could argue that the proposed confidence interval of Desaigues et al., ranging from 29,450 to 117,800 euros (in 2012 euros), should also be included in our analysis. Using this lower bound value of a life year lost together with a middle value for costs would lead to benefit to cost ratios that are still larger than one (factor of 1.2).

5.5 Synthesis of the uncertainty analysis

The above uncertainty analysis shows that the outcome of the cost-benefit analysis in Chapter 4 is rather robust against a number of potentially large uncertainties in the emission inventories, emission projections, emission scenarios and the applied air quality model resolution. The lack of a proper quantification of ecosystem benefits leads to a bias to underestimation of the monetised benefits. New insights into the assumed harmfulness of specific particle species within particulate matter can change the conclusions reached as to whether a nitrogen emission control area would pass a cost-benefit analysis test. On the other hand, long-term exposure to low concentrations of ozone might prove to be more harmful to human health than currently assumed. This would give more emphasis to nitrogen oxide reductions as this pollutant is an ozone precursor, together with volatile organic compounds.

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Annexes

Annex 1: IMO criteria for a proposal for designation of an emission control area

For designating a sea area such as an ECA for certain air pollutants, a common application that meets the following IMO criteria for designation (IMO, 2008: Appendix III) should be sent to the IMO by the parties that have a common interest:

- a clear delineation of the proposed area of application, along with a reference chart on which the area is marked;
- the type or types of emission(s) that is or are being proposed for control (i.e. NO_x or SO_x and particulate matter or all three types of emissions);
- a description of the human populations and environmental areas at risk from the impacts of ship emissions;
- an assessment that emissions from ships operating in the proposed area of application are contributing to ambient concentrations of air pollution or to adverse environmental impacts. Such assessment shall include a description of the impacts of the relevant emissions on human health and the environment, such as adverse impacts on terrestrial and aquatic ecosystems, areas of natural productivity, critical habitats, water quality, human health, and areas of cultural and scientific significance, if applicable. The sources of relevant data including methodologies used shall be identified;
- relevant information pertaining to the meteorological conditions in the proposed area of application to the human populations and environmental areas at risk, in particular prevailing wind patterns, or to topographical, geological, oceanographic, morphological, or other conditions that contribute to ambient concentrations of air pollution or adverse environmental impacts;
- the nature of the ship traffic in the proposed Emission Control Area, including the patterns and densities of such traffic;
- a description of the control measures taken by the proposing Party or Parties addressing land-based sources of NO_x, SO_x and particulate matter emissions affecting the human populations and environmental areas at risk that are in place and operating concurrent with the consideration of measures to be adopted in relation to provisions of regulations 13 and 14 of Annex VI;
- the relative costs of reducing emissions from ships when compared with land-based control measures, and the economic impacts on shipping engaged in international trade.

Annex 2: Background information on emission projections for North Sea shipping

The emission projections for North Sea shipping in this study were derived using a four-step approach.

- Assumptions were made on growth rates for North Sea shipping based on a quick scan of international literature, resulting in a growth in tonne-kilometres;
- Assumptions were made on transport efficiency improvements, based on the 2009 IMO greenhouse gas study, resulting in a decrease in energy used per tonne-kilometre;
- The effects of IMO and EU emission legislation on emissions of air polluting substances were modelled with the Dutch Shipping Emission inventory and Monitoring model (EMS), resulting in a decrease in emissions (e.g. NO_x, SO_2, $PM_{2.5}$) per unit of energy used;
- Assumptions were made on the market penetration of LNG and the use of shore-side electricity in harbours, and emission projections were adjusted accordingly.

The assumptions and calculations made in each step are described in more detail below.

Growth in trade volumes on the North Sea

To derive emission projections for North Sea shipping in 2030, assumptions were made on the growth of seaborne trade on the North Sea. The assumptions were based on a quick scan of existing studies on future maritime transport. A wide range of assumptions is used regarding the future growth of shipping in international literature. In general, pre-crisis studies show higher growth rates than post-crisis studies.

In their study on policy measures to reduce ship emissions in the seas surrounding the EU, Cofala et al. (2007) use growth projections from the TREMOVE European transport model of 2.5% for cargo vessels and 3.9% for passenger vessels. These projections were used for all EU sea regions. In the European EX-TREMIS project different growth rates were used for maritime trade for different ship types and different EU countries (Chiffi et al., 2008). The growth rates for the period up to the year 2020 vary mainly between 2% and 3% (in tonnage and tonne-miles) and were based on previous growth rates between 1997 and 2005 in the different regions and for the different ship types. Growth rates for the 2021–2030 period were assumed to be one percentage point lower than those for the period up to 2020, therefore, varying mostly between 1% and 2%.

In the second IMO greenhouse gas study (Buhaug et al., 2009), different scenarios are presented for the future growth of international shipping, based primarily on assumptions on global developments from the SRES storylines of the IPCC. Different growth rates are derived for sea shipping, short sea shipping (i.e. ships used in short sea shipping) and for container ships. Buhaug et al. present two sets of growth projections for international shipping. The first set is derived from the expected worldwide growth in GDP in the IPCC scenarios combined with the historic correlation between global GDP and demand for sea transport. The second set is based on a study by OPRF for one of the IPCC scenarios. OPRF uses more detailed assumptions on changes in transport patterns and routes and modal shifts to derive growth projections for international shipping. This leads to lower growth rates than the first approach, in which only GDP growth is taken into account. Because both methods contain uncertainties, Buhaug et al. decide to use the average of both approaches for their study and to construct upper and lower bounds that are wide enough to cover the results from both approaches. The resulting annual growth rates for the tonne-miles vary mostly between 2% and 3% in the different scenarios, with the lower bound estimates varying between 1% and 2% and the upper bound estimates varying between 3% and 5%. The specific growth rates for sea shipping and short sea shipping are of the same order of magnitude, whereas the growth rate for container shipping is approximately two to three times higher. Buhaug et al. did not produce specific growth scenarios for different world regions.

All the aforementioned studies were completed before the economic and financial crisis in 2008/2009. In the European iTREN-2030 project, an integrated transport and energy baseline for the EU was developed until 2030, taking into account the potential impact of the economic crisis on long-term economic growth in the EU (Schade et al., 2010). In this study, it is assumed that the growth rates in the field of trade and commercial transport have been disproportionately high over the last 15 years due to the 'globalisation bubble' between 2002 and 2007 and the 'strong dynamics of trade with the counters of central and eastern Europe after the political change in 1990' (Schade et al., 2010). The growth rates seen in the last 15 years, therefore, are not expected to continue. Annual GDP growth in the EU27 is expected to be 2.3% between 2011 and 2015, reflecting the economic recovery after the crisis. For subsequent years, the growth rates are expected to decline due to the dampening effects of high public debt and ageing of the EU population and subsequent decline in the labour force. Average annual GDP growth in the EU27, therefore, is assumed to be 1.4% between 2016 and 2020, 1.2% between 2021 and 2025, and 1.0% between 2025 and 2030.

Table A2.1
Average annual growth rates of shipping in the North Sea (2009–2030, in tonne-kilometres)

	Central case	Lower bound	Upper bound
Container shipping	3.5%	2.0%	5.0%
Other	1.5%	0.5%	2.5%
All ships	**2.1%**	**1.0%**	**3.3%**

Source: PBL

Table A2.2
Assumptions on efficiency improvements between 2007 and 2030 in current study (fleet averages)

	Central case	Lower bound	Upper bound
Efficiencies of scale	-4%	0%	-14%
Speed	-10%	0%	-22%
Technological and operational improvements[1]	-10%	-2%	-14%
All ships	**-22%**	**-2%**	**-42%**

1) Excluding changes in ship sizes and operational speed
Source: PBL (based on Buhaug et al., 2009)

In the recent update of the EU energy scenarios by Capros et al. (2010), assumptions also were made about the economic recovery after the crisis. The pattern of economic growth after the crisis is consistent with the 'sluggish recovery' scenario presented in the Europe 2020 strategy. This means that economic growth is expected to continue at the same level as before the crisis. Annual GDP growth, therefore, is assumed to be 2.2% between 2011 and 2020. However, between 2020 and 2030, annual economic growth is projected to slow down to 1.7%.

In conclusion, most pre-crisis studies show average annual growth rates for international shipping varying roughly between 2% and 4%, with upper and lower bound cases of 5% and 1%. Recent post-crisis studies for sea transport and other economic activities in the EU expect future economic growth to be lower than pre-crisis levels. Based on these studies, we assumed an average annual growth rate in North Sea shipping of 2% (in tonne-kilometres), using a bandwidth of 1% to 3%.

Most shipping-related studies assume different growth rates for different types of ships, with growth in container transport usually being higher than in other cargo types. This is relevant for the current study since the largest container ports in Europe are positioned alongside the North Sea. In the current study we also used differentiated growth rates for different ship types. In accordance with the IMO greenhouse gas study, we use an average annual growth rate for container shipping that is two percentage points higher than that of other cargo shipping. This results in an average annual growth rate of 3.5% for container shipping and 1.5% for other ship types.

Table A2.1 shows the average annual growth rates for North Sea shipping used in this study.

Efficiency improvements in North Sea shipping

Because of efficiency improvements, growth in trade volumes on the North Sea will not necessarily result in similar growth in energy use. The assumptions on future improvements in transport efficiency by North Sea shipping in the current study were derived from the second IMO greenhouse gas study (Buhaug et al., 2009). Chapter 5 of the IMO study gives an overview of potential technological and operational measures for reducing fuel consumption and related emissions from international shipping. The study shows that the potential for energy savings and emission reductions is substantial. Combined, the different technological and operational measures can result in energy savings of up to 25% to 75% compared with 2007 levels, with the upper bound of the bandwidth requiring speed reductions and the use of low-carbon fuels and/or renewable energy.
In Chapter 7 of the IMO study, different scenarios are presented for future emissions from international shipping. The assumptions used within the different scenarios are derived from an open Delphi process based on expert opinion and analyses (Buhaug et al., 2009). The projected transport efficiency improvements in international shipping are subdivided into three elements:
1. efficiencies of scale
2. speed
3. ship design and operation.

For each of these factors, assumptions are made on developments between 2007 and 2020/2050. Because of the uncertainties involved, a base case and a low and high estimate is presented for each factor. In the current study, we used the assumptions for the base case, as presented in Tables 7.11, 7.12 and 7.13 of Buhaug et al. (2009). These assumptions are presented in Table A2.2 and are described in more detail below.

Efficiencies of scale

The first factor, efficiencies of scale, relates to the size of the ships, with larger ships generally being more efficient per tonne-kilometre than smaller ships. The fleet projections for 2020 used by Buhaug et al. (2009) are derived from Lloyd's Register–Fairplay Research. Between 2020 and 2050, no structural changes in the fleet are modelled. Based on the projections of Buhaug et al., we assumed an efficiency improvement of 4% by 2030, compared with 2007, due to the deployment of larger ships, with a bandwidth of between 0% and 14%.

Speed

The second factor, speed, has a major influence on the fuel efficiency of maritime shipping, with the propulsion power requirement being roughly proportional to the third power of speed. Reducing speed, therefore, may be very effective in reducing fuel consumption and related emissions. Cariou (2011) shows that a 55% reduction in fuel consumption can be realised by container ships when sailing speeds are reduced by 30%, although part of this will be compensated by the longer journey time which results in more days at sea for the same trip. Due to the longer journey times transport capacity will decline and more (or larger) ships will be required to transport the same amount of cargo.

In recent years, bunker prices have increased and transport capacity has grown faster than transport demand, due to the economic crisis. Therefore, slow steaming has become an attractive way to reduce operational costs and absorb part of the capacity surplus. MARIN (2011b) shows that the operational speeds of specifically the larger ships in the North Sea decreased significantly between 2007 and 2009, see also Figure 2.5. Cariou (2011) estimates that slow steaming in 2010 reduced worldwide shipping emissions by around 11%, compared with 2008 emission levels.

The surplus shipping capacity, however, expected to decline in the long term, with the expected economic growth leading to an increase in transport demand and with ordered shipping capacity being reduced to match demand. Therefore, it is assumed that the current reduction in operational speeds, as shown in Figure 2.5, is only temporary. However, some shipping liners have announced that they will continue with slow steaming in the future. Buhaug et al. (2009) assume a reduction in sailing speeds of 5% by 2020 and 10% by 2050, compared with pre-crisis (2007) levels. Based on these figures, we used a 7% reduction in sailing speeds for North Sea shipping in 2030 compared with the 2007 (pre-crisis) levels, with a bandwidth of 0% to 17%. The bandwidth is derived from the upper and lower cases from Buhaug et al. (2009).

The impact of lower sailing speeds on power demand is modelled using a third-power relationship between speed and power as described in MARIN (2011b). The decrease in sailing speeds leads to a reduction in transport capacity, requiring a larger number of ships to transport the same amount of goods. This effect was also taken into account. The 7% reduction in operational speeds results in a 10% reduction in energy use in 2030 compared with 2007 (ceteris paribus). Since operational speeds already decreased in 2009 compared with 2007 due to the economic crisis, the reduction in energy use by 2030 is expected to equal approximately 7%, compared with 2009.

Ship design and operation

The third factor influencing the energy efficiency of maritime shipping relates to ship design and operation (excluding speed changes). Buhaug et al. (2009) present assumptions on expected efficiency improvements due to developments in ship design, technology and operation. It is assumed that only those improvements will take place that are cost-effective in the different scenarios. The assumptions also take into account that the short-term potential for improvement is rather limited because of the slow renewal of the fleet. The fleet average efficiency improvement due to improvements in ship design, technology and operations is assumed to be 2% in 2020 and 25% in 2050. Based on the figures, for 2030 an efficiency improvement is used of 10% compared with 2007 levels, with a bandwidth of between 2% and 14%. This bandwidth is also derived from the upper and lower cases from Buhaug et al. (2009).

Combined effect of efficiency improvements and new IMO measures

Combining the aforementioned assumptions on efficiencies of scale, sailing speeds and improvements in ship design and operation lead to an aggregate fleet-average efficiency improvement of approximately 22% in the base case in 2030 compared with 2007 levels, which means the average annual improvement is approximately 1%. The resulting bandwidth is 2% to 42%, which means approximately a 0% to 2% annual improvement.

In July 2011, the Marine Environment Protection Committee (MEPC) of the IMO agreed on mandatory measures to reduce greenhouse gas emissions from international shipping in the form of the Energy Efficiency

Table A2.3
Air quality policies for international shipping in the baseline emission projection

Sulphur	• Worldwide reduction in maximum sulphur content in marine bunker fuels to 3.5% in 2012 and 0.5% in 2020. • Reduction in the sulphur content of marine fuels in all sulphur emission control areas (SECAs) down to 1.0% from July 2010 and down to 0.1% from 2015. • 0.1 % sulphur fuel at berth in ports.
Nitrogen oxides	• Ships produced between 2000 and 2010 need to meet Tier I emission standards that are up to 10% stricter than those for pre-2000 ships (uncontrolled). • Post-2010 vessels need to meet Tier II standards, which require a reduction of up to 15% compared with Tier I.

Source: based on IMO, 2011 and EU, 2005

Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) for all ships (IMO, 2011). The EEDI sets a minimum energy-efficiency level per tonne-kilometre for different ship types, applying only to new ships. This minimum level is tightened over time. The SEEMP provides insight into ship or fleet efficiency performance over time and urges ship owners and operators to review efficiency during each phase of operation and consider improvements to optimise the energy-efficiency performance of the existing fleet. Bazari and Longva (2011) estimate that both measures combined could lead to a 23% reduction in energy use in 2030 compared with business as usual. This is a slightly higher improvement than the combined effect of speed reductions and technological improvements assumed in the base case of this study, but falls well within the bandwidth.

Effects of IMO and EU legislation on emissions and fuel quality

The emission baseline for 2030 includes current legislation on emissions standards for sulphur and nitrogen oxides from the revised MARPOL Annex VI of 2008 (Table A2.3) (IMO, 2008) and current EU emission legislation for the sulphur content of fuel for ships at berth in EU harbours. This means that the reduction in the maximum allowable sulphur content to 0.1% in 2015 in sulphur emission control areas (including the North Sea) is part of the baseline.

In the economic impact assessment, the Danish EPA (2012) gives an overview of available NO_x abatement technologies to apply with Tier II and Tier III emissions standards. They conclude that available information points to three technology routes to comply with Tier III: Selective Catalytic Reduction (SCR), Exhaust Gas Recirculation (EGR) or Liquefied Natural Gas (LNG). No specific assumptions are made in the current study on the technologies used to comply with Tier III. It is only assumed that nitrogen oxide emissions of Tier III ships will be reduced by approximately 75% compared with Tier II emission levels, in line with the tightening of the emission standards from Tier II to Tier III. Tier II nitrogen oxide emission levels are assumed to be 15% to 20% lower than Tier I emission levels, again in line with the tightening of the IMO nitrogen oxide emission standards.

The impact of the above-mentioned IMO emission legislation on air polluting emissions of North Sea shipping was estimated using the Dutch Shipping Emission inventory and Monitoring model (EMS) developed by TNO (Denier van der Gon and Hulskotte, 2010). The model distinguishes ten ship types and nine age classes.

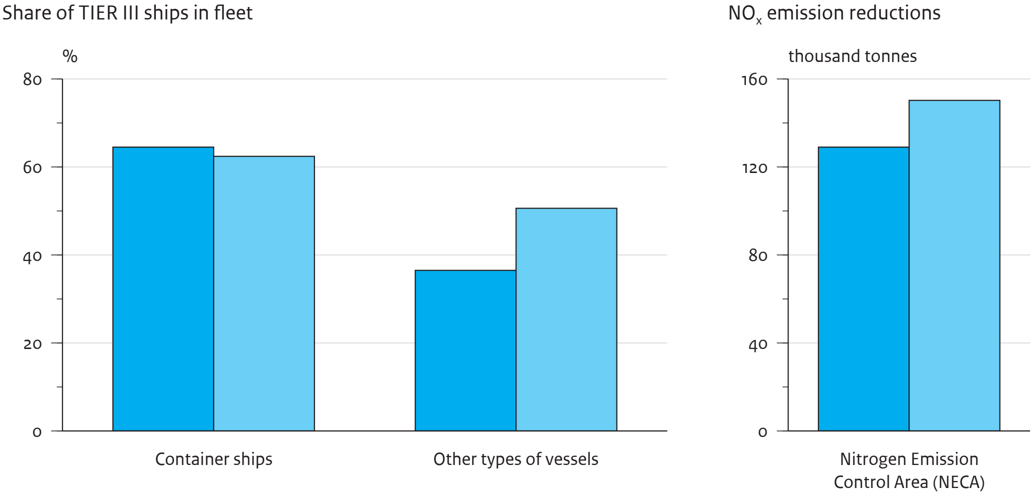
Modelling the future fleet age profile

The future fleet is described in EMS using a stochastic approach with Weibull functions describing the share of different age classes in the fleet. The parameters of these functions were estimated based on the age distribution within the Lloyd's global shipping characteristics database for 2008. Different parameters were estimated for container ships and for other ships. Because of higher growth rates for container shipping, it is assumed that the container fleet will expand faster in future years and therefore the future container fleet will be relatively young compared with other ship types. The EMS model calculations show that in 2030 approximately 64% of the container fleet must comply with Tier III standards (i.e. built in 2016 or thereafter), whereas the remaining 36% is built before 2016. For other ship types, only 37% must comply with Tier III standards. These fleet age profiles compare well with the more recent information on the age distribution of the current world merchant fleet given by UNCTAD (2011, Table 2.4). The EMS model estimates an average age for container ships of 12 years and for other ship types of 19 years. Average ages of the current world fleet are, for example, 11 years for container ships and 23 years as an overall average (UNCTAD, 2011, Table 2.4).

Comparisons between the future fleet as modelled by EMS and the fleet assumptions used in the economic impact assessment by the Danish EPA (2012) show that assumptions on the composition of the future container

Figure A2.1

Differences in fleet age profiles used by PBL and Danish EPA and impacts on NO_x emissions, 2030



Source: PBL (including data from Danish EPA 2012)

fleet are very similar, but assumptions on other ship types differ (Figure A2.1). The future fleet by EMS is somewhat older, with about 37% of other ships complying with Tier III requirements in 2030 (i.e. built in 2016 or thereafter). The Danish EPA estimates a younger fleet with about 51% of the other ship types complying with Tier III in 2030. As mentioned before, a larger share of Tier III compliant ships in 2030 leads to a larger reduction (about 16%) in nitrogen oxide emissions, to higher costs of nitrogen oxide abatement (about 16%), but also to a close to linear increase (about 16%) in environmental and societal benefits (see Section 5.1).

The above differences between the future fleets used in the economic and the environmental impact study are most likely caused by the use of different data and different methodologies for deriving the future fleet. Our Weibull functions that model the future age composition of the fleet were estimated using data on the age profile of the current worldwide merchant fleet. The Danish EPA used specific data for the current North Sea fleet and used a different approach to model the renewal of the fleet, as described in Chapter 3 of their report. The current fleet on the North Sea is relatively young compared with the worldwide fleet. This, combined with a different approach used in the economic study, would result in a younger fleet by 2030.

In general, the renewal of the world and North Sea fleet is influenced by economic factors and international regulations. Worldwide capacity has grown at a record pace in recent years: in 2010, a record amount of new constructions was added to the world fleet (UNCTAD, 2011). This was the result of orders placed before the 2008 economic crisis. The increase in the fleet size compared with the decrease in demand led to an oversupply of capacity. Therefore, new orders in coming years will be lower than in previous years. Because of the large amount of new capacity recently added to the fleet, the current fleet is relatively young. By 2030, however, this current wave of new ships will represent a cohort of relatively old ships, of which many will still be in use. This means that the age profile of the future fleet could be very different from the current profile. This is one of the reasons why the differences in the fleet age distributions as used in this report and in the Danish EPA (2012) are probably well within the ranges of uncertainty that are inherently connected to future prognoses.

Future use of LNG and shore-side electricity for North Sea shipping

LNG

LNG can be used as an alternative fuel for shipping activities. The major advantage of using LNG is that it is a relatively clean fuel that contains no sulphur. Additionally, the combustion temperatures in an LNG engine are lower than in an average diesel engine, therefore NO_x emissions from LNG engines are up to 90% lower than those from diesel engines. Because of these features, LNG-propelled ships do not require exhaust gas after-treatment to meet the future emission requirements in SO_x and NO_x emission control areas, including the Tier III standards for NO_x. A major disadvantage of using LNG is that up to

Table A2.4
Assumptions about market penetration of LNG for North Sea shipping by 2030

	Central case	Lower bound	Upper bound
Short sea shipping	25%	5%	50%
Tanker	10%	0%	20%

Source: PBL (based on Buhaug et al., 2009)

three times more space is required for onboard storage of the fuel compared with diesel. Additionally, the current availability of LNG bunker facilities in ports is low and LNG mainly seems relevant for new constructions, since retrofitting existing ships requires major modifications to the engine of the ship (Buhaug et al., 2009; MAGALOG, 2008).

Because of the current lack of bunker facilities for LNG and the limited range compared with diesel-fuelled ships, LNG seems most suitable for short sea shipping and specifically for ships engaged in regular trading routes (EMSA, 2010). Some preliminary estimates by EMSA for a medium-large ferry show that payback times of investments in LNG technology to comply with SECA regulations from 2015 can be very short (less than a year) compared with using marine gas oil (MGO). The results of the calculations are however uncertain and depend very much on assumptions on future prices of LNG and MGO. Similar calculations for Denmark by Stuer-Lauridsen et al. (2010) show that there may only be a positive case for LNG terminals in a number of busy ports and in the most fuel-consuming ferries and short sea cargo ships, while using slightly different assumptions on future MGO and LNG prices leads to the conclusion that it is most profitable to use MGO instead of LNG.

In conclusion, any current assumption on the future market penetration of LNG in North Sea shipping is very uncertain. We have therefore used assumptions on market penetration based on the IMO greenhouse gas study (Buhaug et al., 2009) in the base case, in combination with a broad bandwidth, as shown in Table A2.4.

These assumptions apply to the 2030 baseline and are expected to be the result of the tightening of the SECA requirements on the maximum allowable sulphur content of marine fuels from 2015 onwards. The costs of complying with these requirements are much higher than the costs of complying with the requirements in a nitrogen emission control area. Therefore the SECA requirements, which are part of the baseline for 2030, are expected to be the main driver of the market penetration of LNG. No further market penetration is assumed to result from the assignment of a nitrogen emission control area in the North Sea. The assumptions in Table A2.4 are thus applied in all 2030 scenarios.

For the emission calculations, short sea shipping was defined as all RoRo cargo/vehicle, passenger and tug/supply ships and all other ships below 10,000 GT. The use of LNG is assumed to lead to a 90% reduction in nitrogen oxide emissions, whereas emissions of sulphur dioxide and particulate matter ($PM_{2.5}$) are basically non-existent (EMSA, 2010). Since using LNG is sufficient to comply with the Tier III nitrogen oxide standards, no further emission reduction is assumed in the NECA and MFR scenarios for ships using LNG. Consequently, a higher market penetration of LNG ships in the baseline leads to lower nitrogen oxide emission reductions with the assignment of a nitrogen emission control area.

Shore-side electricity

Shore-side electricity is currently used in a limited number of North Sea ports, mainly by ferries and by some container ships that dock regularly in the same port. Ericsson and Fazlagic (2008) give an overview of existing installations in the ports of Sweden, Germany and Belgium. In Hoek van Holland, the Netherlands, the first connection for large sea-going ferries is expected to be completed in 2012. It is expected that the application of shore-side electricity will increase in the future in order to abate local air pollution and noise nuisance. To promote the application, Sweden and Germany recently obtained permission from the EU to apply reduced taxes to the electricity delivered to ships at berth. Despite these and other ongoing developments, it is not expected that a large share of ocean-going ships at berth will be using shore-side electricity by 2030. It requires substantial investments in onshore infrastructure as well as onboard ships, and is currently only applied in ports where the same ship docks regularly. Moreover, the lack of international standards for shore-side electricity systems onboard ships and at berth hampers the development. We assumed that, by 2030, 5% of the ships at berth will use shore-side electricity. In the uncertainty analysis we used a bandwidth of 1% to 10%.

Annex 3: Emissions from international shipping in the North Sea and in ports

Table A3.1
Carbon dioxide and air polluting emissions from international shipping in 2009 in the North Sea and the ports

Ship type	CO_2	NO_x	SO_2	$PM_{2.5}$	CO	HC
	thousand tonnes per year					
Oil tanker	2,813	59	22	3.3	10	1.7
Chemical/LNG tanker	3,082	65	24	3.5	11	1.9
Bulk carrier	1,638	44	15	2.3	7	1.3
Container ship	6,231	151	58	8.3	26	4.1
General dry cargo	2,337	50	19	2.5	9	1.7
RoRo cargo/vehicle	2,389	56	21	2.9	9	1.7
Reefer	504	14	5	0.7	2	0.5
Passenger	1,037	20	9	1.1	4	0.7
Miscellaneous	487	10	4	0.5	3	0.4
Tug/supply	146	3	1	0.1	1	0.1
Fishing	6	0	0	0.0	0	0.0
Non-merchant	1	0	0	0.0	0	0.0
Total	**20,671**	**472**	**177**	**25**	**82**	**14**

Source: PBL (derived from MARIN 2011b)

Table A3.2
Nitrogen oxide emissions by main ship type in 2009 in the North Sea and its ports

Ship type	At sea	Manoeuvring and sailing in port area	At berth	Total
	thousand tonnes per year			
Container ships	136	11	4	151
Chemical/LNG Tankers	58	4	3	65
Oil tankers	51	1	7	59
RoRo cargo/vehicle	48	4	4	56
General dry cargo	45	3	2	50
Bulk carriers	41	1	1	44
Passenger	18	1	1	20
Reefers	13	0	1	14
Miscellaneous	7	1	2	10
Tug/supply	2	0	1	3
Total	**418**	**27**	**27**	**472**

Source: PBL (derived from MARIN 2011b)

Annex 4: Emissions on land and at sea in Europe

Table A4.1
Emissions in 2009 in the EU27 countries, Norway and Switzerland (thousand tonnes)

Country	NO_x	SO_2	CO	VOC	NH_3	$PM_{2.5}$	PM_{10}
	thousand tonnes per year						
Austria	169	21	464	144	61	19	30
Belgium	254	103	410	146	76	24	45
Bulgaria	129	662	334	121	62	40	55
Cyprus	20	26	22	9	6	2	3
Czech Republic	233	169	608	238	76	34	47
Denmark	139	12	365	108	62	28	39
Estonia	27	26	84	31	11	12	16
Finland	167	56	394	124	33	26	39
France	1,038	322	2 607	951	647	268	362
Germany	1,152	391	2 608	1 151	572	106	185
Greece	284	338	694	235	54	47	67
Hungary	152	88	380	141	73	26	40
Ireland	94	41	185	58	112	10	16
Italy	1,036	259	3 646	1 412	393	135	185
Latvia	32	4	168	64	13	18	21
Lithuania	48	22	178	70	47	12	18
Luxembourg	39	1	38	10	6	3	4
Netherlands	293	47	577	196	133	21	33
Norway	171	23	980	169	22	41	52
Malta	7	11	4	4	3	1	1
Poland	721	824	1 855	492	342	110	172
Portugal	207	109	528	202	71	78	118
Romania	242	477	1 006	408	150	123	162
Slovakia	78	51	242	68	27	12	22
Slovenia	44	19	226	37	19	7	9
Spain	1,128	551	1 629	802	348	126	193
Sweden	172	30	574	169	51	24	43
Switzerland	73	16	357	100	64	9	14
United Kingdom	1,244	439	1,961	848	311	79	128
Total	**9,393**	**5,139**	**23,123**	**8,508**	**3,844**	**1,441**	**2,120**

Source: based on IIASA, 2011

Table A4.2

Emissions in 2009 in European seas (thousand tonnes)

Sea	NO_x	SO_2	CO	VOC	NH_3	$PM_{2.5}$	PM_{10}
	thousand tonnes per year						
Baltic Sea	340	109	40	15	0	15	16
North Sea	472	177	82	14	0	25	26
Atlantic Ocean	747	535	36	34	0	61	64
Medit. Sea	1,617	1,134	177	76	0	130	137
Black Sea	84	60	11	4	0	7	7
Total	**3,260**	**2,015**	**345**	**143**	**0**	**238**	**251**

Source: PBL (adjusted data based on CIAM 2011a and Cofala et al., 2007)

Table A4.3

Emissions in 2009 in the EU27 countries, Norway and Switzerland (thousand tonnes)

Country	NO_x	SO_2	CO	VOC	NH_3	$PM_{2.5}$	PM_{10}
	thousand tonnes per year						
Albania	20	19	70	31	20	8	10
Kola Karelia - RUO	32	28	443	37	3	6	8
St Pburg - Novgorod RUP	170	133	2,005	175	21	39	54
Kaliningrad - RUA	20	7	233	25	4	5	8
Belarus	157	84	654	204	134	54	72
Ukraine	790	1 032	6,778	626	248	371	557
Moldova	23	6	141	30	15	10	14
Rest of Russian Federation (EMEP)	1,845	4,366	25,650	1,047	430	529	929
Croatia	71	51	209	100	31	18	25
Bosnia-Herzegovina	31	203	93	39	18	18	31
Macedonia	33	110	54	21	9	12	22
Kazakhstan	50	237	279	50	18	11	22
Georgia	30	9	223	19	97	8	12
Armenia	13	4	104	28	25	5	7
Turkey	774	1,755	1,839	565	428	311	437
North Africa	79	313	277	79	173	0	0
Azerbaijan	43	15	293	9	25	19	29
Rest north-east Atlantic Ocean	0	0	0	0	0	0	0
External part of Russian Federation	236	162	839	241	74	73	118
Serbia	84	217	301	81	33	34	53
Montenegro	57	178	259	66	26	29	45
Uzbekistan	17	170	27	39	63	0	0
Turkmenistan	16	175	27	39	69	0	0
Caspian Sea	16	150	26	37	62	0	0
Aral Sea	14	139	23	32	2	0	0
Asia part modified (EMEP)	16	171	27	39	82	0	0
Total	**4,638**	**9,733**	**40,875**	**3,658**	**2,109**	**1,560**	**2,455**

Source: interpolated data based on IIASA, 2011

Table A4.4

Emissions in 2030 baseline in the EU27 countries, Norway and Switzerland (thousand tonnes)

Country	NO_x	SO_2	CO	VOC	NH_3	$PM_{2.5}$	PM_{10}
	thousand tonnes per year						
Austria	75	18	279	109	61	12	24
Belgium	150	80	310	129	79	19	42
Bulgaria	62	92	188	73	61	30	43
Cyprus	9	5	9	5	7	1	2
Czech Republic	109	90	279	144	67	22	34
Denmark	64	11	141	66	52	16	27
Estonia	16	10	42	17	10	7	10
Finland	99	39	245	85	28	20	32
France	414	174	1,676	645	625	189	285
Germany	568	306	1,804	959	550	81	160
Greece	177	88	387	135	53	30	45
Hungary	63	59	214	96	68	20	33
Ireland	54	27	111	50	110	7	14
Italy	522	173	2,427	818	385	90	144
Latvia	15	3	85	42	12	12	15
Lithuania	22	15	86	51	46	9	15
Luxembourg	10	1	21	6	5	1	3
Malta	2	1	2	3	2	0	0
Netherlands	139	38	398	159	129	13	25
Norway	126	26	1,280	126	24	28	41
Poland	330	403	724	329	358	81	143
Portugal	90	60	350	160	72	59	87
Romania	128	133	727	265	148	95	127
Slovakia	50	44	201	55	22	10	16
Slovenia	19	12	214	26	17	5	7
Spain	504	274	1,117	613	365	87	158
Sweden	76	28	420	118	44	17	34
Switzerland	41	10	196	80	64	7	13
United Kingdom	506	160	1 372	674	294	48	98
Total	**4,444**	**2,382**	**15,306**	**6,037**	**3,759**	**1,017**	**1,674**

Source: based on IIASA, 2011

Table A4.5

Emissions in 2030 baseline in European seas (thousand tonnes)

Sea	NO_x	SO_2	CO	VOC	NH_3	$PM_{2.5}$	PM_{10}
	thousand tonnes per year						
Baltic Sea	228	11	40	33	0	4	5
North Sea	446	15	76	9	0	13	14
Western part of the North Atlantic Ocean	762	116	36	76	0	14	14
Medit. Sea	1,649	251	177	168	0	29	31
Black Sea	86	13	11	9	0	2	2
Total	**3,171**	**405**	**339**	**295**	**0**	**62**	**66**

Source: PBL (adjusted data based on CIAM 2011a and Cofala et al., 2007)

Table A4.6

Emissions in 2030 baseline in other countries included in this study

Country	NO_x	SO_2	CO	VOC	NH_3	$PM_{2.5}$	PM_{10}
	thousand tonnes per year						
Albania	15	12	57	25	26	7	10
Kola Karelia - RUO	31	40	443	35	4	8	10
St Pburg - Novgorod RUP	163	187	2,005	165	26	48	64
Kaliningrad - RUA	20	10	233	24	5	7	9
Belarus	154	96	641	155	153	53	73
Ukraine	701	1,236	8,650	490	304	461	664
Moldova	17	5	132	22	19	9	13
Rest of Russian Federation (EMEP)	1,716	6,215	25,650	958	538	629	1,063
Croatia	38	21	90	55	34	12	18
Bosnia-Herzegovina	20	49	70	27	21	13	18
Macedonia	16	14	25	11	9	7	9
Kazakhstan	48	334	279	47	22	13	26
Georgia	29	13	223	18	120	9	14
Armenia	13	6	104	26	31	6	9
Turkey	849	1,556	1,081	412	537	317	477
North Africa	79	313	277	79	173	0	0
Azerbaijan	41	21	293	8	31	24	35
Rest north-east Atlantic Ocean	0	0	0	0	0	0	0
External part of Russian Federation	228	228	839	227	91	90	139
Serbia	47	58	271	56	28	27	36
Montenegro	36	38	234	47	24	21	28
Uzbekistan	16	240	27	37	78	0	0
Turkmenistan	16	247	27	36	86	0	0
Caspian Sea	15	212	26	35	77	0	0
Aral Sea	13	196	23	30	2	0	0
Asia part modified (EMEP)	16	242	27	36	101	0	0
Total	**4,337**	**11,587**	**41,728**	**3,063**	**2,540**	**1,760**	**2,713**

Source: based on IIASA, 2011

Annex 5: Concentrations and depositions in Europe

Table A5.1

Average annual anthropogenic $PM_{2.5}$ concentrations in the baseline and the scenarios for 2030

Country	2009	2030 baseline	2030 scenarios			
			NECA	MFR	CONTR.I	CONTR.II
			µg/m³			
Austria	4.30	2.66	2.65	2.64	2.64	2.63
Belgium	7.68	5.10	5.05	4.99	4.93	4.87
Bulgaria	6.10	3.96	3.96	3.95	3.95	3.95
Cyprus	5.55	4.43	4.43	4.43	4.43	4.43
Czech Republic	6.22	3.97	3.96	3.95	3.94	3.93
Denmark	4.70	3.03	3.00	2.97	2.93	2.90
Estonia	3.66	3.14	3.14	3.13	3.13	3.12
Finland	1.72	1.60	1.60	1.59	1.59	1.59
France	4.90	3.06	3.04	3.02	3.00	2.99
Germany	5.76	3.74	3.71	3.68	3.66	3.64
Greece	5.47	3.08	3.08	3.08	3.07	3.07
Hungary	6.85	4.49	4.48	4.47	4.47	4.46
Ireland	3.00	2.09	2.07	2.04	2.01	2.00
Italy	4.96	2.79	2.79	2.79	2.78	2.78
Latvia	4.33	3.72	3.71	3.71	3.70	3.70
Lithuania	4.90	4.10	4.09	4.08	4.08	4.07
Luxembourg	7.33	4.82	4.80	4.77	4.74	4.72
Netherlands	7.29	4.64	4.58	4.49	4.40	4.30
Norway	1.18	0.94	0.94	0.93	0.93	0.93
Poland	6.48	4.43	4.42	4.41	4.40	4.39
Portugal	4.46	3.03	3.03	3.03	3.03	3.03
Romania	6.81	4.76	4.76	4.75	4.75	4.75
Slovakia	6.18	4.16	4.15	4.14	4.14	4.13
Slovenia	5.57	3.39	3.38	3.37	3.37	3.37
Spain	3.14	1.94	1.94	1.94	1.93	1.93
Sweden	1.53	1.18	1.17	1.17	1.16	1.16
Switzerland	4.07	2.38	2.37	2.37	2.36	2.35
United Kingdom	3.77	2.44	2.41	2.37	2.33	2.30
Average	**4.17**	**2.77**	**2.76**	**2.75**	**2.74**	**2.73**

Source: PBL (based on NMI-EMEP calculations)

Table A5.2

Average annual anthropogenic PM_{10} concentrations in the baseline and the scenarios for 2030

Country	2009	2030 baseline	2030 scenarios			
			NECA	MFR	CONTR.I	CONTR.II
	µg/m³					
Austria	6.40	4.36	4.35	4.33	4.32	4.32
Belgium	12.98	10.03	9.96	9.86	9.77	9.70
Bulgaria	8.70	6.06	6.05	6.05	6.04	6.04
Cyprus	9.69	8.49	8.49	8.49	8.48	8.48
Czech Republic	8.89	6.10	6.09	6.06	6.04	6.04
Denmark	11.05	8.91	8.86	8.79	8.72	8.68
Estonia	6.32	5.41	5.40	5.39	5.37	5.37
Finland	3.48	3.14	3.13	3.13	3.12	3.12
France	9.16	6.91	6.88	6.84	6.80	6.78
Germany	9.40	6.90	6.86	6.81	6.77	6.75
Greece	8.82	5.96	5.96	5.95	5.95	5.95
Hungary	9.47	6.53	6.52	6.50	6.49	6.49
Ireland	10.33	9.20	9.16	9.11	9.07	9.06
Italy	8.43	5.74	5.73	5.72	5.72	5.71
Latvia	7.04	6.04	6.03	6.01	6.00	5.99
Lithuania	7.70	6.50	6.49	6.47	6.45	6.45
Luxembourg	11.39	8.44	8.40	8.35	8.30	8.28
Netherlands	13.36	10.27	10.18	10.04	9.91	9.80
Norway	3.60	3.19	3.18	3.16	3.15	3.15
Poland	9.46	6.94	6.92	6.90	6.88	6.87
Portugal	10.09	8.18	8.18	8.17	8.17	8.16
Romania	9.29	6.71	6.71	6.70	6.69	6.69
Slovakia	8.69	6.04	6.03	6.01	6.00	6.00
Slovenia	7.98	5.28	5.27	5.26	5.25	5.24
Spain	7.09	5.56	5.55	5.54	5.53	5.53
Sweden	3.75	3.15	3.14	3.12	3.11	3.10
Switzerland	6.20	4.17	4.16	4.15	4.13	4.13
United Kingdom	10.09	8.47	8.42	8.36	8.30	8.26
Average	**7.57**	**5.79**	**5.77**	**5.75**	**5.73**	**5.72**

Source: PBL (based on NMI-EMEP calculations)

Table A5.3
Average annual anthropogenic nitrogen dioxide concentrations in the baseline and the scenarios for 2030

Country	2009	2030 baseline	2030 scenarios			
			NECA	MFR	CONTR.I	CONTR.II
			µg/m³			
Austria	5.46	2.28	2.26	2.25	2.23	2.23
Belgium	14.92	7.23	6.89	6.46	6.12	6.12
Bulgaria	2.49	1.31	1.31	1.30	1.30	1.30
Cyprus	1.64	1.08	1.08	1.08	1.08	1.08
Czech Republic	7.39	3.20	3.18	3.15	3.13	3.13
Denmark	6.56	3.33	3.15	2.91	2.72	2.72
Estonia	2.98	1.75	1.74	1.71	1.70	1.70
Finland	2.08	1.20	1.19	1.17	1.16	1.16
France	5.06	2.15	2.10	2.03	1.98	1.98
Germany	9.08	4.04	3.95	3.84	3.75	3.75
Greece	2.41	1.53	1.53	1.53	1.52	1.52
Hungary	4.92	2.28	2.27	2.26	2.25	2.25
Ireland	2.34	1.33	1.30	1.27	1.24	1.24
Italy	5.95	3.07	3.07	3.06	3.05	3.05
Latvia	2.86	1.65	1.64	1.61	1.59	1.59
Lithuania	3.43	1.94	1.92	1.90	1.88	1.88
Luxembourg	14.28	4.86	4.79	4.71	4.65	4.65
Netherlands	15.65	7.82	7.26	6.53	5.94	5.94
Norway	1.30	0.77	0.74	0.70	0.67	0.67
Poland	6.48	2.91	2.88	2.85	2.83	2.83
Portugal	3.50	1.68	1.67	1.67	1.67	1.67
Romania	2.85	1.57	1.56	1.55	1.55	1.55
Slovakia	5.01	2.48	2.47	2.46	2.44	2.44
Slovenia	5.55	2.59	2.58	2.57	2.56	2.56
Spain	3.69	1.57	1.57	1.56	1.56	1.56
Sweden	2.13	1.11	1.08	1.04	1.01	1.01
Switzerland	4.71	2.41	2.40	2.38	2.37	2.37
United Kingdom	6.75	3.33	3.16	2.94	2.76	2.76
Average	**4.49**	**2.14**	**2.10**	**2.05**	**2.01**	**2.01**

Source: PBL (based on NMI-EMEP calculations)

Table A5.4

Average annual ozone (SOMO35[1]) in the baseline and the scenarios for 2030

Country	2009	2030 baseline	2030 scenarios			
			NECA	MFR	CONTR.I	CONTR.II
			ppb*days			
Austria	3,780	2,385	2,376	2,362	2,346	2,345
Belgium	2,352	2,006	2,018	2,011	1,965	1,962
Bulgaria	3,238	2,030	2,026	2,019	2,012	2,011
Cyprus	3,548	2,908	2,905	2,901	2,896	2,896
Czech Republic	3,001	1,784	1,774	1,756	1,736	1,735
Denmark	1,887	1,461	1,446	1,407	1,343	1,342
Estonia	1,177	831	823	811	796	796
Finland	666	496	491	485	478	478
France	3,131	2,007	1,995	1,973	1,942	1,941
Germany	2,788	1,879	1,867	1,842	1,806	1,805
Greece	3,783	2,579	2,574	2,567	2,560	2,559
Hungary	3,251	1,847	1,840	1,828	1,815	1,814
Ireland	2,063	1,821	1,817	1,803	1,776	1,775
Italy	4,760	3,251	3,244	3,234	3,223	3,222
Latvia	1,361	915	907	893	878	877
Lithuania	1,604	1,056	1,047	1,033	1,018	1,017
Luxembourg	2,500	2,013	2,001	1,977	1,940	1,939
Netherlands	2,069	1,862	1,896	1,913	1,852	1,848
Norway	1,294	1,118	1,111	1,099	1,082	1,082
Poland	2,316	1,394	1,383	1,366	1,346	1,345
Portugal	3,469	2,379	2,374	2,367	2,358	2,358
Romania	2,843	1,739	1,734	1,726	1,718	1,717
Slovakia	3,070	1,800	1,793	1,781	1,767	1,766
Slovenia	3,928	2,394	2,388	2,377	2,365	2,365
Spain	3,668	2,461	2,455	2,446	2,436	2,436
Sweden	1,143	881	872	858	840	840
Switzerland	4,103	2,716	2,707	2,693	2,675	2,675
United Kingdom	1,966	1,757	1,757	1,743	1,703	1,701
Average	**2,579**	**1,759**	**1,752**	**1,738**	**1,719**	**1,718**

1) SOMO35 stands for ozone concentrations accumulated dose over a threshold of 35 parts per billion (ppb) (=70 µg/m³). It is an annual sum of the daily differences between modelled (or measured) maximum daily 8-hour running mean concentrations greater than 35 ppb and the threshold of 35 ppb.

Source: PBL (based on NMI-EMEP calculations)

Table A5.5

Average annual ozone (AOT40 crops[1]) in the baseline and the scenarios for 2030

Country	2009	2030 baseline	2030 scenarios NECA	MFR	CONTR.I	CONTR.II
			ppb*hour			
Austria	10,768	3,715	3,677	3,620	3,560	3,559
Belgium	7,463	4,864	4,833	4,708	4,469	4,458
Bulgaria	7,895	3,183	3,169	3,148	3,127	3,125
Cyprus	3,920	2,309	2,304	2,297	2,289	2,288
Czech Republic	9,633	3,463	3,413	3,338	3,257	3,255
Denmark	4,847	2,598	2,475	2,245	1,966	1,964
Estonia	2,055	838	808	764	718	717
Finland	998	399	386	366	347	347
France	7,728	2,915	2,862	2,775	2,671	2,669
Germany	9,031	3,991	3,909	3,769	3,603	3,600
Greece	7,923	3,642	3,630	3,612	3,593	3,592
Hungary	10,053	3,550	3,520	3,477	3,431	3,430
Ireland	3,540	2,207	2,167	2,093	1,986	1,984
Italy	12,953	6,149	6,122	6,081	6,038	6,036
Latvia	2,831	1,101	1,065	1,010	952	951
Lithuania	3,827	1,490	1,451	1,393	1,332	1,331
Luxembourg	7,893	4,281	4,197	4,063	3,916	3,913
Netherlands	6,323	4,419	4,437	4,323	3,914	3,901
Norway	1,467	790	755	701	645	644
Poland	7,760	2,996	2,945	2,870	2,789	2,787
Portugal	9,042	4,457	4,435	4,402	4,365	4,364
Romania	7,172	2,818	2,801	2,777	2,752	2,751
Slovakia	9,679	3,386	3,353	3,306	3,255	3,254
Slovenia	12,282	4,941	4,910	4,864	4,816	4,814
Spain	9,714	4,351	4,329	4,296	4,261	4,260
Sweden	1,956	908	870	812	751	751
Switzerland	10,223	3,895	3,859	3,806	3,750	3,748
United Kingdom	4,442	2,831	2,771	2,646	2,452	2,448
Average	**6,612**	**2,880**	**2,842**	**2,778**	**2,702**	**2,700**

1) AOT40 stands for ozone concentrations accumulated dose over a threshold of 40 ppb (=80 µg/m³). It is an annual sum of the differences between hourly ozone concentrations greater than 40 ppb and the threshold of 40 ppb. The summation is over all hourly values modelled or measured between 08:00 and 20:00 Central European Time each day and for days in the three month crop-growing season from 1 May to 31 July.

Source: PBL (based on NMI-EMEP calculations)

Table A5.6

Average annual nitrogen deposition in the baseline and the scenarios for 2030

Country	2009	2030 baseline	2030 scenarios			
			NECA	MFR	CONTR.I	CONTR.II
	Mol N eq/ha/yr					
Austria	790	634	633	631	630	630
Belgium	1,120	967	959	947	936	936
Bulgaria	469	398	397	397	396	396
Cyprus	238	247	247	247	246	246
Czech Republic	808	628	627	624	622	622
Denmark	602	476	471	463	457	457
Estonia	328	262	261	259	257	257
Finland	183	140	139	138	137	137
France	687	574	572	569	566	566
Germany	1,021	842	838	831	826	826
Greece	398	344	343	343	343	343
Hungary	588	470	469	469	468	468
Ireland	566	513	511	508	506	506
Italy	731	606	606	605	604	604
Latvia	411	335	334	331	330	330
Lithuania	564	485	483	481	479	479
Luxembourg	1,033	828	824	817	812	812
Netherlands	1,300	1,149	1,140	1,126	1,113	1,113
Norway	151	114	112	110	108	108
Poland	741	630	628	625	624	624
Portugal	387	331	331	330	330	330
Romania	509	435	434	433	433	433
Slovakia	659	505	504	503	502	502
Slovenia	870	689	688	687	686	686
Spain	411	345	345	344	344	344
Sweden	220	164	162	160	158	158
Switzerland	937	805	804	802	800	800
United Kingdom	588	491	487	480	475	475
Average	**535**	**443**	**441**	**438**	**436**	**436**

Source: PBL (based on NMI-EMEP calculations)

Table A5.7
Average annual acid deposition in the baseline and the scenarios for 2030

Country	2009	2030 baseline	2030 scenarios			
			NECA	MFR	CONTR.I	CONTR.II
	Mol acid (H^+) eq/ha/yr					
Austria	1,029	794	792	791	789	789
Belgium	1,582	1,274	1,265	1,254	1,243	1,240
Bulgaria	1,123	653	653	652	652	652
Cyprus	451	398	397	397	397	397
Czech Republic	1,157	845	843	841	839	839
Denmark	792	586	581	573	567	565
Estonia	516	413	411	410	408	408
Finland	300	247	246	245	244	244
France	888	694	692	688	686	685
Germany	1,337	1,060	1,056	1,049	1,044	1,043
Greece	866	526	526	526	525	525
Hungary	929	666	666	665	664	664
Ireland	731	623	621	618	616	616
Italy	976	750	749	748	748	748
Latvia	624	502	500	498	496	496
Lithuania	830	676	675	673	671	671
Luxembourg	1,346	1,032	1,027	1,021	1,016	1,015
Netherlands	1,680	1,389	1,380	1,366	1,353	1,349
Norway	230	173	172	170	168	167
Poland	1,194	905	903	901	899	898
Portugal	600	478	478	477	477	477
Romania	991	674	674	673	673	673
Slovakia	1,075	763	762	761	760	760
Slovenia	1,247	912	912	911	910	910
Spain	597	461	461	460	460	460
Sweden	325	242	240	238	236	236
Switzerland	1,146	945	944	942	941	940
United Kingdom	813	619	615	609	603	602
Average	**783**	**593**	**591**	**589**	**587**	**587**

Source: PBL (based on NMI-EMEP calculations)

Annex 6: Health and terrestrial ecosystem impacts in Europe

Table A6.1
Annual total health impacts aggregated for the EU27, Norway and Switzerland

Health impact (population at risk, units)	2009	2030 baseline	2030 scenarios			
			NECA	MFR	CONTR.I	CONTR.II
Quantification against ozone exposure						
Acute mortality (all ages, premature deaths)	26,137	22,244	22,197	22,060	21,790	21,778
Respiratory hospital admissions (65yr+, cases)	23,533	24,026	23,978	23,831	23,537	23,524
Minor restricted activity days (15–64yr)	64,742,581	43,796,584	43,710,132	43,444,711	42,907,371	42,883,225
Days with respiratory medication use (adults 20yr+)	23,102,762	17,719,107	17,683,708	17,576,095	17,359,463	17,349,718
Quantification against $PM_{2.5}$ exposure						
Exposure chronic mortality (life years lost)	1,791,890	1,021,913	1,017,042	1,010,029	1,003,594	997,540
Infant mortality (0–1yr, deaths)	342	159	159	158	157	156
Chronic bronchitis (27yr+, new cases)	76,393	50,800	50,554	50,201	49,878	49,573
Respiratory hospital admissions (all ages, cases)	30,140	19,275	19,180	19,043	18,918	18,800
Cardiac hospital admissions (all ages, cases)	18,588	11,888	11,829	11,745	11,667	11,594
Restricted activity days (15–64yr)	162,932,992	92,872,300	92,423,567	91,777,064	91,184,157	90,625,073
Days with respiratory medication use (children 5–14yr)	1,689,402	946,429	941,526	934,449	927,928	921,727
Days with respiratory medication use (adults 20yr+)	13,979,257	9,051,411	9,007,415	8,944,062	8,886,008	8,831,337
Days with lower respiratory symptoms (5–14yr)	77,821,578	48,635,953	48,383,971	48,020,317	47,685,168	47,366,548
Days with lower respiratory symptoms (15yr+)	142,472,954	91,664,087	91,217,514	90,574,387	89,984,906	89,429,527

Source: PBL (based on EMRC calculations)

Table A6.2
Ecosystem area with average annual nitrogen deposition exceeding critical load

Country	Total ecosystem area	Areas with exceedance					
		2009	2030 baseline	2030 scenarios			
				NECA	MFR	CONTR.I	CONTR.II
		1,000 km²					
Austria	40.3	31.7	13.6	13.5	13.3	13.2	13.2
Belgium	6.2	5.0	3.5	3.4	3.4	3.3	3.3
Bulgaria	48.3	19.2	12.8	12.8	12.8	11.4	11.4
Cyprus	2.5	0.6	0.6	0.6	0.6	0.6	0.6
Czech Republic	27.6	27.6	27.5	27.5	27.5	27.5	27.5
Denmark	3.6	3.6	3.4	3.4	3.3	3.3	3.3
Estonia	24.7	6.8	2.4	2.4	2.3	2.3	2.3
Finland	240.4	63.3	16.9	16.6	15.8	15.5	15.5
France	180.1	151.4	122.3	121.7	121.0	119.1	118.8
Germany	102.9	59.8	42.0	41.6	41.1	40.6	40.6
Greece	53.8	48.5	40.9	40.8	40.8	40.7	40.7
Hungary	20.8	20.6	16.2	16.1	15.9	15.9	15.8
Ireland	2.4	1.8	1.6	1.6	1.6	1.6	1.6
Italy	124.8	45.3	27.3	26.9	26.8	26.8	26.8
Latvia	35.8	30.8	23.4	23.1	22.8	22.7	22.7
Lithuania	19.0	18.8	18.2	18.1	18.1	18.1	18.1
Luxembourg	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Netherlands	4.4	3.6	3.4	3.3	3.3	3.3	3.3
Norway	136.1	12.3	2.7	2.2	1.9	1.7	1.7
Poland	90.3	85.7	78.5	78.4	78.3	78.2	78.2
Portugal	31.0	18.2	12.5	12.5	12.5	12.4	12.4
Romania	98.0	1.9	1.2	1.2	1.2	1.2	1.2
Slovakia	20.5	20.5	20.0	20.0	20.0	20.0	20.0
Slovenia	11.0	8.6	1.2	1.1	1.1	1.1	1.1
Spain	187.1	157.8	138.0	137.8	137.6	137.4	137.4
Sweden	150.7	53.1	25.1	24.1	22.9	22.0	22.0
Switzerland	9.6	9.2	7.4	7.3	7.3	7.3	7.3
United Kingdom	92.2	11.2	5.1	4.5	4.3	4.0	4.0
Average	**1,765.4**	**917.9**	**668.6**	**663.8**	**658.5**	**652.0**	**651.7**

Source: PBL (based on NMI-EMEP and RIVM-CCE calculations)

Table A6.3
Average annual accumulated excess (AAE) deposition of nitrogen loads

Country	2009	2030 baseline	2030 scenarios			
			NECA	MFR	CONTR.I	CONTR.II
	Mol N eq/h/yr					
Austria	149.0	37.1	36.5	35.8	35.2	35.2
Belgium	315.6	165.9	160.6	153.4	147.3	147.0
Bulgaria	107.7	70.3	70.1	69.9	69.8	69.8
Cyprus	8.4	8.9	8.8	8.8	8.7	8.7
Czech Republic	671.9	458.4	456.2	453.3	451.0	450.9
Denmark	410.2	228.6	221.0	211.0	202.7	202.3
Estonia	19.9	7.9	7.8	7.6	7.5	7.5
Finland	13.0	1.7	1.6	1.5	1.4	1.4
France	265.0	140.4	138.4	135.7	133.4	133.4
Germany	222.7	109.0	106.7	103.8	101.4	101.3
Greece	174.0	118.0	117.7	117.3	117.0	117.0
Hungary	330.1	191.2	190.6	189.8	189.1	189.1
Ireland	232.7	164.2	161.9	158.8	156.2	156.2
Italy	112.4	59.2	59.1	58.9	58.7	58.7
Latvia	134.6	74.0	72.9	71.5	70.4	70.4
Lithuania	333.0	247.4	245.7	243.6	241.8	241.7
Luxembourg	705.6	485.0	479.5	472.3	466.2	466.2
Netherlands	571.3	387.8	378.9	366.2	355.1	354.9
Norway	4.6	0.4	0.4	0.3	0.2	0.2
Poland	430.6	292.1	290.1	287.5	285.4	285.3
Portugal	54.7	24.3	24.2	24.1	23.9	23.9
Romania	3.0	1.5	1.5	1.5	1.4	1.4
Slovakia	425.0	244.5	243.4	242.0	240.8	240.8
Slovenia	106.7	6.8	6.7	6.6	6.5	6.5
Spain	182.1	120.7	120.4	119.9	119.5	119.5
Sweden	43.0	12.6	11.9	11.2	10.6	10.5
Switzerland	319.8	188.6	187.3	185.7	184.3	184.3
United Kingdom	23.7	6.1	5.7	5.2	4.8	4.7

Source: PBL (based on NMI-EMEP and RIVM-CCE calculations)

Table A6.4

Forest area with average annual deposition exceeding critical load for acidification

Country	Total forest area	Areas with exceedance					
		2009	2030 baseline	2030 scenarios			
				NECA	MFR	CONTR.I	CONTR.II
		1,000 km²					
Austria	35.7	0.0	0.0	0.0	0.0	0.0	0.0
Belgium	6.2	0.7	0.3	0.3	0.3	0.2	0.2
Bulgaria	48.3	0.5	0.0	0.0	0.0	0.0	0.0
Cyprus	1.2	0.0	0.0	0.0	0.0	0.0	0.0
Czech Republic	21.6	5.2	3.3	3.3	3.3	3.3	3.3
Denmark	2.3	0.1	0.0	0.0	0.0	0.0	0.0
Estonia	18.4	0.0	0.0	0.0	0.0	0.0	0.0
Finland	240.4	2.1	1.3	1.3	1.3	1.3	1.3
France	170.7	4.8	1.5	1.5	1.5	1.5	1.4
Germany	99.8	19.4	6.7	6.6	6.4	6.3	6.3
Greece	17.6	0.5	0.0	0.0	0.0	0.0	0.0
Hungary	13.5	1.3	0.4	0.4	0.4	0.4	0.4
Ireland	4.3	0.5	0.1	0.1	0.1	0.1	0.1
Italy	88.9	0.0	0.0	0.0	0.0	0.0	0.0
Latvia	22.4	1.8	1.0	1.0	1.0	1.0	1.0
Lithuania	14.4	5.7	5.2	5.2	5.2	5.2	5.2
Luxembourg	0.7	0.1	0.1	0.1	0.0	0.0	0.0
Netherlands	5.3	4.1	3.1	3.1	3.1	3.1	3.1
Norway	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Poland	87.6	40.2	25.1	25.0	24.9	24.8	24.8
Portugal	17.8	0.6	0.5	0.5	0.5	0.5	0.5
Romania	98.0	16.2	1.0	1.0	1.0	1.0	1.0
Slovakia	17.0	1.5	0.3	0.3	0.3	0.3	0.3
Slovenia	10.8	0.0	0.0	0.0	0.0	0.0	0.0
Spain	69.5	0.1	0.0	0.0	0.0	0.0	0.0
Sweden	150.7	3.1	0.7	0.7	0.6	0.6	0.6
Switzerland	9.6	0.3	0.2	0.2	0.2	0.2	0.2
United Kingdom	19.7	1.9	0.8	0.8	0.7	0.7	0.7
Total	**1 292.6**	**110.6**	**51.7**	**51.4**	**50.8**	**50.5**	**50.3**

Source: PBL (based on NMI-EMEP and RIVM-CCE calculations)

Table A6.5

Annual AAE deposition for acidification in all ecosystems

Country	2009	2030 baseline	2030 scenarios			
			NECA	MFR	CONTR.I	CONTR.II
	Mol acid (H^+) eq/h/yr					
Austria	0.0	0.0	0.0	0.0	0.0	0.0
Belgium	66.9	20.5	20.0	19.4	18.8	18.4
Bulgaria	8.5	0.0	0.0	0.0	0.0	0.0
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0
Czech Republic	98.0	31.9	31.6	31.2	30.9	30.9
Denmark	2.7	0.3	0.2	0.2	0.1	0.1
Estonia	0.0	0.0	0.0	0.0	0.0	0.0
Finland	1.2	0.7	0.7	0.7	0.7	0.7
France	7.8	1.4	1.3	1.2	1.1	1.1
Germany	54.1	12.4	12.1	11.7	11.4	11.3
Greece	2.0	0.0	0.0	0.0	0.0	0.0
Hungary	13.5	1.0	0.9	0.9	0.9	0.9
Ireland	6.5	1.1	1.1	1.1	1.0	1.0
Italy	0.0	0.0	0.0	0.0	0.0	0.0
Latvia	5.9	2.5	2.4	2.4	2.4	2.4
Lithuania	97.9	52.5	52.2	51.7	51.3	51.2
Luxembourg	51.0	1.0	0.8	0.5	0.4	0.4
Netherlands	651.5	367.1	360.6	351.4	343.4	340.4
Norway	15.3	4.5	4.3	4.0	3.8	3.7
Poland	216.7	78.4	77.9	77.3	76.8	76.7
Portugal	8.2	5.1	5.1	5.1	5.1	5.1
Romania	29.6	0.4	0.4	0.4	0.4	0.4
Slovakia	24.4	0.7	0.7	0.7	0.7	0.7
Slovenia	0.1	0.0	0.0	0.0	0.0	0.0
Spain	0.2	0.0	0.0	0.0	0.0	0.0
Sweden	4.2	1.7	1.7	1.7	1.7	1.7
Switzerland	12.9	6.2	6.2	6.2	6.1	6.1
United Kingdom	40.3	13.5	13.2	12.8	12.5	12.3

Source: PBL (based on NMI-EMEP and RIVM-CCE calculations)

Table A6.6
Catchment area with average annual deposition exceeding critical load for acidification

Country	Total forest area	Areas with exceedance					
		2009	2030 baseline	2030 scenarios			
				NECA	MFR	CONTR.I	CONTR.II
		1,000 km²					
Finland	33	1.2	1.0	1.0	1.0	1.0	1.0
Norway	177	16.9	8.5	8.3	7.8	7.6	7.6
Sweden	292	23.9	18.2	18.2	18.2	18.2	18.1
United Kingdom	15	6.1	4.8	4.8	4.6	4.6	4.3
Total	**518**	**48.2**	**32.5**	**32.3**	**31.6**	**31.4**	**31.0**

PBL (based on NMI-EMEP and RIVM-CCE calculations)

Table A6.7
Annual AAE deposition of acidifying substances for freshwater ecosystems

Country	2009	2030 baseline	2030 scenarios			
			NECA	MFR	CONTR.I	CONTR.II
	Mol acid (H^+) eq/ha/yr					
Finland	3.0	1.9	1.9	1.9	1.9	1.9
Norway	15.3	4.5	4.3	4.0	3.8	3.7
Sweden	5.6	2.5	2.5	2.5	2.5	2.5
United Kingdom	129.6	50.9	50.0	48.9	48.1	47.6

PBL (based on NMI-EMEP and RIVM-CCE calculations)

Annex 7:
Monetised benefits in the North Sea countries and per EU country

Table A7.1
Monetised annual health impacts aggregated for the eight North Sea countries

Health impact	Mortality valuation	2009	2030 baseline	2030			
				NECA	MFR	CONTR.I	CONTR.II
Quantification against ozone exposure				million euros per year			
Mortality	Low	487	452	451	448	438	438
	Mid	702	651	651	647	633	633
	High	1,687	1,567	1,566	1,554	1,521	1,520
Respiratory hospital admissions		26	28	28	28	27	27
Minor restricted activity days		1,277	941	941	934	914	913
Days with respiratory medication use		11	9	9	9	9	9
Quantification against $PM_{2.5}$ exposure				million euros per year			
Adult mortality (VOLY)	Low	38,363	22,506	22,311	22,030	21,765	21,502
	Mid	55,339	32,465	32,184	31,779	31,395	31,016
	High	133,023	78,039	77,365	76,390	75,469	74,557
Adult mortality (VSL)	Low	99,676	73,954	73,332	72,433	71,588	70,759
	High	203,012	150,623	149,355	147,524	145,802	144,115
Infant mortality	247	132	131	128	127	125	49,573
	510	271	269	265	262	258	
Chronic bronchitis		8,969	6,045	5,995	5,921	5,850	5,780
Hospital admissions		61	40	40	39	39	39
Restricted activity days (15–64yr)		8,301	4,789	4,747	4,687	4,631	4,574
Days with respiratory medication use		9	6	6	6	6	6
Days with lower respiratory symptoms		5,332,806	3,446,828	3,417,378	3,374,970	3,333,740	3,293,688
Total damage (VOLY, low)		62,837	38,264	37,946	37,476	37,013	36,583
Total damage (VOLY, mid)		80,275	48,554	48,148	47,550	46,965	46,416
Total damage (VOLY, high)		159,208	95,182	94,383	93,206	92,061	90,977
Total damage (VSL, low)		124,614	90,044	89,296	88,205	87,157	86,159
Total damage (VSL, high)		229,196	167,766	166,371	164,340	162,394	160,535

Source: PBL (based on EMRC calculations)

Table A7.2
Monetised annual health benefits by 2030 under the NECA scenarios and cases aggregated for the eight North Sea countries

Total benefits by valuation	NECA	MFR	CONTR.I	CONTR.II
	million euros per year			
Total benefits (VOLY, low)	318	788	1,251	1,681
Total benefits (VOLY, mid)	405	1,004	1,589	2,138
Total benefits (VOLY, high)	801	1,978	3,123	4,205
Total benefits (VSL, low)	747	1,838	2,887	3,884
Total benefits (VSL, high)	1,395	3,426	5,372	7,231

Source: PBL (based on EMRC calculations)

Table A7.3
Monetised annual health benefits by 2030 under the NECA scenarios and cases, per North Sea country

Country	NECA		CONTR.I	
	VOLY (low to high range)	VSL (low to high range)	VOLY (low to high range)	VSL (low to high range)
	million euros per year			
Belgium	24–59	54–102	60–153	141–263
Denmark	6–15	14–26	16–40	37–67
France	60–150	132–243	144–356	311–574
Germany	84–209	223–421	199–495	527–993
Netherlands	46–118	111–207	119–303	282–527
Norway	1–5	4–6	5–11	8–15
Sweden	4–8	7–13	8–21	19–34
United Kingdom	94–239	205–379	238–602	514–952
Total	**318–802**	**749–1,397**	**789–1,980**	**1,838–3,424**

Source: PBL (based on EMRC calculations)

Table A7.4

Monetised health benefits by 2030 per European country relative to the baseline

Country	NECA		CONTR.I	
	VOLY (low to high range)	VSL (low to high range)	VOLY (low to high range)	VSL (low to high range)
	million euros per year			
Austria	3–6	6–11	6–16	14–27
Belgium	23–59	55–102	60–153	141–263
Bulgaria	1–2	2–4	2–5	5–9
Cyprus	0–0	0–0	0–0	0–0
Czech Republic	5–13	12–22	12–31	28–52
Denmark	6–15	14–25	16–40	36–67
Estonia	0–1	1–1	1–2	1–3
Finland	1–2	2–3	1–3	2–5
France	60–150	131–242	144–355	311–574
Germany	84–208	223–420	199–494	527–992
Greece	1–2	2–3	1–2	2–4
Hungary	3–9	8–15	8–20	19–35
Ireland	5–13	13–24	13–32	32–60
Italy	7–17	17–31	21–51	51–94
Latvia	0–1	1–2	1–3	3–6
Lithuania	1–4	3–6	3–8	7–13
Luxembourg	1–2	1–2	2–4	3–5
Malta	0–0	0–0	0–0	0–1
Netherlands	46–118	110–207	119–302	282–527
Norway	2–4	3–6	4–10	8–15
Poland	18–45	40–74	41–105	92–171
Portugal	0–1	1–2	2–4	4–8
Romania	3–9	8–14	8–20	18–33
Slovakia	2–5	4–7	4–12	10–18
Slovenia	0–1	1–2	1–3	2–5
Spain	7–16	14–26	14–33	29–52
Sweden	3–8	7–13	9–21	18–34
Switzerland	2–6	5–10	7–17	15–28
United Kingdom	94–239	205–379	238–602	514–952
EU27+Norway+Switzerland	**380–955**	**888–1 655**	**938–2 348**	**2,176–4,052**

Source: PBL (based on EMRC calculations)

Table A7.5
Indicative ranges for reductions in crop damage from reduced ozone levels, million euros/year

Country	Low benefit			High benefit		
	NECA	MFR	CONTR.I	NECA	MFR	CONTR.I
	million euros per year					
Austria	0.11	0.27	0.45	0.33	0.81	1.33
Belgium	0.28	1.40	3.53	0.42	2.16	5.45
Bulgaria	0.05	0.11	0.16	0.25	0.61	0.98
Cyprus	0.00	0.00	0.00	0.00	0.01	0.02
Czech Republic	0.22	0.55	0.91	0.62	1.58	2.59
Denmark	0.67	1.92	3.44	1.73	4.96	8.88
Estonia	0.00	0.00	0.00	0.05	0.11	0.16
Finland	0.00	0.00	0.00	0.12	0.29	0.46
France	3.40	9.00	15.7	8.16	21.6	37.6
Germany	3.22	8.72	15.2	6.80	18.4	32.2
Greece	0.20	0.51	0.82	0.67	1.68	2.74
Hungary	0.20	0.48	0.79	0.90	2.18	3.56
Ireland	0.06	0.18	0.35	0.13	0.37	0.71
Italy	1.85	4.66	7.61	3.92	9.88	16.1
Latvia	0.00	0.00	0.00	0.08	0.20	0.32
Lithuania	0.04	0.08	0.13	0.31	0.77	1.25
Luxembourg	0.00	0.00	0.00	0.02	0.06	0.11
Netherlands	-0.31	1.64	8.61	-0.47	2.49	13.1
Norway	0.05	0.13	0.21	0.11	0.27	0.44
Poland	0.68	1.68	2.77	2.99	7.39	12.1
Portugal	0.12	0.29	0.48	0.22	0.57	0.95
Romania	0.21	0.52	0.82	1.24	2.98	4.81
Slovakia	0.06	0.14	0.22	0.22	0.53	0.87
Slovenia	0.01	0.02	0.04	0.02	0.06	0.09
Spain	0.78	1.96	3.19	1.65	4.12	6.75
Sweden	0.15	0.38	0.61	0.59	1.50	2.44
Switzerland	0.07	0.16	0.26	0.15	0.38	0.61
United Kingdom	1.63	5.01	10.2	2.87	8.86	18.1
Total	**14**	**40**	**77**	**34**	**95**	**175**

Source: PBL (based on EMRC calculations)

A nitrogen emission control area in the North Sea would reduce levels of nitrogen dioxide, ozone and particulate matter, in the longer term, in a cost-effective way. It also would reduce nitrogen depositions on nature. Such a control area requires new ships to emit 75% less in nitrogen oxide, from 2016 onwards. The benefits of this air measure to public health are estimated to exceed the costs of emission control equipment for international shipping. However, this report also show that there are still effective air measures that can be taken on land. Using only land-based measures would however limit the potential air quality improvement in the North Sea region.

This policy study is a publication by

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