MNP Report 500092004/2007

Effectiveness of international emission control measures for North Sea shipping on Dutch air quality

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Acknowledgements

The authors would like to thank IIASA for providing the scenarios used in this study to determine the air quality effects of international emission control measures on North Sea shipping. Thanks are also due to Jan Hulskotte from TNO for his help in interpreting relationships between marine fuel quality and the particulate matter emissions.

Rapport in het kort

Effectiviteit van internationale emissiemaatregelen bij de zeescheepvaart op de Noordzee voor de Nederlandse luchtkwaliteit

De uitstoot van de zeescheepvaart op de Noordzee draagt significant bij aan de luchtkwaliteitsproblematiek in Nederland en Europa. De verwachte groei van de zeescheepvaart zal leiden tot een toename van de bijdrage van deze sector, tenzij er extra maatregelen worden genomen. Het belang van extra maatregelen wordt nog eens onderstreept door het streven in de Europese Unie naar een steeds betere luchtkwaliteit. Dit alles heeft ertoe geleid dat maatregelen tegen luchtverontreinigende uitstoot van zeeschepen hoog op de beleidsagenda's staan van de Internationale Maritieme Organisatie en van de Europese Commissie.

Het Milieu- en Natuurplanbureau heeft op verzoek van het ministerie van verkeer en waterstaat de effectiviteit van een aantal emissiereducerende maatregelen bij de zeescheepvaart op de Noordzee beoordeeld voor de Nederlandse regionale en stedelijke luchtkwaliteit in 2020. De maatregelen betreffen onder meer schonere brandstoffen en verschillende motortechnische maatregelen bij bestaande en nieuwe zeeschepen. Uit deze studie blijkt dat een pakket met emissiemaatregelen bij de zeescheepvaart op de Noordzee kosteneffectiever is dan een pakket met emissiemaatregelen die bij andere sectoren kunnen worden genomen. Een toekomstig kostenoptimaal pakket aan aanvullende bestrijdingsmaatregelen tegen luchtverontreiniging bevat dan ook maatregelen op land en op zee.

Trefwoorden: zure depositie, luchtkwaliteit, kosteneffectiviteit, stikstofdepositie, stikstofdioxide, walstroom, Noordzee, fijn stof, zeescheepvaart

Contents

Summary

- Under current legislation, the contribution of North Sea shipping to air pollution in the Netherlands will increase between 2000 and 2020. The contribution is significant compared to that of Dutch land-based sectors and other countries. For instance, in 2020, North Sea shipping will contribute about 21% to acid deposition, about 17% to nitrogen oxide concentrations and about 5% to total particulate matter concentrations. For comparison, Dutch agriculture and industry-energy-refineries will contribute about 5% and 2%, respectively, to particulate matter levels in 2020.
- With the ambitious emission control measures for sea shipping, the years of life lost due to exposure to particulate matter, can be reduced by several percent in 2020; nitrogen dioxide concentrations in urban areas decreased by 1 to 5% in 2020; and the ecosystem area unprotected against acidification decreased with 7 percent point to about 50%.
- These ambitious emission control measures at sea could achieve about one-third of the effect on Dutch air pollution compared to a set of land-based emission control measures needed to meet the air quality ambitions of the European Commission for 2020.
- Such measures at sea are more cost-effective than the land-based measures. Thus, a cost-optimal strategy on air pollution abatement in Europe needs to include measures for both sea and land-based sources.
- The compulsory use of low sulphur fuel (1.5%) from 22 November 2007 on the North Sea will significantly decrease the contribution of North Sea shipping to acidification and exposure to particulate matter.
- Provision of shore-side electricity for sea-going vessels berthed in the Port of Rotterdam contributes to an improved air quality in the Rotterdam-Dordrecht urban area by 2020. To promote application of shore-side electricity, international standards and phase-in schedules are needed.

Sea shipping contributes increasingly to air pollution problems in the Netherlands

Emissions of sulphur dioxide, nitrogen oxides and particulate matter from North Sea shipping contribute significantly to air pollution in the Netherlands (and other countries) in 2005 and 2020 (Table 1). As shipping volumes around Europe are expected to increase, the contribution to air pollution will also increase unless further international abatement measures are taken. The increase in contribution to nitrogen oxide concentrations is highest since no additional measures for nitrogen oxide emissions for shipping have been agreed. The growth in contribution to acid deposition will be small due to the ‘Sulphur Emission Control Area’ regulations (SECA) that require a lower sulphur content in fuels used in the North and Baltic Seas as from 22 November 2007. The contribution of ship emissions to air pollution is the highest in the west of the Netherlands and decreases eastwards.

Table 1 Contribution of emissions from North Sea shipping to air pollution in the Netherlands under current legislation (percentage of total average concentrations or depositions)

Air quality	**2005**	**2020**
Nitrogen oxide concentrations	8%	17%
PM_{10} concentrations	4%	5%
Nitrogen deposition	4%	7%
Acid deposition	19%	21%

Emission control measures at sea effectively reduce nation-wide air pollution

Because of the projected increase of North Sea shipping emissions, the Dutch Ministry of Transport, Public Works and Water Management has requested the Netherlands Environmental Assessment Agency to assess the effectiveness of technical abatement measures under consideration by the International Maritime Organization (IMO) and the European Union (EU). International agreement is needed to effectively implement the considered measures. Measures for abating emissions of sulphur dioxide, particulate matter and nitrogen oxide include low sulphur residual or distillate fuel oils and engine measures on existing and new ships. The role of market based instruments like differentiated harbour dues, which can promote an early introduction of such technical measures, is not assessed here.

The effectiveness and cost-effectiveness of such measures was assessed using three emission control scenarios from the International Institute for Applied Systems Analysis (IIASA) for 2020: medium, high and Maximum Technical Feasible Reductions (MTFR) ambition scenarios. For comparison, the indicative effects are presented of an ambitious land-based emission control scenario to meet the air quality ambitions of the European Commission for 2020 (Thematic Strategy on Air Pollution). Most recent estimates show that the cost for this land-based scenario in Europe ranges from 3.5 billion €/yr to 11.8 billion €/yr, depending on the benefits of additional climate policy (Amann et al., 2007c).

Table 2 Impact of emission control scenarios for North Sea shipping in 2020 using as baseline the scenario in 2020 under current legislation (CLE), and compared with the land-based emission control scenario (Thematic Strategy on Air Pollution)

Impact	**Indicator**	**2020 CLE**	**Emission control scenarios in 2020**			
			Medium (at sea)	**High (at sea)**	**MTFR (at sea)**	**Thematic Strategy (at land)**
Eutrophication	Unprotected eco-system area (%)	73	72	70	66	63
Acidification	Unprotected eco-system area (%)	58	58	51	46	37
Health effects of $PM_{2.5}$	Years Of Life Lost (index)	100	99	96	92	89

This study revealed that the high and MTFR ambition scenarios lead to substantial improvements in protection against eutrophication and acidification, and reduction in years of life lost (Table 2). With a high ambition scenario for sea shipping measures, the years of life lost due to exposure to particulate matter can be reduced by about 4% in 2020. For the environmental impacts shown in Table 2, the high ambition scenario at sea achieves about one-third of the effect of the land-based emission control scenario. The MTFR scenario at sea achieves about two-third of the effect of the land-based scenario.

Emission control measures at sea are cost-effective

The costs of the North Sea scenarios and the effects (benefits) in the Netherlands are compared in this study with the land-based scenario (Thematic Strategy) which was determined for the Netherlands and surrounding countries. This shows that the sea-based medium and high ambition scenarios are more cost-effective (Table 3). The sea-based MTFR scenario, however, seems somewhat less cost-effective than the land-scenario especially because of the expensive low sulphur distillate fuels. An MTFR ambition including use of cheaper, low sulphur residual fuel is more cost-effective but is expected to lead to slightly higher particulate matter levels. The use of marine distillates could become relatively more cost-effective provided the ambition for air quality in the European Union is raised, and/or the production costs of distillate fuels decline.

A recent study by IIASA also shows that a cost-optimal air pollution abatement scenario includes measures both at sea and on land (Amann et al., 2007b). Taking measures at sea also implies that fewer land-source measures are needed to meet the air quality ambitions of the Thematic Strategy.

Table 3 Cost- efficiency for the sea and land-based scenarios for three air quality indicators in 2020, expressed in million euros for one percent improvement

	Medium (at sea)	**High (at sea)**	**MTFR (at sea)**	**Thematic Strategy (at land)**
Acidification	5	27	71	49
Eutrophication	4	94	150	123
Years of life lost	8	90	152	156

Shipping measures improve urban air quality

This study shows that compared to the baseline scenario with current legislation in 2020, the high ambition scenario at sea reduces the average nitrogen dioxide concentrations in Dutch urban areas by an additional 1-5% in 2020 (i.e. 0.2-0.9 $\mu g/m^3$). This effect comprises about 70% of the effect that can be achieved by a land-based scenario based on European Commission’s Thematic Strategy on Air Pollution for all EU-countries. The high ambition scenario reduces the average urban particulate matter concentrations in the Netherlands by an additional 1-2% (i.e. 0.2-0.4 $\mu g/m^3$) in 2020. This comprises about 30% of the effect achieved by the land-based scenario. Although the absolute reductions in urban nitrogen dioxide and particulate matter concentrations resulting from shipping measures may seem small, they constitute a substantial proportion of air pollution that can be reduced by policy.

Shipping measures contribute to the compliance with air quality standards in 2020

Concentrations of nitrogen dioxide and particulate matter are expected to decrease substantially in Dutch urban areas between 2000 and 2020. This will be achieved through current air quality legislation and the envisaged additional European strategy for land-based sources (Thematic Strategy on Air Pollution). If necessary, additional national and local measures will need to be implemented in order to comply with European air quality standards for particulate matter in 2005[1] and nitrogen dioxide in 2010. Timely shipping measures can also reduce exceedance on land before 2020. If all necessary European, national and local measures are implemented in time, air quality standards should not be exceeded on land after 2020.

However, without the additional European, national and local measures, standards could still be exceeded in 2020 at persistent hotspots along motorways (ring roads) and in very busy streets in the major Dutch cities. In that case, an exploratory pilot study shows that about 10% of the remaining hotspots could be removed by implementing the high ambition scenario for North Sea shipping up to 2020.

Shipping measures may be needed to comply with future air quality standards

The current proposals for new air quality standards for the European Union contain new and stricter standards for the finer part of particulate matter ($PM_{2.5}$). A recent model study shows that it may be hard for the Netherlands to comply with these new standards for $PM_{2.5}$ with only European and national measures on land (Velders et al., to be published). To comply with the possible new standards, it may be necessary to implement additional measures in urban agglomerations and also at the North Sea and in ports.

Shore-side electricity reduces air pollution from sea ships at berth

Providing shore-side electricity (or cold ironing) for sea ships berthed in Dutch ports is an option for abatement of local air pollution caused by on-board generation of electricity with auxiliary diesel engines. An exploratory pilot study shows that shore-side electricity can reduce nitrogen dioxide concentrations in some parts of the Rotterdam-Dordrecht urban area by 1-3 $\mu g/m^3$ in 2020. Without additional European, national and local measures, air quality standards could still be exceeded in 2020 at persistent hotspots along motorways (ring roads) and in very busy streets in the major Dutch cities. In that case, the large-scale application of shore-side electricity could significantly reduce the remaining number of hotspots, especially in the Rotterdam-Dordrecht area with its extensive port areas.

[1] Proposals for new air quality legislation indicate that the dates of entry into force for particulate matter and nitrogen dioxide limit values might be postponed by five years.

The introduction of shore-side electricity is hampered due to concerns about the high costs and long-term efforts required to install or retrofit and expand utility lines, substations and sea ships. Moreover, the lack of international standards for shore-sided electricity increases the risks for investments in this measure.

1 Introduction

Sea shipping measures on the current agenda of IMO and European Commission

Air pollution in many countries is caused by emissions from both land and sea sources. International sea shipping is expected to contribute increasingly to air pollution especially in countries close to intensive shipping routes (Figure 1). The need for further control of air pollutant emissions from ships and to take account of current technology prompted the International Maritime Organisation (IMO) in 2005 to revise the air pollution regulations in their convention MARPOL Annex VI. The revision is planned for completion in 2008. In Europe, the need to abate air pollutant emissions from land and sea-based sources is set out in the Thematic Strategy on Air Pollution (TSAP) of the European Commission (CEC, 2005).

Initiated by these developments, the Netherlands Ministry of Transport, Public Works and Water Management requested the Netherlands Environmental Assessment Agency to analyse the increasing contribution of international sea shipping to regional and urban air pollution in the Netherlands, and the effects of potential emission control scenarios in the North Sea. The role of market based instruments like differentiated harbour dues, which can promote an early introduction of such technical measures, is not assessed in this study.

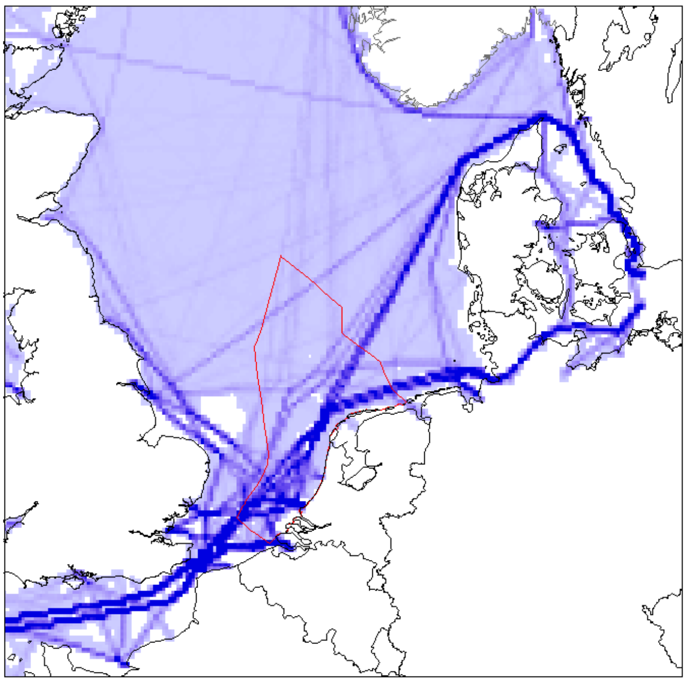

Figure 1: International shipping routes and activities on the North Sea. The red line indicates the Dutch continental shelf

Air pollution reduces life expectancy and threatens ecosystems

Air pollution is associated with high concentrations of nitrogen dioxide (NO_2) and particulate matter (PM_{10} or $PM_{2.5}$) in urban areas and the atmospheric deposition of nitrogen and oxidised sulphur compounds. Public health studies indicate that short-term and long-term exposure to particulate matter reduces life expectancy (Buijsman et al., 2005). However, the relationship between long-term exposure and effects is not clear. Nitrogen dioxide is a proxy for traffic related air pollution which has been correlated with reduced lung capacity in epidemiologic studies. Furthermore, high depositions of nitrogen and oxidised sulphur threaten the vitality of ecosystems by acidification and eutrophication.

Without further action, shipping emissions will increase in and around Europe

In 2000, emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and particulate matter from sea shipping around Europe accounted for approximately 20, 20 and 10% respectively of total emissions (land- and sea-based). The proportion of emissions from sea shipping in the total air pollutant emissions in Europe is expected to increase up to 2020 due to the expected increase in shipping activities in combination with the foreseen additional abatement of land-based emissions. By 2020 without further abatement measures, the proportion of sea shipping in total European sulphur dioxide emissions (land and sea based) may increase to 45%, nitrogen oxides emissions to 40%, and particulate matter emissions to 25%.

Development in North Sea shipping emissions under current legislation

The North Sea differs from other sea areas surrounding Europe with regard to sulphur dioxide emissions. It is a dedicated Sulphur Emission Control Area (SECA) where international standards for the sulphur content of fuels apply from 22 November 2007. In a SECA, the sulphur content of fuel oil used onboard ships may not exceed 1.5%. Alternatively, ships must fit an exhaust gas cleaning system. Decreased sulphur content in fuels will also decrease emissions of particulate matter. As a result of this regulation as well as the expected increase in shipping volumes, the sulphur dioxide emissions on the North Sea will not increase but will decrease by about 8% between 2000 and 2020. Particulate matter emissions will increase in this period by about 35% which is less than the increase in non-SECA areas (about 60%). Nitrogen oxide emissions on the North Sea will increase by about 45% between 2000 and 2020.

Can emission control at sea contribute to solve the air pollution in the Netherlands?

Because of the overall increasing contribution of North Sea shipping to air pollution in the Netherlands in 2020, the following aspects were analysed:

1. the contribution of North Sea emissions to air pollution in the Netherlands between 2000 and 2020;
2. in 2020, the potential benefits and cost-effectiveness of various scenarios for emission control (nitrogen oxide and sulphur dioxide reductions) in North Sea shipping for national and urban air quality in the Netherlands;
3. in 2020, the potential benefits of providing shore-side electricity to sea ships berthed (cold ironing) in Dutch ports.

The emission control measures discussed in this report include submissions made by members to the sub-committee on Bulk Liquids and Gases (BLG) of the International Maritime Organization (IMO), in the framework of the revision of the Annex VI of the

MARPOL convention. The effects of these measures on urban air quality in the Netherlands have been estimated using three emission control scenarios (Cofala et al., 2007).

The emission control measures submitted to IMO, the accompanying control scenarios, the resulting emission reductions and their costs are presented in chapter 2. The effect of these emission control scenarios on national and urban air quality in the Netherlands is examined in chapter 3. Chapter 4 presents the potential local effects on air quality of the use of shore-side electricity in Dutch ports.

2 Emission control scenarios for North Sea shipping

2.1 Emission control measures submitted to IMO

For revision of the air pollution regulations in Annex VI of the MARPOL convention, several emission control measures have been submitted by a number of countries to IMO and are currently under discussion. Measures especially to reduce sulphur dioxide and nitrogen oxide emissions from sea shipping are presented in Table 4. Reduced sulphur levels in fuel and the use of distillate fuels also reduce particulate matter emissions. The effects of these measures on the Dutch urban air quality are estimated (in chapter 3) using emission control scenarios (see section 2.2).

In addition to measures taken at sea, use of shore-side electricity by ships berthed in Dutch ports is also analysed as a local abatement measure. It is assumed that the proportion of sea-going vessels in Dutch ports using shore-side electricity will be 50% in 2015 and 100% in 2020. The emission reduction and the potential effects of this measure are presented in chapter 4.

Table 4 Emission control measures submitted to IMO

Number	Measures	Submission references
1	Global S Fuel 4.5%, in SECA 1% S fuel in 2010, 0.5% S fuel in 2015	IMO, 2007a
2	Distillate fuels for all ships and a global S fuel: 1% in 2012, 0.5% in 2015	IMO, 2007a
3	New engines: reduction in 2010 of NO_x 10% for two-stroke and 20% for four-stroke; 2015 NO_x 30% for two and four-stroke	IMO, 2006 IMO, 2007c IMO, 2007d
4	20% NO_x reduction in 2010 on ships build between 1985-2000	IMO, 2006
5	SCR (80-90% reduction) on new ships from 2015	IMO, 2006; IMO, 2007c
6	Submission USA BLG 11/5, NO_x standards for existing ships (20% reduction in 2012) and new ships (15-25% after 2011 and 80% after 2016), S Fuel 0.1% in 2011 within 200 miles zones	IMO, 2007b

2.2 Three emission control scenarios for the North Sea

The effects on urban air quality in the Netherlands of the measures submitted to IMO have been estimated using three emission control scenarios generated in the framework of the revision of the national emission ceilings (NEC revision) (Cofala et al., 2007). The three scenarios feature combinations of measures (engine techniques) and fuel standards (such as sulphur content) for different ship categories on the North Sea (see Table 5). All submissions to IMO can be placed somewhere in the range of the low ambition to maximum ambition scenario (see Table 5). More information on the emission control technologies is given in the studies conducted by Cofala et al. (2007) and ENTEC (2005 b, d, e).

The scenario analysis started from the baseline for 2020, which outline the effects of Current Legislation on emissions from North Sea shipping. At the other end, the Maximum Technical Feasible Reduction scenario (MTFR) comprises implementation of the best available control technology on all international shipping in the North Sea. In this study, the fuel quality in the MTFR scenario of Cofala et al. (2007) was adjusted and assumes the use of cleaner marine distillates with low sulphur content on all ships instead of residual fuel oil with low sulphur content. MTFR for nitrogen oxide implies that all ships have to be retrofitted with SCR. This may be quite an extreme assumption since it is doubtful whether there is sufficient space to install an SCR at all existing ships (Dick Brus, Ministry of Transport, Public Works and Water Management, The Hague, the Netherlands, personal communication 2007). To explore the range between these two extreme benchmark cases, two intermediate scenarios with a medium and high ambition level for the technical measures applied have been analysed.

Table 5 Emission control scenarios with measures for international shipping

Pollutant	**Measures**	**Indicative scenario for submissions to IMO**[1]
Baseline		
SO_2	Sulphur content as in the EU Marine Fuel Directive (OJ L 191/59, 2005): 1.5% S fuel for all ships in North Sea and Baltic Sea; 1.5% S fuel all passenger ships in other EU seas; 0.1% S fuel at berth in ports.	
NO_x	MARPOL NO_x standards for ships built since 2000	
Medium ambition – all ships		
SO_2	As in the baseline	
NO_x	Slide valve retrofit on all slow-speed engines pre-2000[2], internal engine modifications for all new engines post-2010.	Submission 4
High ambition - all ships		
SO_2	0.5% S residual fuel oil or scrubbing equivalent (2g SO_2/kWh) in North Sea and Baltic, and for passenger vessels everywhere[3].	Submissions 1 and 2
NO_x	Slide valve retrofit on all slow-speed engines pre-2000, humid air motors for all new engines post-2010.	Submissions 3
Maximum technically feasible reduction (MTFR) for all ships		
SO_2	0.5% S medium distillates for all ships in all EU seas, 0.1% at berth.	Submissions 1, 2 and 6[4]
NO_x	Selective catalytic reduction (SCR) on all ships (retrofit & new build).	Submissions 5[4] and 6[4]

[1] See Table 4.

[2] Later engines already have these installed.

[3] Assumed that 75% of ships use 0.5% fuel; 25% use exhaust gas cleaning.

[4] The USA submission containing a 0.1% sulphur fuel content within the 200 miles zone does not fit well into one of the three scenarios. The effect of the proposed nitrogen oxide measures is probably between the high ambition and the MTFR emissions scenario of IIASA.

2.3 Emissions in the baseline and three control scenarios

Table 6 presents emissions of air pollutants from international shipping in 2000 and 2020 on the North Sea for the baseline scenarios (including current legislation) and the emissions in 2020 according to the three emission control scenarios specified in section 2.2.

Baseline scenarios with current legislation

Future shipping activities in this scenario study follow the assumptions of the TREMOVE European transport model (De Ceuster et al., 2006), which suggest for the baseline case, annual growth rates of 2.5% for cargo vessels and 3.9% for passenger vessels (Cofala et al., 2007). TREMOVE assumes constant fuel economy and constant proportion of activities in- and outside the 12-mile zones, between the flag types of vessels, and applies the same growth rates to international shipping across all sea regions. Growth rates for shipping assumed in this report are at the low end of a range of projections considered by other studies (Skjolskvik et al., 2000; Corbett et al., 2007).

The baseline development of the sulphur dioxide emissions on the North Sea (and Baltic Sea) is different from other sea areas surrounding Europe because the North Sea is a dedicated Sulphur Emission Control Area (SECA). In the North Sea SECA area, international standards for the sulphur content of fuels apply as from 22 November 2007. In a SECA, the sulphur content of fuel oil used on board ships may not exceed 1.5%. Alternatively, ships must fit an exhaust gas cleaning system. The decreased sulphur content in fuels will also decrease particulate matter emissions. As a result of this SECA regulation and taking into account the expected increase in shipping volumes, sulphur dioxide emissions from North Sea shipping will not increase but will decrease by about 8% between 2000 and 2020. Particulate matter emissions will increase in this period by about 35% which is, however, less than the increase in non-SECA areas (about 60%). Nitrogen oxides emissions from North Sea shipping will increase by about 45% between 2000 and 2020.

Table 6 Emissions of air pollutants (kilotons) from North Sea shipping (all vessels) in 2000 and 2020 (Cofala et al., 2007)

Pollutant	**2000**	**2020 (kiloton)**			
		Baseline	**Medium ambition**	**High ambition**	**MTFR ambition**
SO_2	443	406	406	149	137
NO_x	649	946	859	688	108
PM	50	68	68	56[1]	32[2]

[1] Cofala et al., (2007) and ENTEC (2005) assume a conservative reduction of 2% for $PM_{2.5}$ emissions associated with the reduction of sulphur content from 1.5 to 0.5% in residual fuel oil. Other studies suggest that a higher reduction of about 18% for $PM_{2.5}$ emissions is possible (see Text box 1).

[2] This study assumes that all ships use medium distillates with low sulphur content (0.5% S; see Text box 1).

Additional abatement with the emission control scenarios in 2020

In addition to the baseline scenario with current MARPOL conditions, several emission control scenarios have been elaborated by Cofala et al. (2007). A general description of the emission control technologies included in three scenarios is presented in Table 5. Further information can be obtained from ENTEC (2005b, d, e).

Medium ambition scenario

The medium ambition scenario contains only internal engine modifications for current and new marine engines. Such modifications will reduce nitrogen oxide emissions by only 9% compared with the baseline projection for 2020.

High ambition scenario

The high ambition scenario includes humid air motor techniques on new ships and applies a low sulphur content (0.5% sulphur) in residual fuel oil. Instead of using low sulphur residual fuel, it is assumed that 25% of the ships apply seawater scrubbing for reducing their sulphur dioxide emissions. Compared to the baseline projection in 2020, these measures reduce the emissions of sulphur dioxide, nitrogen oxides and particulate matter ($PM_{2.5}$) by about 63, 27 and 18% respectively in 2020. The reduction of primary emitted particulate matter is related to a reduction in sulphur content from 1.5 to 0.5% in the residual fuel used (see Text box 1).

Maximum technical feasible reduction

The maximum technically feasible emission reduction scenario (MTFR) includes selective catalytic reduction on existing and new marine engines and a switch from residual fuel (1.5% sulphur) to marine distillates (0.5% sulphur) on all ships (see Text box 1). Compared to the baseline in 2020, these measures reduce the emissions of sulphur dioxide, nitrogen oxides and particulate matter ($PM_{2.5}$) by about 66, 89 and 55% respectively.

2.4 Costs of the emission control scenarios

The baseline costs for North Sea shipping and the additional costs for all ships in the three emission scenarios are presented in Table 7. The emission control costs are calculated taking into account all projected shipping activities on the North Sea in 2020 together with the measures in the emission control scenarios. Costs of sulphur dioxide and nitrogen oxide measures in ships are taken from Cofala et al. (2007) and presented in Text box 2. This Text box also gives some information on the costs of land-based measures currently being implemented or costs of future land-based measures.

Compared with the baseline case, the measures in the medium ambition scenario for all ships lead to an annual increase in costs of about € 3 million. Additional costs of the measures in the high ambition scenario are about € 330 million annually. On top of the baseline, additional costs for measures in the maximum technically feasible reduction scenario (MTFR) amount to approximately €1,400 million annually. It needs to be stressed that the MTFR scenario in this study assumes the use of cleaner and more expensive marine distillates with a low sulphur content of 0.5% for all North Sea ships. The cost of marine distillates is estimated to be about twice as much as residual fuel oil (ENTEC, 2005e; ECN, 2007).

Text box 1: Particulate matter emissions depend on fuel type and sulphur content

Several studies show that particulate matter emissions from large marine diesels depend on the fuel type and its sulphur and ash content (USEPA, 2003; Wärtsila, 2003, 2006; Kasper et al., 2007; TNO-ECN, 2007). In residual or heavy fuel oil constituents, such as ash, asphalt, metals, oxides and sulphur and its high viscosity contribute to the formation of particulate matter. Other constituents of the emitted particulate matter include unburned compounds such as carbon soot and hydrocarbons from fuel and lubricating oil. The more expensive distillate fuels generally have a much lower sulphur and ash content, and lower viscosity. As a result, the quantity of the particulate matter formation is much lower.

In this study, the effect of lowering the sulphur content on the North Sea from 2.7 to 1.5 % has been included in the baseline for 2020, as current legislation makes this mandatory from November 2007. The studies above show that lowering the sulphur content of residual fuel oil from 2.7 to 1.5% results in a reduction of particulate matter emissions of about 18%. A decrease in sulphur content in residual fuel oil from 1.5 to 0.5% is included in the high ambition scenario. The effect of this measure on particulate matter emissions is derived from the studies mentioned above. Measurements by TNO-ECN (2007) and Wärtsila (2003, 2006) suggest that an additional reduction in the sulphur content in residual fuel oil from 1.5 to 0.5% could lead to a further 18% reduction in particulate matter emissions. The precise relationship between sulphur content and particulate matter emissions, however, has not been established because few studies have been carried out. Moreover, some studies report difficulties in measuring this relationship. Probably, these uncertainties prompted ENTEC (2005d) and Cofala et al. (2007) to assume a conservative figure of 2% for the reduction of particulate matter related to the decreased sulphur content from 1.5 to 0.5% in residual oil.

A switch from residual fuel oil with 1.5% sulphur content to marine distillates with 0.5% sulphur content is included in the MTFR scenario for 2020 in this study. Based on USEPA (2003) and the above mentioned studies, a maximum reduction of particulate matter emissions of 55% associated with this measure on the North Sea is assumed.

Another uncertainty in this scenario study is the lack of specific data for the North Sea on the proportion of sea ships that run on medium distillates with low sulphur content. Estimates range from 10% (Cofala et al., 2007), which is used in this study, to as much as 25% (Jan Hulskotte, TNO, Apeldoorn, the Netherlands, personal communication 2007).

The uncertainties in the relationship between sulphur content, fuel type and reduction in particulate matter emissions and uncertainties about the number of ships already running on marine distillates have been taken into account in this study by using conservative and high-end estimates of particulate matter reductions in the calculations of air quality (see chapter 3, Tables 9 and 12).

Table 7 Cost of emission control (M€/yr) on North Sea shipping (Cofala et al., 2007)

Pollutant	**Vessel type**	**2020**			
		Baseline	**Medium ambition**	**High ambition**	**MTFR ambition**
SO_2	Total	197	197	462	1,200[1]
NO_x	Total	4	7	74	458
	Total	201	204	536	1,660[1]

[1] The cost calculation by Cofala et al. (2007) has been adjusted for the costs of using low sulphur marine distillate fuel oil.

Text box 2: Costs of air pollution abatement measures at sea and on land

Costs of individual measures at sea

Marginal costs of sulphur dioxide measures for shipping in the emission control scenarios in this report range between € 800 and € 900/ton for low sulphur fuel oil (1.5 - 0.5% sulphur). Unit costs for low sulphur marine distillates (with 0.5% sulphur) amount to about € 2,000/ton, being about twice the cost for low sulphur residual fuel oil. Costs for seawater scrubbing range from € 450 to € 550/ton depending on the measure to be applied to a newly built or existing ship (retrofit).

Marginal costs of nitrogen oxide measures for shipping in the emission control scenarios in this report range from less than €40/ton for internal engine modifications, approximately €500 /ton for humid air motors up to € 1,200 to € 1,800/ton for Selective Catalytic Reduction (SCR) on new ships, depending on the sulphur control policies in a given sea region. Costs of retrofitting ships with SCR are higher than for new built vessels.

Costs of individual measures at land

The marginal costs of land-based sulphur measures that can be taken in the Netherlands up to 2010 range from € 600 to € 13,000/ton (Hammingh et al., 2006). The measures consist of fuel switch in refineries, flue gas desulphurisation (FGD) or optimising FGD in several types of industries, refineries and power plants. The most expensive measures include FGD in aluminium industries and decreasing the sulphur content in fuels for off-road.

The marginal costs of nitrogen oxide measures currently taken in the sectors energy, industry, refinery and transport in the Netherlands range from € 1,000 to € 3,500/ton. The measures include low NO_x burners and Selective Catalytic Reduction (SCR). Cost estimates for future emission standards for light and heavy duty vehicles (Euro-6, mandatory from about 2013/2014) amount to about € 3,000 and € 9,000/ton, respectively.

Uncertainty

These cost estimates for shipping measures are within a 30-50% uncertainty range, compared to the best estimate figures quoted by ENTEC (2005d, e). Cost estimates for measures for land-based sources are also subject to considerable uncertainty.

3 Impacts of emission control scenarios for North Sea shipping on Dutch air quality

This chapter deals with the contribution of North Sea shipping to air pollution in the Netherlands and the effect of three emission control scenarios at sea on national indicators for public health, ecosystems and urban air quality. For reasons of comparison, the effects of a land-based emission control scenario for 2020 on urban air quality are also presented. This scenario is illustrative [2] of the ambition for land-based sources given in the Thematic Strategy on Air Pollution (CEC, 2005). Model calculations were carried out with the GAINS-NL model (Annex 1).

3.1 Contribution of North Sea shipping to air pollution in the Netherlands

The contribution of emissions from North Sea shipping to the Dutch air quality in 2005 ranges from around 5% for particulate matter concentrations to about 20% for deposition of oxidized sulphur (Figure 2). North Sea shipping contributes significantly to air pollution in the Netherlands when compared to contributions from other Dutch land sectors and other countries (see Text box 3). The estimates for 2020 are according to the scenario with current legislation (including SECA regulations from 2007 onwards).

The highest increase in contribution from shipping is to nitrogen oxide concentrations, rising from about 8% in 2005 to 17% in 2020. This increase is related to the growth of the cargo and passenger ship activities between 2000 and 2020 (section 2.3) and the fact that current legislation contains no additional abatement measures for nitrogen oxide emissions from ships. The concentration of nitrogen oxides (NO_x) is related[3] to the concentration of nitrogen dioxide (NO_2) for which there are European air quality limit values. Also, there are European air quality limit values for particulate matter (see Text box 4).

The relatively low contribution of sea shipping to nitrogen deposition compared to sulphur deposition is the result of the relatively large contribution of ammonia from agriculture in the Netherlands[4].

Since emissions of nitrogen oxides and particulate matter from international shipping are increasing (section 2.3) and emissions on land are expected to decrease, the absolute

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[2] The land-based scenario is based on the national 'land' baselines scenarios from August 2006 and the indicative national emissions ceilings of December 2006 (Amann et al., 2006).

[3] Nitrogen oxides emissions from combustion processes contain both nitrogen monoxide and nitrogen dioxide emissions. Nitrogen monoxide is converted in the atmosphere by ozone and by reactive volatile organic compounds into nitrogen dioxide.

[4] The ammonia emissions by sea shipping are yet very small and are neglected in this study.

contribution of sea shipping to nitrogen oxides and particulate matter concentrations and nitrogen deposition is increasing (see Table 8). On the contrary, the absolute contribution of North Sea shipping to sulphur deposition in the Netherlands is decreasing because the expected increase in shipping volumes is more than compensated by the SECA measure, a reduced sulphur content of fuels (2.7% to 1.5%). Since sulphur dioxide emissions on land are expected to decrease more substantially up to 2020, the relative contribution (depicted in Figure 2) of sea shipping to sulphur deposition is still increasing slightly.

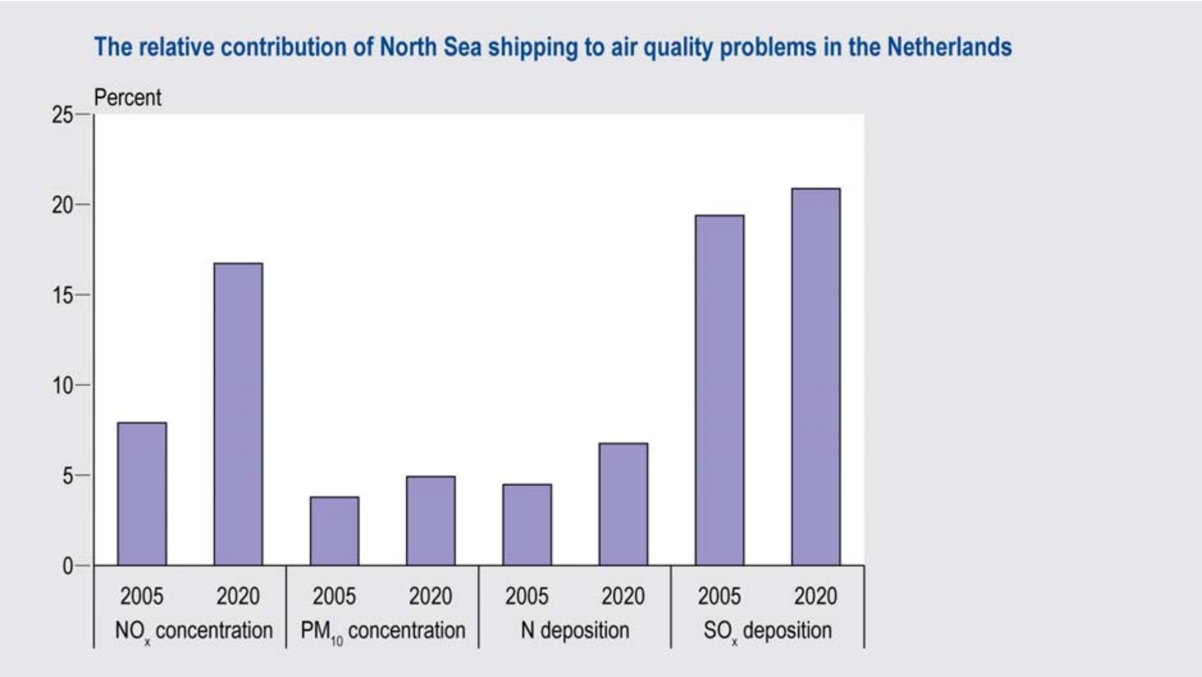

Figure 2 Relative contributions of North Sea shipping to average nitrogen oxide and particulate matter concentrations and to deposition of nitrogen and oxidized sulphur compounds in the Netherlands in 2005 and 2020.

Table 8 Absolute contribution of sea shipping and land-based sources to nitrogen oxide levels, particulate matter concentrations and to nitrogen and acid depositions in 2005 and 2020

	NO_x concentration ($\mu g/m^3$)		**PM_{10} concentration ($\mu g/m^3$)**		**Nitrogen deposition (moles/ha.yr)**		**Acid deposition (moles/ha.yr)**	
	2005	**2020**	**2005**	**2020**	**2005**	**2020**	**2005**	**2020**
North Sea	2.6	3.4	1	1.2	67	88	195	160
Land sources	30	17	25[1]	22[1]	1420	1220	810	600
Total	**33**	**20**	**26**	**23**	**1490**	**1310**	**1005**	**760**

[1] Corrected for non-modelled sources such as natural sea salt, soil material, hemispheric background and other unknown sources (Velders et al., 2007a).

Text box 3: Contribution of North Sea shipping to Dutch particulate matter concentration

Composition of anthropogenic particulate matter concentration

Model estimates using GAINS-NL (Annex 1) show anthropogenic sources – as far as they are known – to explain about 40% of the measured particulate matter concentration in the Netherlands in 2020 (Figure 3). About 15% of the measured concentration originates in anthropogenic sources in the Netherlands. In local urban areas this level is higher (30%-45%), especially due to traffic (see also Table 13). About 25% of the measured concentration originates in anthropogenic sources abroad, including North Sea shipping.

North Sea shipping contributes 5% to measured particulate matter concentration in the Netherlands, a contribution that is significant when compared to the anthropogenic contributions of Dutch land-based sectors and other countries (Figure 3). The North Sea shipping contribution to anthropogenic particulate matter concentration in the Netherlands in 2020 is comparable to that of Dutch agriculture and higher than the contributions of such other Dutch sectors as industry, energy, refineries, transport and domestic. Contributions from countries like Belgium, France and the UK are lower than North Sea shipping, with only Germany contributing more.

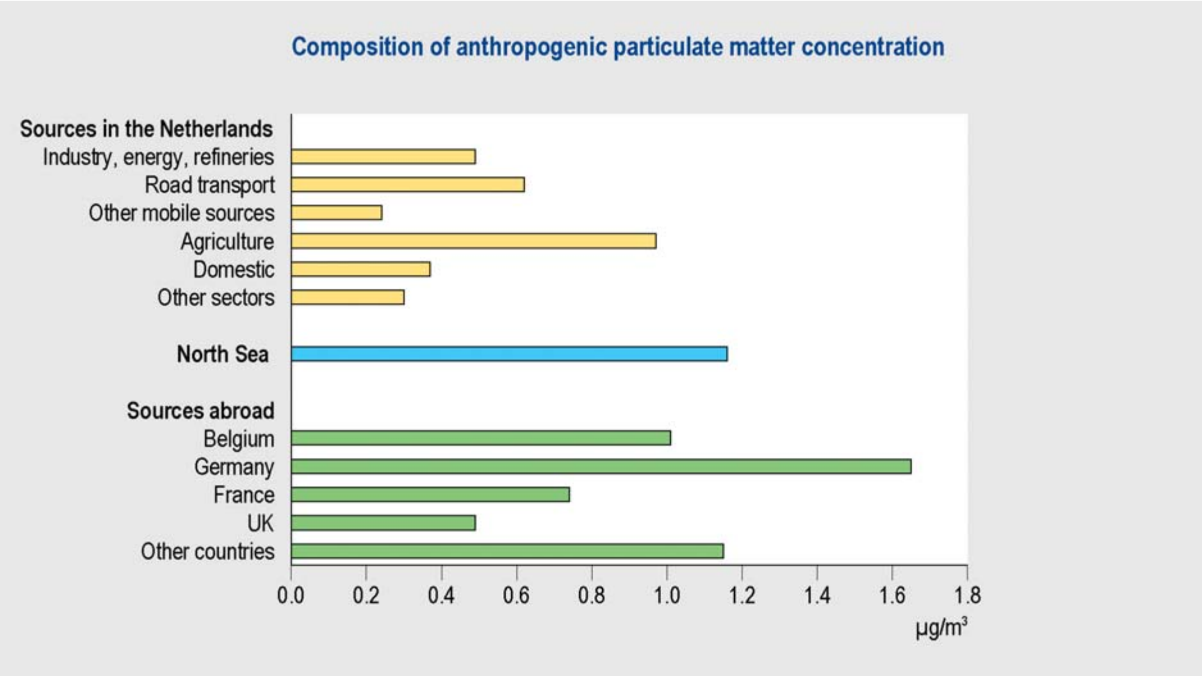

Figure 3 Contributions of anthropogenic sources in the Netherlands and other European countries, along with North Sea shipping contributions to the annual average concentration of particulate matter in the Netherlands in 2020. Source: GAINS-NL model calculations for 2020 under current legislation.

Composition of total particulate matter concentration

As previously mentioned, the known anthropogenic sources contribute about 40% of total measured particulate matter concentration in the Netherlands in 2020. The other 60% in 2020 (estimated at about 14 $\mu g/m^3$) comes from sea salt, Northern Hemisphere background concentration, soil dust and other sources. Soil dust and other sources form the non-modelled portion of particulate matter comprising biological material, water and the contribution made by non-modelled or incorrectly modelled sources. Consequently, this contribution can also include some anthropogenic sources. See Buijsman et al. (2005) for further explanation.

Better fuel quality and nitrogen oxide abatement important in reducing particulate matter from shipping

The contribution of sea shipping to the concentrations of particulate matter in the Netherlands is determined by both direct (and primary) and indirect (or secondary) emissions of particulate matter. The latter is formed during atmospheric transport from direct emissions of nitrogen oxide and sulphur dioxide. In 2020, all emissions from North Sea shipping are estimated to contribute about 5% to the total particulate matter (PM_{10}) concentrations in the Netherlands. About 20 % point of this estimated contribution is due to primary (direct) particulate matter emissions from ships, about 30 % point to secondary (indirect) particulate matter from sulphur dioxide emissions, and about 50 % point from nitrogen oxide emissions.

The above implies that, in order to abate the absolute contribution of ship emissions to particulate matter concentrations in the Netherlands, fuel quality and sulphur content need to be improved and nitrogen oxide emissions reduced. Abating total particulate matter contributions from sea (and land-based) sources is important since the European air quality limit values for particulate matter apply to the total (measured) particulate matter.

The relatively small contribution of primary particulate matter emissions from shipping to total particulate matter levels in the Netherlands makes the results of this study rather insensitive to the uncertainty in the relationship between marine fuel quality (and its sulphur content) and the quantity of primary particulate matter emissions (see Text box 1 in section 2.3, and Tables 9 and 12).

It is largely unknown which compounds in particulate matter have to be abated in order to reduce the public health effects. However, it would seem that there are little direct health effects of sea salt aerosol and secondary inorganic fractions, such as sulphate and nitrate aerosol in particulate matter (Schlesinger and Cassee, 2003). It is not yet possible to quantify the health effects of the direct particulate matter emissions from combustions sources such as marine diesel engines. However, there are indications that such emissions play a role in the health effects related to short- and long-term exposure. Policy such as cleaner marine fuels that focuses on reducing emission of primary fractions of particulate matter could, therefore, be beneficial in terms of public health (Buijsman et al., 2005).

Spatial distribution of shipping contribution to air quality

As illustrated in Figures 4 and 5, the contribution of North Sea emissions shows a declining gradient from coastal to inland regions, for the concentration of particulate matter, nitrogen oxides and the deposition of oxidized sulphur in 2020. This also illustrates that abatement measures in the North Sea shipping will have the highest impact in the west and north of the Netherlands. The gradient in contribution to particulate matter concentrations is less pronounced than that for nitrogen dioxide and acid deposition.

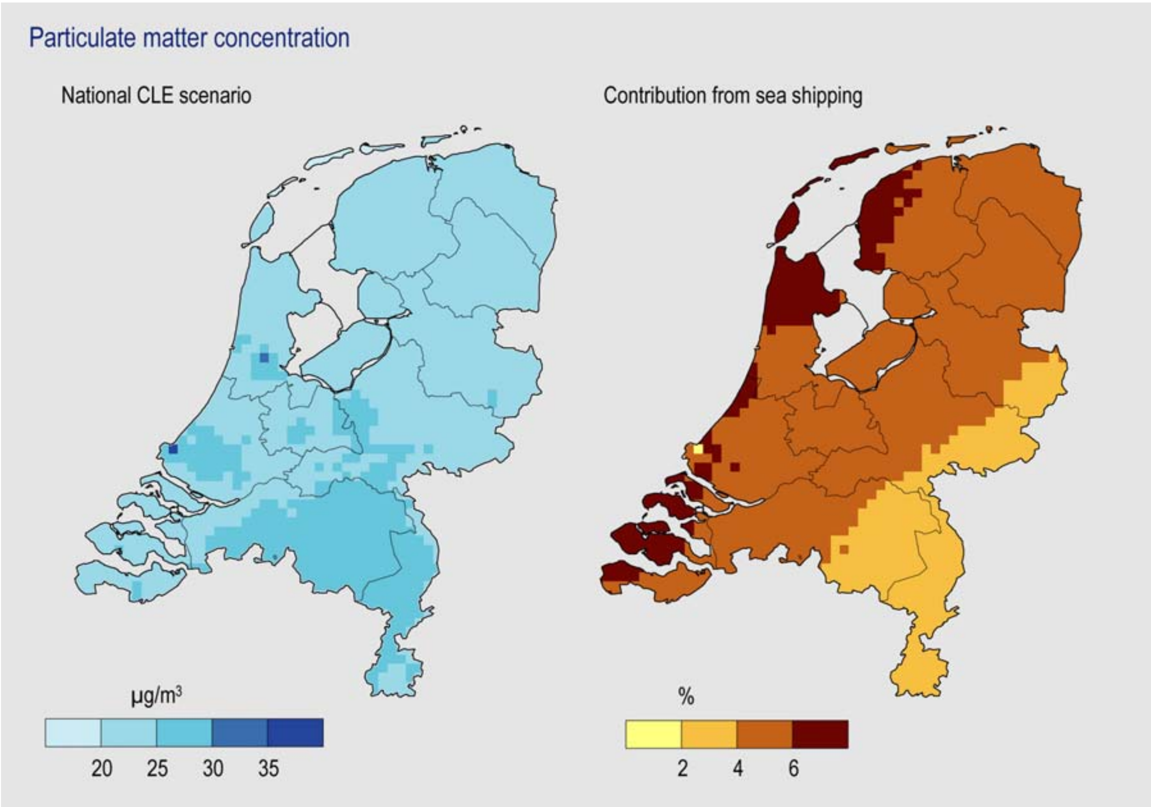

Figure 4 Spatial distribution of particulate matter concentrations in the Netherlands in 2020 (under current legislation) and the contribution of North Sea shipping in 2020

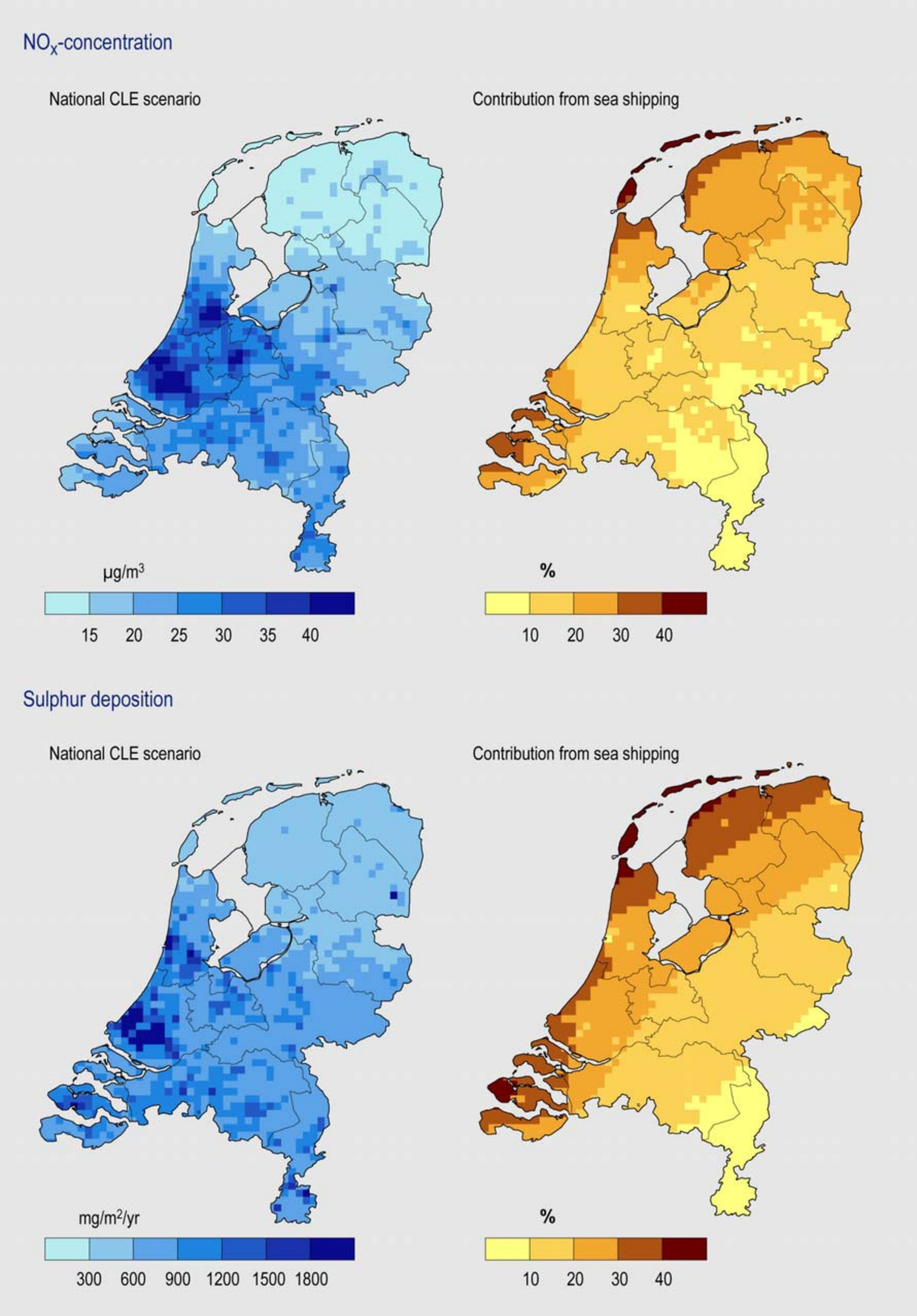

Figure 5 Spatial distribution of nitrogen oxide concentrations and deposition of oxidized sulphur in the Netherlands in 2020 (under current legislation) and the contribution of North Sea shipping in 2020

3.2 Potential North Sea shipping measures to reduce adverse effects on man and ecosystems

The following indicators for human health and ecosystems are used to describe the effects of the three emission control scenarios (see chapter 2) in 2020 in relation to the baseline. These impact indicators take into account where concentrations are reduced or deposited in relation to the location of the population and ecosystems:

1. the number of years of life lost (YOLL) due to exposure of the population to particulate matter;
2. the percentage ecosystem area unprotected from acidification and eutrophication, together with the load above the critical value, expressed as Average Accumulated Exceedance (AAE).

The effect of sea and land-based emission control scenarios on the number of life years lost (YOLL) is presented in Table 9. In the model calculations, health effects are attributed to total anthropogenic (primary and secondary) particulate matter concentrations. Contributions of natural origin have not been taken into account.

High and maximum ambition scenarios at sea has significant effects on health

Compared to the baseline situation, the medium ambition scenario contains a few additional measures for abatement of nitrogen oxide emissions from sea shipping. As a result, this scenario reduces the years of life lost by only 1%. The reduced nitrogen oxide emissions lead to reduced formation of nitrate aerosol which is part of secondary (or indirect) particulate matter.

Table 9 Effect of emission control measures for North Sea shipping on years of life lost (YOLL)

Scenario	Index
Baseline	100
Medium ambition	99
High ambition	96
MTFR ambition	90-92[1]
Thematic Strategy – land-ambition	89

[1] The range takes into account the uncertain relationship between the sulphur content of fuels and the primary particulate matter emission

The high ambition scenario reduces the years of life lost by about 4% in 2020. This comprises about 33% of the effect of the land-based scenario (Thematic Strategy) and is largely explained by the reduced sulphur dioxide and nitrogen oxide emissions (by 63% and 27% respectively) that lead to reduced secondary particulate matter formation. A minor part of this effect is caused by the reduced primary (direct) emissions of particulate matter. The different assumptions on the primary particulate matter reductions related to the use of low sulphur residual oil, ranging from a reduction of about 2% (conservative estimate) to 18% (upper estimate) result in changes in the years of life lost below 1%.

The maximum feasible reduction scenario (MTFR) reduces the years of life lost by about 8-10% in 2020. This almost approximates the effect of the land-based scenario (Thematic Strategy). This effect is largely explained by the reduced sulphur dioxide and nitrogen oxide emissions (by 66% and 88%, respectively) that lead to reduced secondary particulate matter formation. A smaller part of this effect is caused by the reduced primary (direct) emissions of particulate matter. The different assumptions on primary particulate matter reductions related to use of distillate fuel oil with low sulphur content, ranging from 2% (conservative estimate) to 55% (upper estimate) reduction, result in changes in the years of life lost of about 2%. The insensitivity of this health indicator to the uncertainty in this assumption is explained by the fact that primary particulate matter emissions ships contributes little to total particulate matter levels in the Netherlands (section 3.1).

Ecosystems benefit from low sulphur fuels for shipping

The medium ambition scenario has a negligible effect on the degree of protection and the excess load regarding acidification and eutrophication (Table 10). This is explained by the fact that this scenario includes measures that only slightly reduce nitrogen oxide emissions.

The high ambition scenario has a greater effect especially on acidification because the sulphur content in residual fuel oil is reduced. The percentage of unprotected ecosystems against acidification decreases from 58 to 51% (7 % point) and the excess load decreases by about 13 %. The effect of this scenario is about one-third of that achieved with the land-based scenario (Thematic Strategy).

Table 10 Effect of emission control measures for North Sea shipping on the protection and Average Accumulated Exceedance (AAE) of ecosystems for acidification

	Acidification[1]		**Eutrophication**	
Scenario	**% unprotected**	**AAE (eq ha^{-1} y^{-1})**	**% unprotected**	**AAE (eq ha^{-1} y^{-1})**
Baseline	58	281	73	334
Medium ambition	58	278	72	329
High ambition	51	244	70	318
MTFR ambition	46	221	66	283
Thematic Strategy	37	161	63	242

[1] Acidification refers to forest ecosystems because the Thematic Strategy is targeted at this ecosystem type.

With the maximum feasible reduction scenario (MTFR), the percentage of unprotected ecosystem area against acidification decreases from 58 to 46% in 2020 compared to the baseline, and the excess load decreases by about 21%. The effect of the substantial nitrogen oxide shipping measures in this control scenario on eutrophication (nitrogen deposition) is relatively smaller. This is because eutrophication in the Netherlands is largely determined by deposition of ammonia and ammonium from intensive agriculture. The effect of this sea-based scenario is about two-thirds of that on ecosystems reached with the land-based scenario (Thematic Strategy).

3.3 Potential North Sea shipping measures for improving urban air quality

Shipping measures reduce nitrogen dioxide concentrations in urban agglomerations

On top of the baseline in 2020, the medium ambition scenario reduces urban nitrogen dioxide concentrations by less than 1%, the high ambition scenario by about 1-5%, and the MTFR scenario by about 5-15% (Table 11). For comparison, the land-based scenario (Thematic Strategy) reduces the urban nitrogen dioxide concentrations in 2020 by 3-10%.

All three sea-based scenarios for nitrogen dioxide result in a gradient with higher reductions in urban agglomerations near the sea, such as Rotterdam-Dordrecht, The Hague-Leiden and Amsterdam, and lower reductions in the east of the Netherlands in Eindhoven and Heerlen-Kerkrade (Table 11). The Dutch urban agglomerations are shown in Annex 2. It should be noted that the reduction gradient of the land-based scenario is the reverse of that of the sea-based scenarios.

The effect on the average urban nitrogen dioxide concentrations of the medium ambition sea-based scenario is about 25% of that of the land-based scenario. For the high ambition scenario, this is about 70% and the effect due to the MTFR scenario at sea is twice as high as that of the land-based scenario.

Impacts on particulate matter (PM_{10}) concentrations in urban agglomerations

On top of the baseline in 2020, the medium ambition scenario reduces the urban particulate matter concentrations by less than 1%; the high ambition scenario by about 1-2%, and the MTFR scenario by about 2-4% (Table 12). For comparison, the land-based scenario (Thematic Strategy) reduces urban particulate matter concentrations in 2020 by 4-7%.

The effect of the medium ambition ‘sea-based’ scenario on the average urban particulate matter concentrations is less than 10% of that of the land-based scenario. For the high ambition scenario, the effect is about 30% and the effect due to MTFR at sea is more than half of the effect by the land-based scenario.

The different assumptions on the primary particulate matter reductions related to the use of low sulphur residual or distillate fuel oil in the high and MTFR scenario result in changes in the urban background concentrations of less than 1%. The insensitivity of this health indicator to the uncertainty in this assumption is explained by the fact that the relatively small contribution of primary particulate matter emissions from ships to total particulate matter levels in the Netherlands (section 3.1).

Table 11 Reductions in averaged nitrogen dioxide concentrations in urban agglomerations in the Netherlands due to emission control scenarios on North Sea shipping in 2020 compared with the Thematic Strategy on Air Pollution for land-based sources

Agglomeration	**NO_2 concentration 2020-CLE (μg/m³)**	**Reductions of concentration for emission control scenarios in 2020 compared to 2020-CLE (μg/m³)**			
		Medium ambition	**High ambition**	**MTFR ambition**	**Effect of the Thematic Strategy on land**
Amsterdam/Haarlem	23.3	0.3	0.7	2.5	0.8
The Hague/Leiden	24.9	0.3	0.9	3.0	0.7
Eindhoven	20.3	0.1	0.4	1.1	1.2
Heerlen/Kerkrade	19.5	0.1	0.2	0.7	1.7
Rotterdam/Dordrecht	26.0	0.3	0.8	2.8	0.9
Utrecht	24.7	0.2	0.5	1.8	0.7
Netherlands	15.9	0.2	0.6	2.0	0.9

Table 12 Reductions in averaged particulate matter concentrations in urban agglomerations in the Netherlands due to emission control scenarios for North Sea shipping in 2020 compared with the effect of the Thematic Strategy on Air Pollution for land-based sources

Agglomeration	**PM_{10} concentration 2020-CLE (μg/m³)**	**Reductions of concentration for emission control scenarios in 2020 compared to 2020-CLE (μg/m³)**			
		Medium ambition	**High ambition**	**MTFR[1] ambition**	**Effect of the Thematic Strategy on land**
Amsterdam/Haarlem	25.1	0.1	0.4	0.9-1.1	1.0
The Hague /Leiden	25.1	0.1	0.4	0.9-1.1	1.1
Eindhoven	26.3	0.1	0.3	0.6-0.7	1.8
Heerlen/Kerkrade	24.9	0.0	0.2	0.5	1.5
Rotterdam/Dordrecht	28.4	0.1	0.4	0.8-1.0	1.2
Utrecht	25.0	0.1	0.4	0.9-1.1	1.1
Netherlands	23.8	0.1	0.4	0.8-0.9	1.2

[1] The range takes account of the uncertainty in the relationship between the sulphur content of fuels and the primary particulate matter emission.

The reductions in particulate matter concentrations in the Netherlands in the three sea based scenarios are largely caused by the reduced precursors emissions (nitrogen dioxide and sulphur dioxide) which contribute to secondary particulate matter concentrations. The gradient in effects on particulate matter concentrations is less pronounced than that for nitrogen dioxide.

Compliance with current air quality standards in 2020

Air quality will improve towards 2020 due to current air pollution legislation. However, without additional European, national and local air quality measures, urban background concentrations increased with contributions from road traffic, will still lead to exceedance of limit values (see Text box 4) for NO_2 and PM_{10} in 2020. Locations with these types of exceedance are referred to as hotspots. Table 13 shows typical high values for traffic contributions (additional to urban background levels) to nitrogen dioxide and particulate matter (PM_{10}) concentrations in Dutch urban agglomerations in 2020. Typical total concentrations at hotspots in 2020 are presented in Table 14. Most of the remaining hotspots in 2020 are located in one of the four urban areas in the Randstad (in the west of the Netherlands). For nitrogen dioxide, most hotspots occur along motorways in urban areas and fewer in busy streets in city centres. For particulate matter (PM_{10}), the division between motorways and busy streets in city centres is less clear.

Table 13 Typical high values for road traffic contribution to NO_2 and PM_{10} concentrations in Dutch urban areas in 2020

Road type	Concentrations (μg/m^3)	
	NO_2	PM10
Motorways	25	7
Other roads	25	10

Table 14 Typical future concentrations at present hotspots, calculated under baseline conditions for 2020

Indicator	Concentrations (μg/m^3)	
	NO_2	PM_{10}
Average	40	35
High value	50	40

The emission control scenarios for sea shipping will reduce the urban background concentrations of nitrogen dioxide and particulate matter. The level of reduction in the urban agglomerations (Tables 11 and 12) indicates that only hotspots with concentrations slightly above the limit values will be removed. An exploratory pilot study (on top of the baseline scenario) shows a reduction in hotspot kilometres in 2020 of tens of percent in the case of the MTFR scenario for both NO_2 and PM_{10}. The high ambition scenario might reduce about 10% of hotspots in 2020 both for NO_2 and PM_{10}. In case of the medium ambition scenario, the reduction is not significant in terms of kilometres. It needs to be stressed that these calculations are based on the baseline scenario for 2020 with current legislation and do not include the additional European, national and local abatement measures required to comply with the limit values in time before 2020.

Text box 4: Air quality standards in Europe

Current air quality standards for nitrogen dioxide and particulate matter

The current air quality standards for nitrogen dioxide and particulate matter in the European Union are as follows:

1 Nitrogen dioxide (NO_2): 40 µg/m^3 as an annual average in force from 2010 onwards;
2 Particulate matter (PM_{10}): 40 µg/m^3 as an annual average in force since 2005;
3 Particulate matter (PM_{10}): 50 µg/m^3 as a daily average, not to be exceeded more than 35 days per year, in force since 2005. The more practical equivalence of 32.3 µg/m^3 as an annual average is used in this study.

Revision of the air quality standards

Part of the air quality legislation is being revised in the period 2006-2008. The proposals for revision from the European Commission, the European Parliament and the Council all contain possibilities to postpone the date of entry into force for about five years for the limit values for nitrogen dioxide and particulate matter. The reason is that many European countries will have difficulties in complying with these standards within the time period. The revision also includes proposals for new standards for the finer fraction of particulate matter, $PM_{2.5}$, for 2010 or 2015. The proposals include limit values for $PM_{2.5}$ and a – non-legally binding – $PM_{2.5}$ exposure reduction target for urban areas. This reduction target, to be accomplished between 2010 and 2020, amounts to between 0 and 20% depending on the initial level of $PM_{2.5}$ in 2010.

With the envisaged additional European air quality strategy (land-based), however, concentrations of nitrogen dioxide and particulate matter are expected to decrease substantially between 2000 and 2020 in urban areas. Moreover, before 2020, many countries should have taken appropriate measures both nationally and locally to comply with the European air quality standards for particulate matter in 2005 and nitrogen dioxide in 2010. Timely shipping measures can also contribute to fewer exceedance on land before 2020. If national plans and programmes are implemented fully, the current standards should not be exceeded in 2020.

Shipping measures may be needed to comply with future air quality standards

The current proposals for new air quality standards for the European Union contain new and stricter standards for $PM_{2.5}$ (see Text box 4). A recent model study shows that it may be difficult for the Netherlands to comply with these new standards for $PM_{2.5}$ using only European and national technical land measures (Velders et al., to be published). To comply with the possible new standards, it may be necessary to implement additional measures in urban agglomerations and streets and also in the North Sea and in Dutch ports.

3.4 Cost-efficiency comparison of sea and land-based emission control scenarios

The costs (chapter 2) of the North Sea scenarios and the effects (sections 3.2 and 3.3) in the Netherlands are compared with costs and effects of the land-based scenario (Thematic Strategy) for the Netherlands and surrounding countries[5] (see Table 15). Costs are taken from Amann et al. (2006 and 2007a) and the effects calculated with the GAINS-NL model. This comparison shows that the sea-based medium and high ambition scenarios are more cost-effective. The sea-based MTFR scenario, however, is somewhat less cost-effective than the land-scenario especially because of the use of expensive low sulphur distillate fuels. An MTFR ambition including the use of the cheaper, low-sulphur residual fuel is more cost-effective but is expected to lead to slightly higher particulate matter levels (see Tables 9 and 12). The use of marine distillates could become relatively more cost-effective if the air quality standards are raised in the European Union, and/or the production costs of distillate fuels decline.

A recent study by IIASA also shows that a cost-optimal air pollution abatement scenario includes measures both at sea and on land (Amann et al., 2007b). Taking measures at sea also implies that fewer measures for land sources are needed to meet the air quality ambitions of the Thematic Strategy.

Table 15 Cost-efficiency for sea and land-based scenarios for three air quality indicators in 2020, expressed in million euros for a one percent improvement

Indicator	**Medium ambition (at sea)**	**High ambition (at sea)**	**MTFR ambition (at sea)**	**Thematic Strategy (at land)**
Acidification	5	27	71	49
Eutrophication	4	94	150	123
Years of life lost	8	90	152	156

[5] The emission sources in the surrounding countries of Belgium, France, Germany, Luxembourg and the UK are the largest contributors to air pollution in the Netherlands. The costs of land-based measures in these countries have been used in the cost-efficiency calculations.

4 Potential impacts of shore side electricity on local air quality

4.1 Shore-side electricity: the pros and cons

Providing shore-side electricity (or cold ironing) to sea (and inland) ships berthed in Dutch ports is an abatement option for local air pollution caused by on-board generation of electricity with auxiliary diesel engines. Another advantage of shore-side electricity could be reduction in noise nuisance to local residents. In this report, only the impacts of providing shore-side electricity to sea ships on air quality have been examined.

The main concerns about shore-side electricity are the high costs and long-term efforts to install or retrofit and expand utility lines, substations and sea and inland ships. Moreover, without international standards for shore-side electricity, the risks in investments in this measure are increased. Some studies show that shore-side electricity may be more cost-effective when applied to larger ships that make frequent calls to the same berth at a specific port (ENVIRON, 2004). Shore-side electricity is already in use for specific ships (cargo ships, container vessels and cruise ships) by the ports of Gothenburg (Sweden), Los Angeles and Long Island (USA).

Not enough information was available to assess the cost-effectiveness of this measure in Dutch ports. Two recent Dutch studies indicate that shore-side electricity at present is not viable for container vessels in Rotterdam (Doves, 2006) and fishing ships in Scheveningen (Van der Meijden, 2006). The reasons include the high costs and the relatively low effects (on air pollution and noise) as well as uncertainty about future shore-side electricity standards. To promote application of shore-side electricity, international standards and phase-in schedules are needed.

4.2 Emissions from sea ships berthed in Dutch ports

The main pollutants from the auxiliary diesel engines on sea ships berthed in Dutch ports are in order of magnitude: nitrogen oxides (NO_x), particulate matter (PM_{10}) and sulphur dioxide (SO_2), see Table 16. The highest emissions are from sea ships berthed in the Port of Rotterdam (Figure 6), with lower emissions in the ports of Amsterdam, IJmuiden and Vlissingen.

Projected emissions of berthed sea ships between 2010 and 2020 are based on the Dutch Global Economy scenario in which the growth of sea ships calling at a Dutch port is assumed to be almost 20% in that period (Hoen et al., 2006). Sulphur dioxide emissions from berthed ships will decrease after 2010 since the maximum sulphur content of fuels is restricted by the EU (Directive 2005/33/EC) to 0.1% in 2010. The projected emission levels of particulate matter in ports from manoeuvring sea ships and berthed ships may need adjustment. Recent measurements conducted by TNO-ECN (2007) shows that such emissions in ports may decrease by 20-25% when the newly found emission factors are applied.

Table 16 Projected emissions (kilotons) from berthed sea ships in the Dutch ports in 2010, 2015 and 2020, (Hoen et al., 2006)

Pollutants	**Emissions (kiloton)**		
	2010	**2015**	**2020**
NO_x	7.2	9.1	10.8
PM_{10}	0.41	0.47	0.53
SO_2	0.27	0.32	0.37

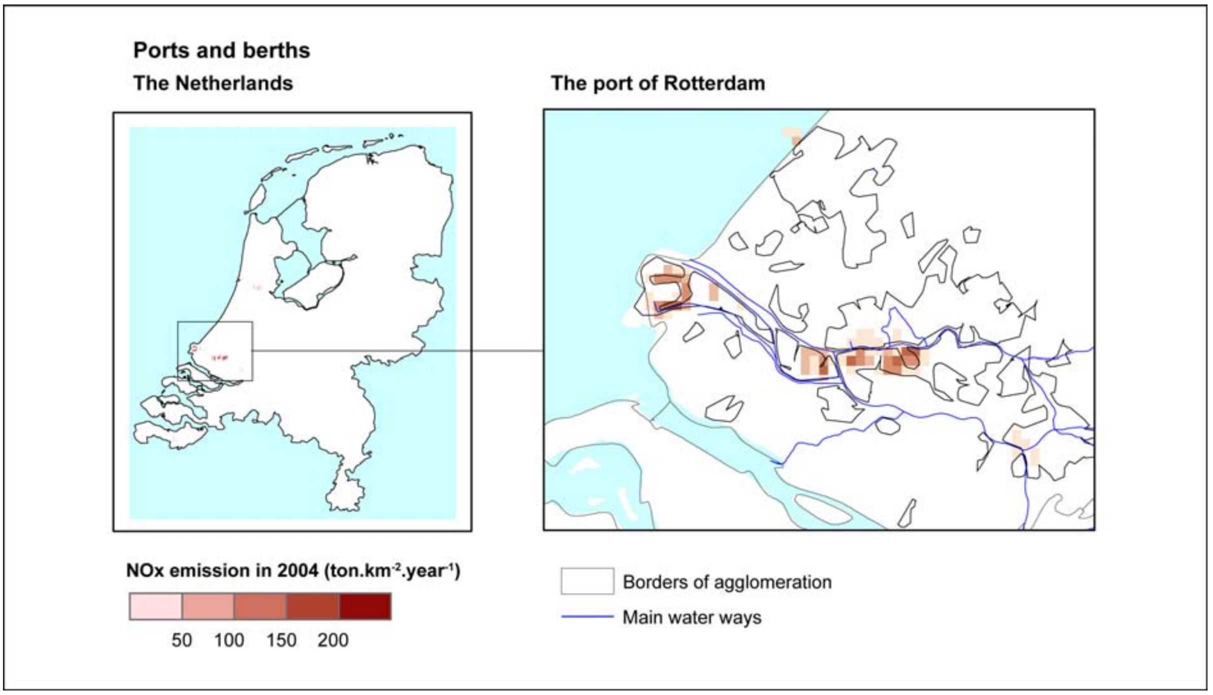

Figure 6 Nitrogen oxide emissions from berthed sea ships in Dutch ports (left) and in the port of Rotterdam (right)(Source: Emission Registration, Netherlands Environmental Assessment Agency, Bilthoven, the Netherlands)

4.3 Effects of shore-side electricity on local air quality

The potential impacts of shore-side electricity use in Dutch ports on the local air quality has been analysed using a baseline scenario (with current legislation) without the measure and an assumed scenario with an implementation rate of shore-side electricity of 0% in 2010, 50% in 2015 and 100% in 2020. It is assumed that shore-side electricity is provided by the Dutch energy sector[6]. In this study, new emission characteristics have been used for the heat content of exhaust plumes from berthed sea ships (Jan Hulskotte, TNO, Apeldoorn, Netherlands, personal communication 2007). Using the projected emissions and their updated characteristics of ship at berth and a multi-annual meteorology, dispersion model calculations were performed on a grid scale of 1 x 1 km^2 for the Netherlands.

As expected, the model calculations show that the main impacts of shore-side electricity are on nitrogen oxides concentrations in and around the port of Rotterdam (see Figure 7). The impacts on air quality are limited to an area of a few kilometres. The reductions of nitrogen dioxide and particulate matter concentrations in the vicinity of Dutch ports with the application of shore-side electricity are given in Table 17. The effects of this measure on the air quality in and around the others ports of Amsterdam, IJmuiden, and Vlissingen are much smaller than in Rotterdam.

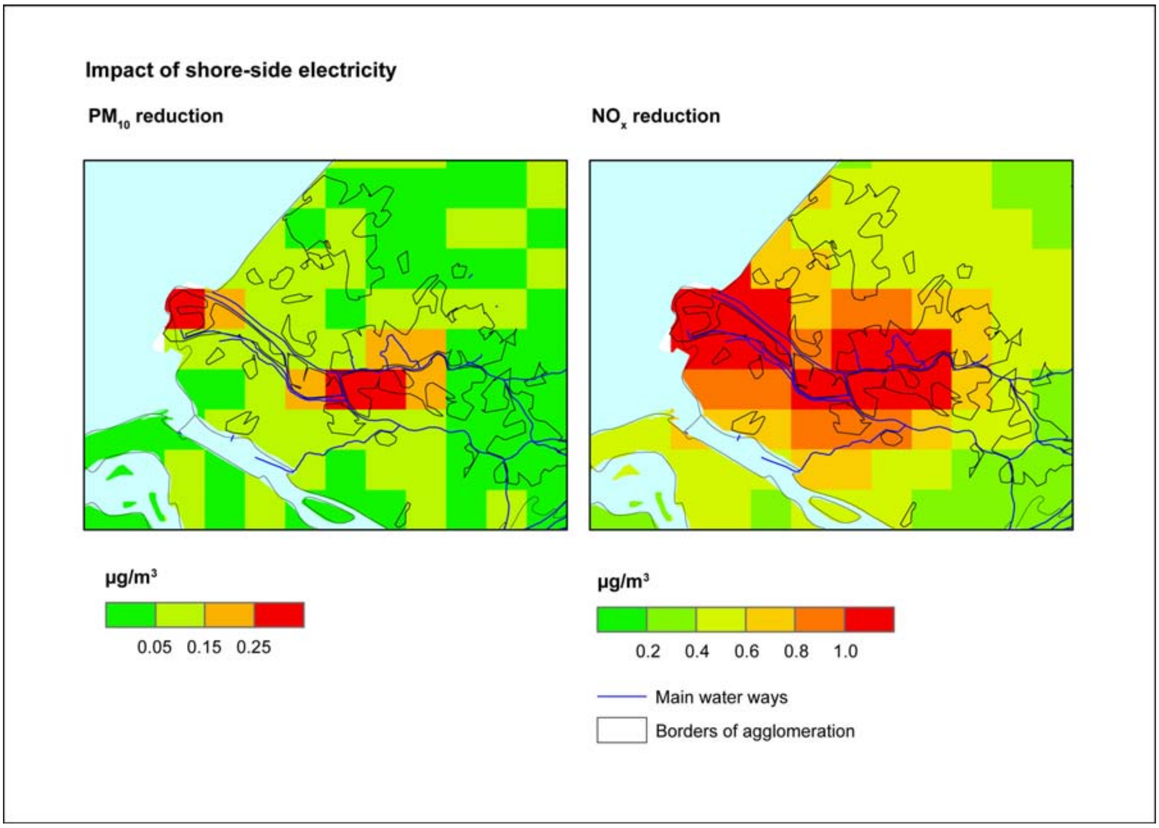

Figure 7 Modelled reductions in local particulate matter and nitrogen dioxide concentrations in the port of Rotterdam with full supply of shore-side electricity in 2020

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[6] The relatively small additional emissions from the Dutch energy sector have not been included in this study. The effects on local air quality are estimated to be quite small since power plants have abatement facilities in place for SO_2, NO_x and PM_{10} and emit the residue pollutants through high stacks.

The effects of shore-side electricity in the port of Rotterdam on nitrogen dioxide reduction in the Rotterdam-Dordrecht area are comparable to the effect of the high and maximum ambitious emission control scenarios at the North Sea (see Table 11). The effect of shore-side electricity on particulate matter concentrations in the Rotterdam-Dordrecht area matches the effect of the high ambition emissions control scenario for North Sea shipping (Table 12). The measure has limited effect on particulate matter concentrations in other ports.

Table 17 Reduction of nitrogen dioxide and particulate matter concentrations in the vicinity of Dutch ports with shore-side electricity supply (µg/m^3)

Ports	**NO_2 reduction (µg/m^3) in**		**PM_{10} reduction (µg/m^3) in**	
	2015	**2020**	**2015**	**2020**
Main port Rotterdam	1	1.5 - 3	0.3	0.4
Amsterdam	0.5	1	<0.1	<0.1
Vlissingen	0.5	1	<0.1	<0.1
IJmuiden	0.2	0.5	<0.1	<0.1

The emission control scenarios for North Sea shipping have a much wider impact than the shore-side electricity option. In order to compare the cost-effectiveness of the shore-side electricity (in Rotterdam) with the measures in the North Sea scenarios, more information is needed on the costs of implementing shore-side electricity in the port of Rotterdam.

Shore-side electricity potentially effective in abating nitrogen dioxide concentrations

The modelled impacts of shore-side electricity on local nitrogen dioxide and particulate matter concentrations on a 1x1km^2 grid were combined with street model calculations. This was done in order to estimate the impacts on hotspots for nitrogen dioxide and particulate matter (see Text box 4) in the Rotterdam/Dordrecht urban areas. These calculations are based on the baseline scenario for 2015 and 2020 with current legislation and no envisaged additional European air quality measures.

The remaining hotspots in 2015 and 2020 are expected to be along busy motorways and urban roads (Velders et al., 2007a). The analysis of the impacts of shore-side electricity shows that the measure could reduce the remaining number of nitrogen dioxide hotspots by several percent in 2015 and by about half in 2020 in the Rotterdam-Dordrecht urban area. Despite the limited effect of shore-side electricity in geographical terms, the measure can usefully contribute to abatement of nitrogen dioxide in especially the Rotterdam-Dordrecht area with its extensive ports and high concentrations of nitrogen dioxide.

As a result of relatively low direct particulate matter emissions, the effect of shore-side electricity on particulate matter concentrations is less than on nitrogen dioxide concentrations

(Table 17). Moreover, indirect particulate matter (secondary aerosols) from sea shipping emissions does not contribute on the urban scale of a few kilometres since its atmospheric formation requires more time and therefore more distance. The relatively low effect of this measure on particulate matter concentrations suggests that it has a limited effect on the number of particulate matter hotspots in 2020.

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Annex 1 Description of GAINS-NL

Introduction

The regional air pollution information and simulation model (RAINS), now called Greenhouse Gas and Air Pollution Interactions and Synergies model (GAINS), is the accepted model for lending support to European negotiations for establishing air quality standards and emission targets. Because GAINS calculations are performed for the whole of Europe, the model has a rather low spatial resolution. This is a drawback for interpreting results in a national context. For this reason, the Netherlands Environmental Assessment Agency has developed a specialised version of GAINS for the Netherlands in collaboration with IIASA. This GAINS-NL model allows for (1) refinement of GAINS output for the Netherlands, (2) search for alternative scenarios to reach the targets set in international negotiations, (3) determination of the consequences of alternative Dutch scenarios for neighbouring countries, and (4) comparison of the cost-effectiveness of Dutch and European control strategies. Moreover, because GAINS-NL is an extended version of GAINS, all GAINS functions are reflected in GAINS-NL.

GAINS model

GAINS is an integrated assessment model which combines information on the development of economy and energy demand, emission control potentials and costs, atmospheric dispersion characteristics and environmental sensitivities to air pollution (Schöpp et al., 1999). The model is web-based.

This multi-pollutant/multi-effect model addresses health effects caused by fine particulates and ground-level ozone, as well as negative effects on ecosystems due to a too high load of acid (acidification), nitrogen (eutrophication) and exposure to elevated levels of ozone.

The GAINS model framework makes it possible to estimate, for a given energy and agricultural scenario, the costs and environmental effects of user-specified emission control policies. This is called the ‘scenario analysis’ mode. Projections of economic activities are available by means of interfaces to specialized energy models.

In addition to the scenario analysis mode, GAINS can be run in an optimization mode. This enables the search for cost-minimal balances of controls of the concerned pollutants over the various economic sectors in all the European countries that simultaneously achieve user-specified targets for human health impacts and for the protection of ecosystems. Economic (control costs) and environmental differences between countries are taken into account in this optimization.

Extensions to the Emissions and Costs modules

Emissions and costs in GAINS are described at a very detailed level, involving a few hundred combinations of activities and economic sectors. Information about emissions and costs can be obtained either at this detailed level or at the aggregated levels of SNAP1, NFR1 or NFR2, all international standards for reporting emissions. However, all these sector breakdowns are fairly process-oriented and do not comply with the actor-oriented division used in Dutch policy making, the VROM[7] division. This VROM division has been added to the output formats of the emissions and costs modules by defining a translation table between the GAINS sector/activity combinations and the VROM actors. In fact, an extended version of the VROM division has been implemented because the VROM division itself is too aggregated to account for differences in dispersion behaviours between sub-classes. For instance, passenger cars and sea shipping belong both to ‘Traffic and transport’, but differ substantially in emission characteristics. Another reason for the extension is that different control measures may be expected for some sub-classes. Therefore, the VROM division was used as a starting point and extended where sub-sectors deviate in dispersion characteristics or where policy measures for sub-sectors may be expected.

Extensions to the Dispersion module

GAINS uses country-to-grid transfer matrices (or source-receptor matrices, SRM) to ‘translate’ emissions at the country level to concentrations and depositions on a grid cell level. These source receptor matrices (SRMs) are derived with the new EMEP Unified model (Simpson et al., 2003). The spatial resolution of this model, and therefore also of the GAINS transfer matrices, is limited to 50 x 50 km^2. This resolution is considered too low to describe in detail the impacts on human health and ecosystems. It was, therefore, decided to complement the EMEP-based source-receptor matrices for the whole of Europe with matrices specific for the Dutch domain with a higher resolution. A 5 x 5 km^2 resolution appeared to be a reasonable compromise between the preferred resolution (1 x 1 km^2), on the one hand, and the response time of the model on the other. The spatial resolution of 5 x 5 km^2 is considered adequate to describe the spatial gradients in urban background concentrations. A correction for the contribution of local emissions as is done in GAINS (City-Delta approach) is therefore not necessary. Unfortunately, the EMEP model cannot be run (yet) with this resolution. It was therefore decided to use the Dutch operational priority substances model (OPS) (Van Jaarsveld, 2004) to derive the required SRMs. OPS is the standard model for the assessment of air quality in the Netherlands, and is extensively validated with results of the Dutch Air Quality Monitoring Network. Velders et al. (2003) showed the results of the new EMEP model for the Netherlands to agree (reasonably) well on a national scale with OPS results for sulphur and reduced nitrogen (concentration as well as deposition). However, marked differences were found for oxidised nitrogen. The EMEP model calculates substantially lower values than OPS for both concentration and deposition.

Not only has the receptor resolution been adapted, but also the resolution of the emission distributions used in deriving the SRMs. Emissions with a spatial resolution of 50 x 50 km^2 are used for the derivation of the EMEP-based SRMs, whereas the emission resolution for the OPS-based SRMs is 5 x 5 km^2 for emissions from the Netherlands and the surrounding

[7] VROM is the Dutch acronym for the Ministry of Housing, Spatial Planning and the Environment

countries, and 0.5 x 0.25 degrees for the other countries. Furthermore, the OPS-based SRMs distinguish between economic sectors, taking account of different atmospheric dispersion behaviour of emissions from different economic sectors. For reasons of controllability, this distinction is only made for Dutch emissions, considering that it is of lesser importance for emissions further away from the Netherlands. An additional advantage of sector SRMs is that these allow for a better spatial allocation of the effects of emission reductions in certain sectors and for the calculation of sector contributions.

The GAINS-NL dispersion module delivers output for the same compounds as GAINS. GAINS-NL also supports the calculation of NO_2 concentrations, NO_2 being a major problem in the Netherlands in urban environments where the annual mean concentrations often exceed the European limit value.

Extensions to the Impacts module

The accuracy of health and ecological impacts is not only determined by the spatial detail in the calculated concentrations or depositions, but also by the detail with which the population or the ecosystems are described.

To calculate ecosystem impacts, GAINS uses the CCE critical load database, generated under the Convention on Long-Range Transboundary Air Pollution (Posch et al., 2001; Hettelingh et al., 2001). This database contains critical load data aggregated across 50 x 50 km^2 grid cells, together with their surface area. The exact position of the ecosystem, which is mostly – and in the Netherlands always – much smaller than 50 x 50 km^2, is not tracked in this database. Thus, increasing the resolution of the deposition calculation is not sufficient for raising the accuracy of the estimate of impacts. GAINS-NL uses a database containing the co-ordinates of the 250 x 250 m grid cells containing ecosystems, along with the dominant ecosystem type and the corresponding critical loads. This information is used to calculate and present the exceedance at a 5 x 5 km^2 level.

For the calculation of health impacts, GAINS-NL contains the number of inhabitants per 5 x 5 km^2 grid cell, split-up into five-year age classes.

Annex 2 Air Quality Framework Directive

In 1996, the Air Quality Framework Directive came into force (EU, 1996). The Framework Directive provides a new and coherent general European framework for ‘evaluating and managing air quality’. The Framework Directive uses a number of important concepts: daughter directives, preliminary assessments, assessment thresholds and zones and agglomerations. The daughter directives are specifications of air quality requirements for certain substances. In the meantime, four daughter directives have appeared (EU, 1999; EU, 2000; EU, 2002; EU, 2005). The concentrations of substances from the first daughter directive, including particulate matter, are an important element in the definition of the zones and urban agglomerations in the Netherlands (Breugel and Buijsman, 2001). The result is a division of the Netherlands into three zones and six urban agglomerations (Figure 8).

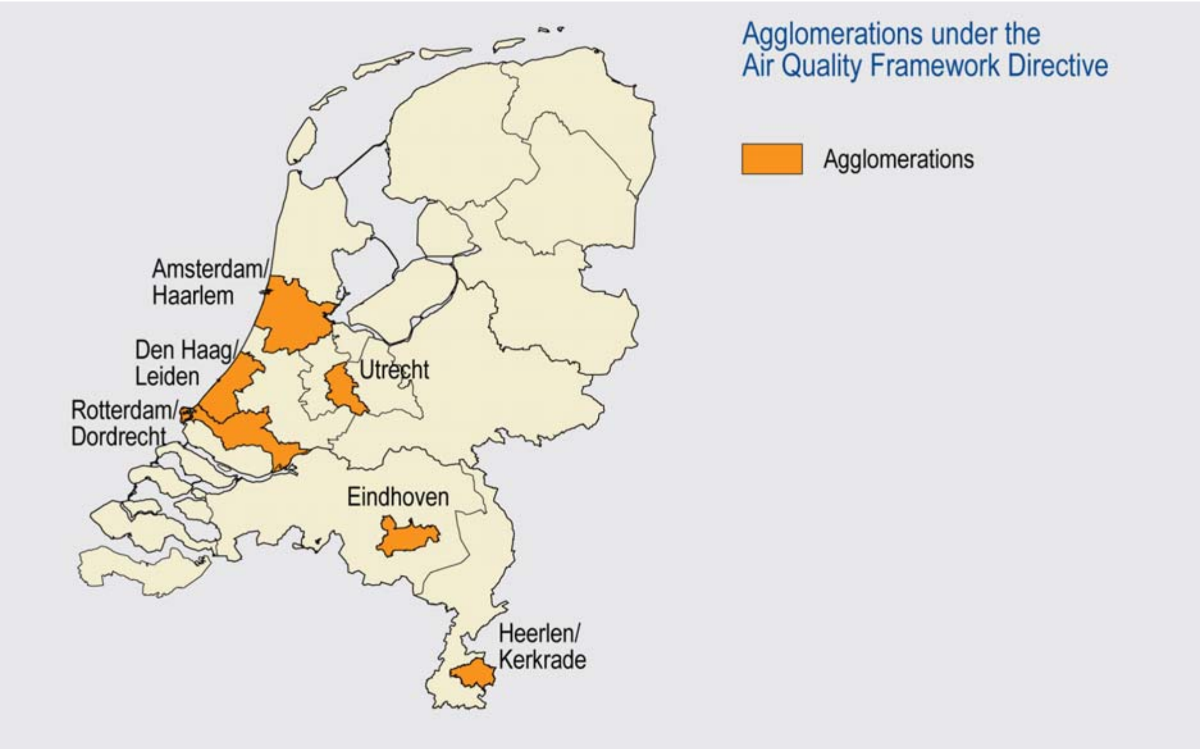

Figure 8 Six Dutch urban agglomerations under the air quality framework Directive